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Ontology based personalized route planning system using a multi-criteria decision making approach

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Abstract

This study presents a generic ontology-based architecture using a multi-criteria decision making technique to design a personalized route planning system. The real world has become too complex to implement entirely within an information system such as geographic information system (GIS). A route planning technique is an essential geo-related decision support tool, especially in intelligent transportation systems (ITS). In ubiquitous GIS environments, personalization can be accomplished through a user's preferences stored on mobile appliances. In this manner, personalized and user-centric route planning services using semantic technologies and ontologies perceive user and context models to satisfy user demands and predict their requirements. In the past few years, several studies have been carried out regarding personalized services. However, the existing route finding algorithms suffer from a number of major difficulties, mainly owing to insufficient criteria modeling for a personalized system. Thus, the present study investigates how a user-centric route planning system can be implemented. In order to address this research issue, an ontology-based knowledge modelling technique using an analytic hierarchical process (AHP) is proposed. This technique can facilitate determination of the choice of criteria used for applying an impedance function in the route finding algorithm. From another perspective, AHP explicitly deals with a hierarchy structure and is essentially a theory of measurement and decision making methodology used for combining or synthesizing quantitative as well as qualitative criteria. User-centric results on real data illustrate the strengths of the present approach. It is anticipated that this new technique can be applied to develop new graph algorithms based on semantic web technology and can be used with new semantic graph structures.

Keywords: GIS; ITS; Route planning system; AHP; Multi-criteria decision making technique; Personalization; User model; Context model; Ontology; Semantic web

1. Introduction

When ubiquitous GIS emerged, travelers were able to plan and enjoy their trips more conveniently. They will be able to find more pertinent information needed for travel if they employ a personalized user-centric route finding application. Personalization is a key element that facilitates the employ of complex services on mobile devices (Short, 2000) and can be accomplished based on user's preferences and a context model. Furthermore, appropriate representation of user preferences and the environmental situation around the user leads to accurate route finding analyses. In other words, whether a certain route is better than another strongly depends on situational preferences and on user preferences. In both mobile and desktop applications, user profiles are usually defined in specific ways, depending on the application. In addition, context awareness and context sensitivity have attracted much attention with the emergence of mobile applications. Furthermore, geospatial information (GI) and geographic information systems (GIS) are significant resources in decision-making analyses at various levels of society and activities. Network analysis, a type of spatial analysis, is the most powerful method in GIS and intelligent transportation systems (ITS). A route planning process based on certain criteria is a common tool for network analysis. In addition, the

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impedance of each segment of a road network is a key factor of any route planning algorithm in GIS and ITS. Impedance is a measure of the amount of cost, or resistance, expected to pass through a link from its origin node to its destination node. Furthermore, higher impedance denotes greater resistance to movement. Additionally, appropriate determination of a road segment impedance model leads to more accurate route planning results. Thus, in order to achieve worthwhile results based on the user's preferences in personalized route planning, appropriate impedance modelling is required. Normally, in a network analysis, road segment impedance is determined as a one-dimensional variable such as distance, speed, or traffic.

The existing impedance models for personalized route planning analyses are inadequate. Road segment impedance can be modeled by several appropriate criteria that indicate road segment characteristics in a GIS network and ITS. In this research, the impedance model includes both a user model and a context model to support the user-centric route planning system. The construction of impedance model is complex due to the inclusion of quantitative as well as qualitative criteria. Additionally, problems of criteria evaluation arise from its inherent complexity, its inherent uncertainty, multiple objectives, and multiple involvements (Clemen, 1996). Measurement is considered to be the foundation of evaluation (Farbey, Land, & Targett, 1993). Also, each measure is assessed according to different criteria. Although some researches have posited more than a single variable for the impedance function of each segment, most did not consider multi-dimensional quantitative and qualitative criteria together. As a result, these approaches do not produce universal method or rules. In addition, many studies have focused on roads inside cities instead of inter-city roads. For example, Jun, Koo, and Koh (2004) proposed the use of regional supply, distance, a road network, and construction cost variables. Thirumalaivasan and Guruswamy (1997) reported various impedance factors that play significant roles in determining the travel time, such as the volume of traffic, the type of road, the road width, and the number of junctions and turns. However, this method is based on an empirical formula instead of a mathematical method. To overcome the abovementioned problems, a suitable method that can model several user and context criteria related to road segment impedance in a route planning process should be developed.

For personalized impedance modelling, in addition to obtaining various criteria, an appropriate method for combining these criteria is necessary. In this research, an ontology-based approach is employed to model the role of decision makers/users for personalized route finding. The ontology-based system allows experts to cooperate with the system, resulting in a list of criteria related to the goal of the personalized impedance modelling. From a criteria combination point of view, analytical hierarchical process (AHP) allows systematic evaluation of multiple criteria, resulting in a hierarchical structure (Saaty, 1980) that can help in dealing with the characteristics of personalized objectives. The incorporation of an ontology-based methodology and a multiple criteria decision making process is expected to be a sound approach in resolving the drawbacks of previous route planning systems.

The objective of this research is to determine an impedance model of road GIS and ITS for a personalized ontology-based route planning system using a multiple criteria decision making method. In order to address this research issue, an ontology-based multi criteria decision model (AHP) is proposed. The impedance model aims to distinguish the appropriate user-centric criteria and combine them in order to obtain the impedance function to be employed in a route finding algorithm.

2. Related works

Personalization route planning has recently become a major goal of GIS and ITS based tourist services, including users' preferences interest and context information. Personalization involves the design of enabling systems to capture or infer the needs of each person, and then to satisfy those needs in a known context (Riecken, 2000). Furthermore, a user profile is vital to personalization. Previously, most personalization applications relied on machine learning techniques that typically require a large amount of data to provide appropriate results. The most direct way to obtain information about the user is to simply ask them (Fink, Kobsa, & Nill, 1998; Kobsa, Koenemann, & Pohl, 2001) while some studies have employed indirect acquisition methods that require no interaction with the user (Shen, Tan, & Zhai, 2005). Additionally, Dey, Abowd, Brown, and Davies (1999) characterize context as "any information that can be used to characterize the situation of an entity". Typical context information includes the user's location and the time. Moreover, there are relationships between the user model and context models (Zipf, 2002; Zipf & Jost, 2006). Some recent works attempted to use ontologies for personalization (Gauch, Chaffee, & Pretschner, 2003). Ontologies have been developed using artificial intelligence to facilitate knowledge sharing and reuse (Guarino, 1998) and to establish a domain of spatial information (Reuter & Zipf, 2005).

Multi-attribute decision making methods can solve two major problems of criteria that are intended to be combined. First, there are issues related to standards for measuring qualitative criteria. A second issue is related to a deficiency regarding changes among and within qualitative and quantitative variables. AHP is one of the most developed multi-attribute decision making methods (Qodsipoor, 1999). Basically, a route planning is an important spatial analysis tool. Normally, in a network analysis, road segment impedance is determined as a one-dimensional variable; an example is "distance", as noted by Chunithipaisan, James, and Parker (2004), "time" by Ziliaskopoulos (1993), "traffic" by Shadewald, Hallmark, and Souleyrette (2001) and in many other research papers. Additionally, using common shortest path algorithms, such as the Dijkstra algorithm (Gallo & Pallottino, 1986) and

A* (Pearl, 1988) may also yield solutions that are not appropriate for users. For instance, users would normally like to drive on main roads, although using some secondary roads may offer the shortest path. Many studies have proposed that different user models can influence route planning processing, and that individual users may not even know their own planning preferences (Rogers, Fiechter, & Langley, 1999; Rothengatter, 1993). A significant application of route finding is in relation to tourism. For example, several current support applications for travel are aimed at providing personalized packages, taking user models into account (Fink et al., 1998; Kobsa et al., 2001).

3. Materials and methods

This work was accomplished using a generic ontology-based architecture employing a multi-criteria decision making technique to extend a user-centric route planning modelling technique that encompasses three stages. First, a general personalized ontology-based user-centric architecture was constructed. Second, road segment ontology was obtained to determine appropriate criteria for designing a road segment impedance model including both user preferences and context characteristics for the personalized route planning. Third, a user model and context model were developed using the obtained criteria. In order to merge these criteria to create a road segment impedance model, a multi-criteria decision making technique employing a 'hierarchical structure' and 'criteria pair wise comparison' was utilized. Finally, after deriving the personalized impedance model, the final personalized algorithm was implemented and verified in a GIS road environment.

3.1. User-centric ontology-based route planning architecture

User-centric route planning services in ubiquitous GIS environments using ontology decision making approaches enable technology to present user behavior and context information to achieve user satisfaction. Route planning is an important form of spatial analysis in any GIS application, such as tourist services. In the present research, to develop personalized tourist route planning services, a user-centric ontology-based abstract model was designed (Fig. 1). An abstract model is a theoretical paradigm that represents something, with a set of components that is created to allow reasoning within a rational framework about these processes. An abstract model provides a scheme containing general, main concepts and their interrelations (Järvelin & Wilson, 2003). As Fig. 1 depicts, the user-centric abstract model of the personalized route planning service has several essential components such as ontology designing, criteria, modelling, and the GIS engine part.

3.2. Ontology-based road segment criteria

The impedance model is an important part of the personalized route planning method. Additionally, in order

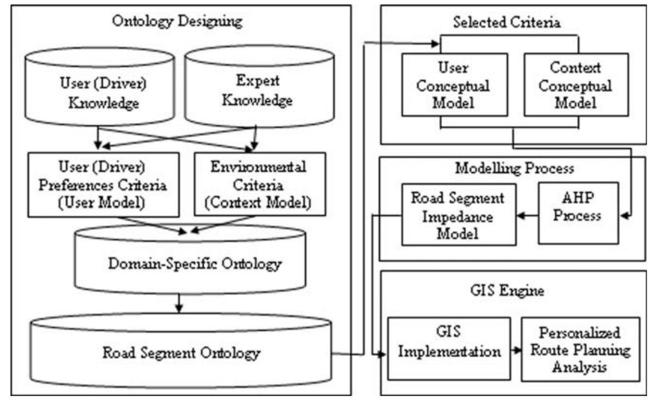

Fig. 1. Ontology based abstract model of personalized route planning system.

to produce the road segment impedance model, determining all efficient criteria related to road segments is crucial. In this study, an ontology-based method was utilized to attain these criteria. The first step for ontology creation is the generation of a domain-specific ontology. Furthermore, after ontology design, all appropriate road segment criteria must be determined.

3.2.1. Domain-specific ontology

A user-centric abstract model has a domain-specific ontology, which is a set of expressions in the model that are proposed to represent some aspects of the modeled object as well as to describe the domain knowledge for the evaluation of the personalized route planning project. A domain-specific ontology models a part of the real world. It represents special meanings of terms in this domain. Additionally, a domain-specific ontology supplies a conceptual structure of the problem domain where information is collected and focused on more specific sets of system. First, after confirming that there was no existing, appropriate ontology that could represent several criteria with respect to road segments, a user-centric domain-specific ontology was built. Next, the approach of Natalya and Deborah's (2001) in developing a related domain-specific ontology and a top–down ontology approach was utilized to construct the domain-specific ontology. The user-centric abstract model shown in Fig. 1 is transformed into the equivalent domain-specific ontology depicted in Fig. 2.

3.2.2. Road segment ontology

After establishing the domain-specific ontology, the road segment ontology was created. In recent years, ontologies have been exploited in many business and scientific studies as a way to share, reuse, and process domain knowledge. An ontology is a real domain model of the real world and the concepts in the ontology must expose this reality. Ontologies are a level of description of the knowledge of a system that is independent of internal structure. The use of ontology offers many advantages such as determining the appropriate criteria for the user and context

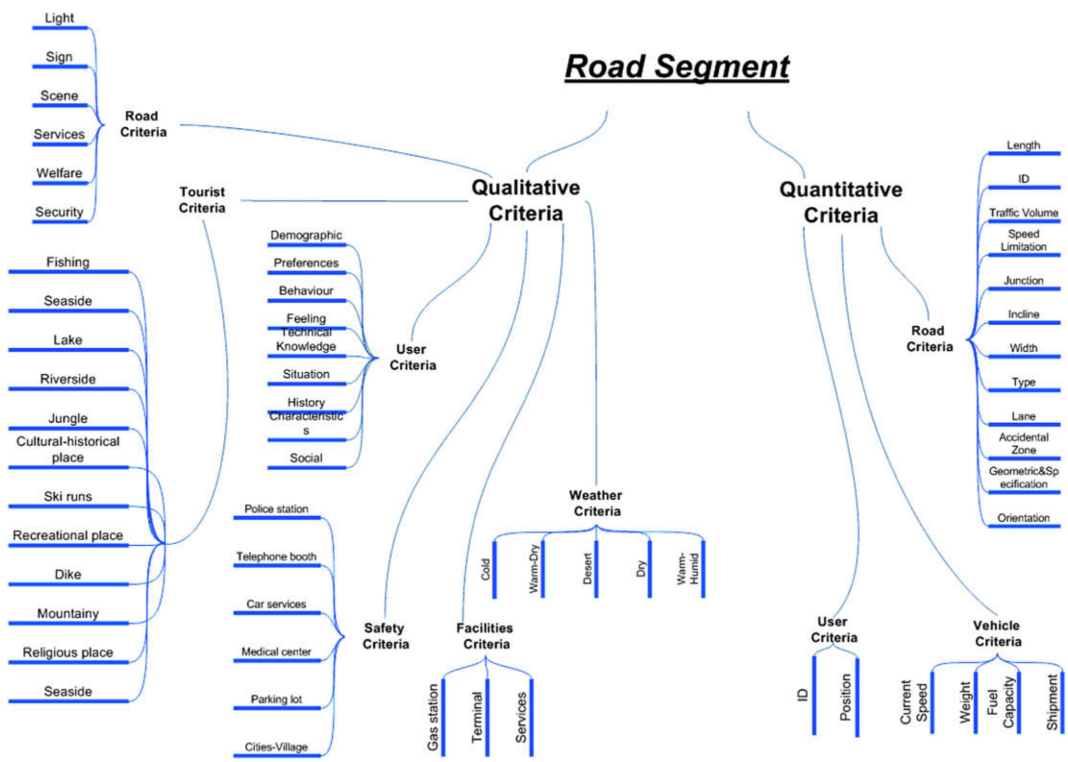

Fig. 2. Domain-specific ontology of road segment.

modelling, playing an alternate role of experts in the decision making process, cooperating with an ontology-based inference engine, domain knowledge modelling, explicating domain assumptions, and employing knowledge-based services. As noted earlier, in a route planning decision context, the ontology-based approach is employed to imitate the role of experts or experienced practices in personalized evaluation processes. The ontology-based procedure enables decision makers to interact with the system for task analysis, in generating a list of criteria. Similar to conceptual data schemes, ontologies are composed of interrelated concepts that identify the proposed meanings of concepts. However, the consensus level regarding ontological content is the main requirement in ontology modeling, and mainly distinguishes consensus level from conceptual data modeling (Jarrar, Demey, & Meersman, 2003). Fig. 3 shows the proposed route planning evaluation ontology, which combines the terms of the route planning evaluation, as well as 'is-a' inherent relations of semantic linkages among all of those selected terms.

3.2.3. Road segment criteria

For the creation of the following personalized road segment ontology, proper criteria of each road segment were determined. In this research, all of the criteria to represent all the characteristics of the road network ontology were divided into two groups comprised of context and user variables. These criteria were selected based on the personalized road segment ontology and their influence on finding the optimum path in the road network. In this research, road commuter traffic, safety, road facilities, and weather conditions are examples of context criteria. The user criteria include factors that affect an individual tourist's trip such as tourist attractions and user preferences to define the impedance model. Each criterion includes various sub criteria. For instance, road commuter traffic is composed of level of services (LOS) A, B, C, D, and E. In addition, the safety criterion is associated with police stations, side-road parking lots, service centers, health and medical treatment services, and telephone booth. Furthermore, the facilities criterion includes gas stations, terminals, and services. The weather criterion consists of moderate, dry, warm-humid, dry-warm, dry-cold, desert, and dry classifications. Finally, seaside areas, recreational facilities, and ski resorts are several sub-parts of the tourist attraction criterion.

3.3. Road segment impedance model

In this study, both the user model and context model are significant components of the user-centric and personalized route planning system for adaptation. In order to combine the user and context criteria that influence the road segment, a multi-criteria decision making technique employing a 'hierarchical structure' and 'criteria pair wise comparison' was utilized for the creation of the impedance model.

3.3.1. User model and context model

The user model and context model were developed on the basis of the criteria obtained in the previous section.

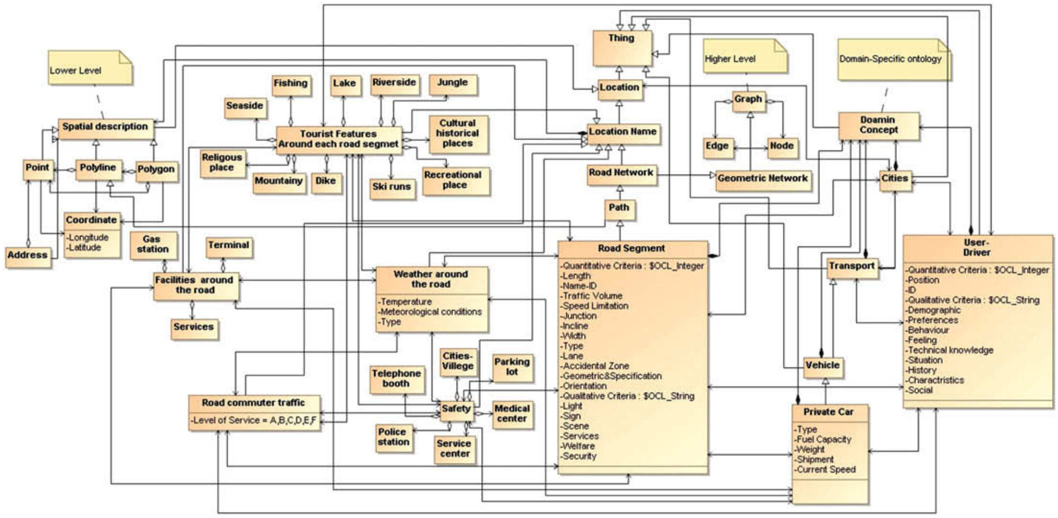

Fig. 3. Personalized road segment ontology.

In order to obtain, organize, and predict profiles of the user via the user model, user-centric applications need to gather general system data such as demographic information and the user's preferences. The most direct method to extract user information and some demographics for the user model is to simply ask the user (Fink et al., 1998). In this work, various parameters were determined for user modelling such as demographics, preferences, and personal and context information (Fig. 4). Demographics relating to personal characteristics include age, gender, nationality, marital status, language, religion, socioeconomic conditions, residence location, and ethnicity.

To facilitate development of personalized route planning services, a user-centric architecture should provide a clear form of interaction view of the user and a general context outlook as well. However, it is not only the user model that might be adapted to the system; the context model can also be utilized as a factor for personalized service. In recent years, there have been extensive attempts to build context models that are situational-aware. This context awareness system has a strong effect on Ubiquitous GIS and ITS. In this research, the context model includes any information that can be utilized to characterize the situation of the road segment for the user-centric route planning. Furthermore, the context is illustrated by environmental parameters around the user for specific situations. Fig. 5 depicts the context factors including constant context and variable context parameters. Vehicle type, speed limit, segment length, current time and speed, and path-allow-vehicle type (paths allow for especial vehicle type) are criteria of constant context information. Furthermore, variable context information is various criteria such as traffic, weather, safety, facilities, and tourism. There is a relationship between the user model and context model (Zipf & Jost, 2006). Personal characteristics determine human behavior and the behavior determines the context, and vice versa.

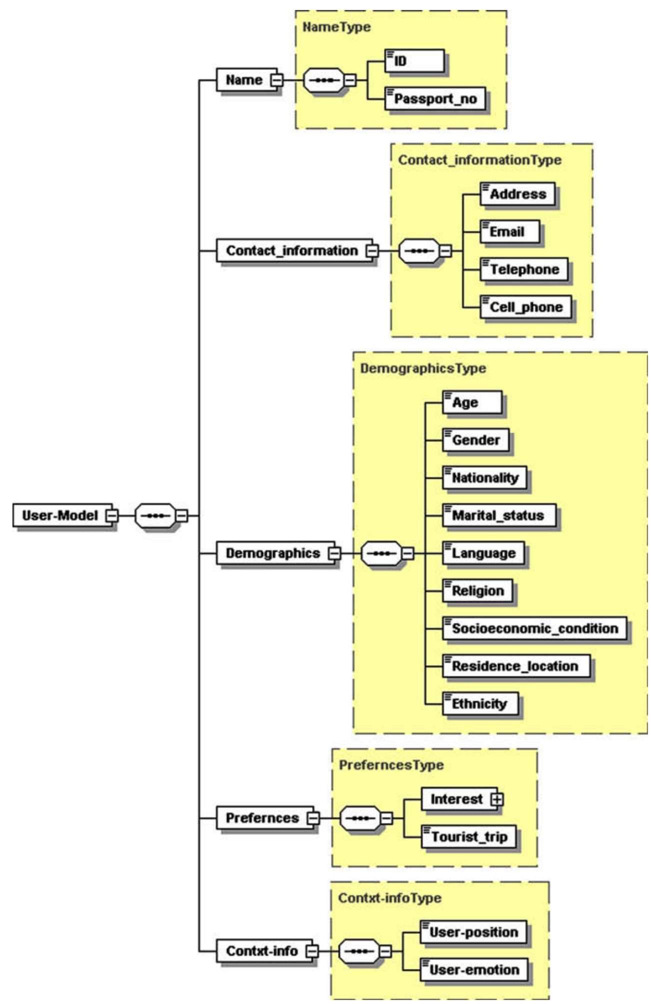

Fig. 4. Road segment user model.

3.3.2. Multi-criteria decision making technique

After determining the appropriate criteria and user and context models for finding a user-centric route in the

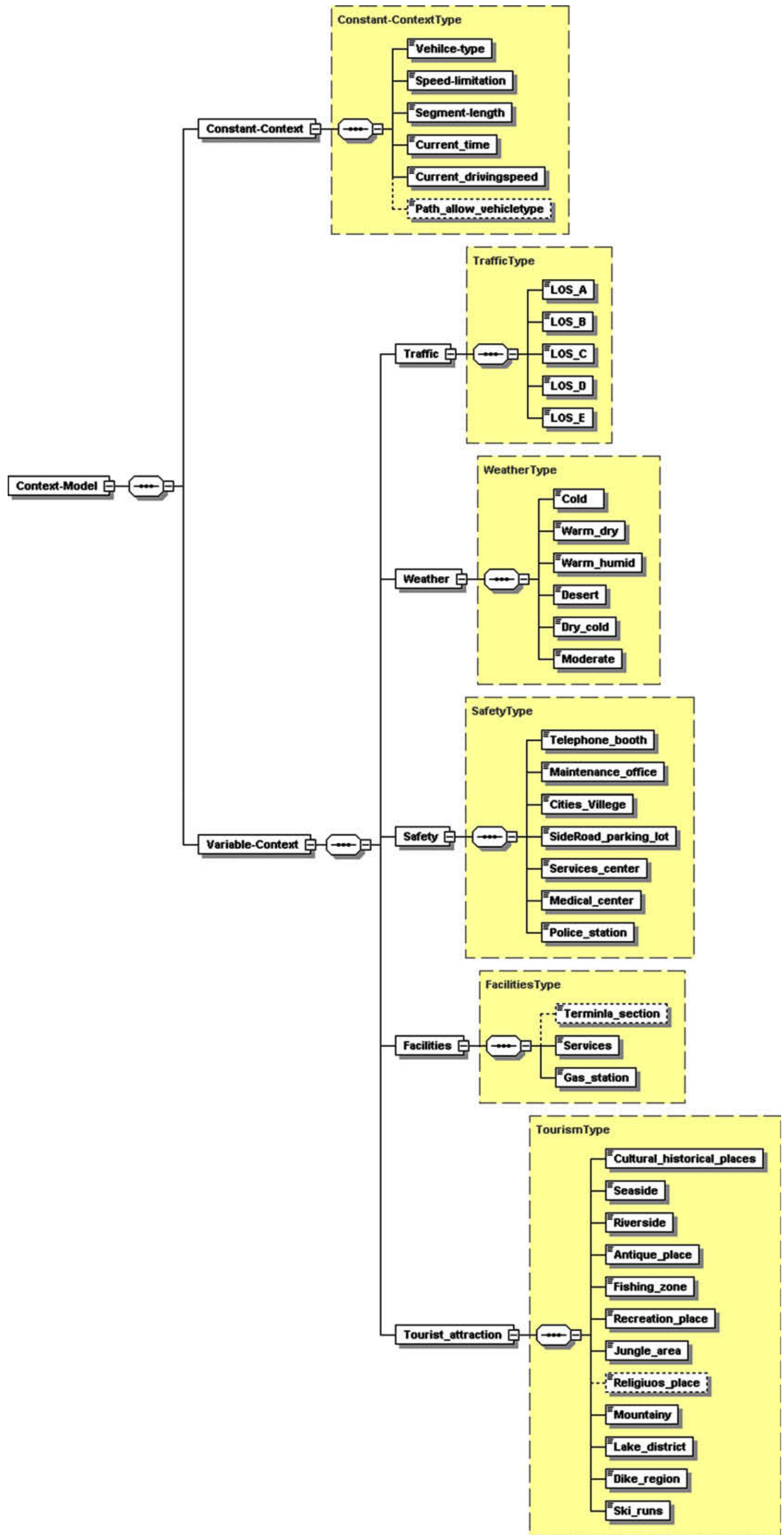

Fig. 5. Road segment context model.

ontology-based architecture, the relations among these criteria must still be identified. Without establishing appropriate relationships among the selected criteria, the criteria would not be able to create a personalized decision function. One of the best structures for establishing relationships among the user-centric route planning criteria is a decision hierarchical framework, which also provides basic rules for evaluation in the multi-criteria decision method, AHP.

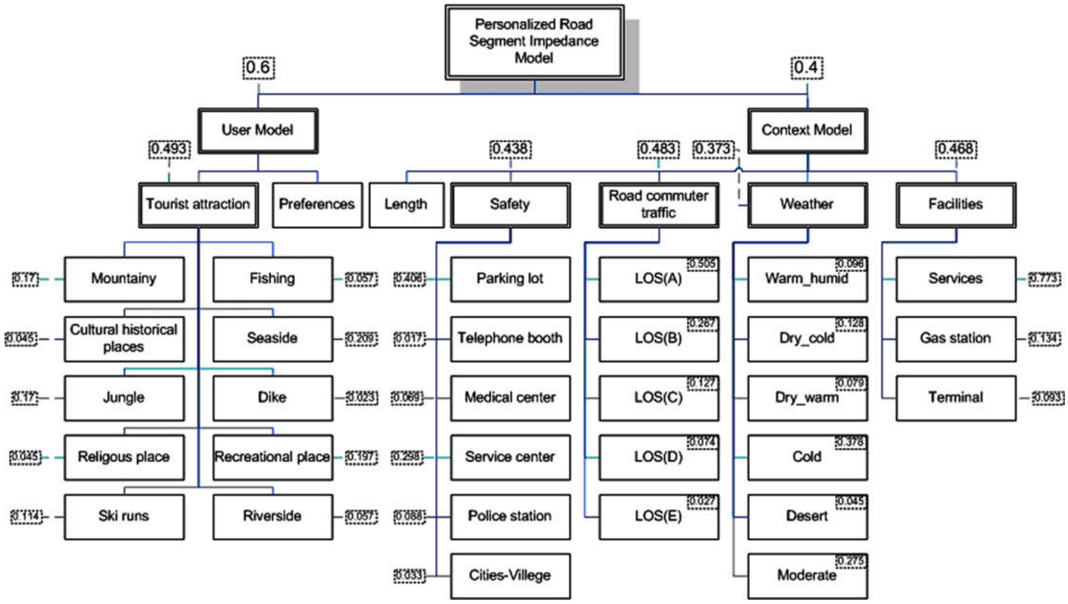

Fig. 6. AHP flowchart model derived from road segment ontology.

Moreover, an ontology typically includes a hierarchical description of important concepts in a domain (is-a hierarchy), and depicts critical properties of each concept via an attribute-value mechanism. The ontology itself is a tree structure and thus it can easily be converted to an AHP structure, which is a hierarchical style, multiple criteria decision-making method (Kwon & Kim, 2004). Additionally, the hierarchical arrangement has been found to be the best way for human beings to cope with complexity (Forman, 1990). For these reasons, a hierarchical approach, which transforms the subjective value of the decision maker's judgments into quantified data, is extremely valuable.

A complex objective, which is divided into several hierarchical elements in a decision hierarchical structure, allows for simple evaluation for weighting and modelling by decision makers in the AHP process. Once the hierarchical decision structure has been established, these criteria are weighted individually at every level relative to each other through a comparative judgment process and consistency index. The user model and context model can then be calculated by simply associating the various criteria in each level with each other. To use both the user and context models, comparative judgment data should be made by both the user and decision makers to prioritize the criteria. The final impedance model for the personalized route planning includes both the user model and context model (Fig. 6).

4. Model implementation and verification

Fig. 6 shows the AHP decision hierarchical structure of the user-centric route planning cost function, which is derived from the road segment ontology. Additionally, during impedance modeling, to obtain the cost model, it is assumed that the user arrives at destinations in the road network in personal vehicles, as opposed to the use of other vehicles such as buses or trucks. In this section, the implementation of the ontology-based road segment impedance model in a GIS road network is described. Then, in order to verify the usefulness of the proposed architecture in a real GIS situation, a case study is presented.

4.1. Model implementation

Subsequent to deriving all criteria and their weight for the personalized road segment impedance model, several methods were taken in account for implementation in a GIS environment for the user-centric algorithm. Some of the criteria were implemented by assigning difference values calculated and weighted by the AHP method for each subcriterion such as the road traffic and weather criteria. The other criteria including security, tourism, and facilities have different sub criteria, which respectively have separate effective zones. There are three methods of differentiating the effective zones: the 'buffering method', 'the use of the average quantity of kilometers', and a 'special method'. A detailed explanation of these methods was presented in Sadeghi Niaraki, Varshosaz, and Behrooz (2004).

In this research, Iranian road network were selected as a study area. To define the appropriate part from whole part of Iranian road network for study area of this study, a number of issues should be considered. The routes of Iran, for example, have special complexities. For instance, due to the extensive area of Iran (1.636 million sq km) and a road network totaling 180,000 km of road, as reported by the Road Maintenance and Transportation Organization of Iran (Fig. 7), there are extremely diverse environmental and weather conditions at different points. Consequently, it is exceedingly challenging to model the entire road network of the country. Thus, modelling should be performed

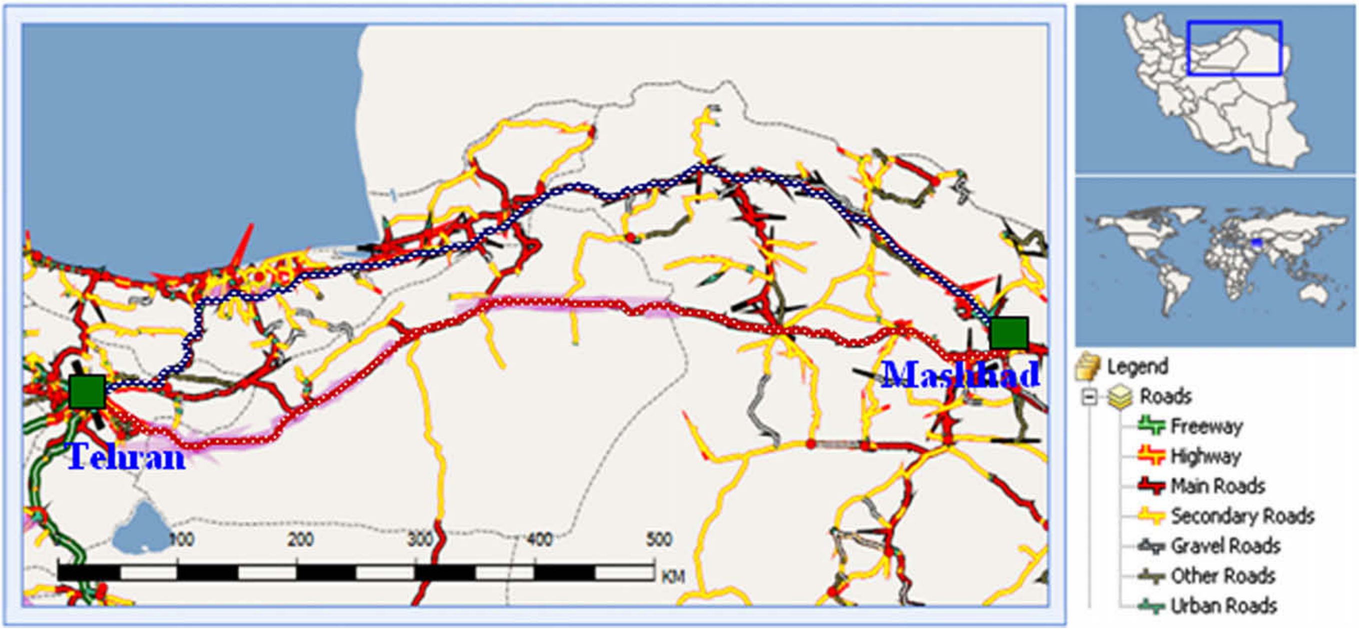

Fig. 7. The result of personalized and none personalized route planning system.

regionally. There are several suitable study areas for the verification of the final model in the Iranian road network (Sadeghi Niaraki, 2002). In this work, the road network between Tehran and Mashhad (55,000 km) was selected as the study area: Tehran is the nation's capital and Mashhad is one of the largest cities in Iran (Fig. 7). In this region, many routes exist between the two cities, and a GIS road network and other features around the roads with a scale of 1:250,000. The GIS data are spatial and non-spatial data of roads and other features in the vicinity of the roads, such as facilities (e.g. gas stations), tourist features (seaside areas, jungles), as well as weather, road traffic, and other data.

4.2. Verification of MDCM

The model verification assessment was conducted using the Iranian road network. Basically, the model verification is performed to verify the utility, generality, accuracy, and reliability of the aforementioned models. In this research, comparisons are made between the route suggested by the personalized route planning method in the GIS road network and that normally chosen by drivers heading to tourist destinations in real situations. As shown in Fig. 7, there are two routes between Tehran and Mashhad: the blue line denotes the 'Haraz route' and red line designates the 'Semnan route'.[1] The Haraz route was suggested by the personalized ontology-based route planning system and the Semnan route was proposed by a common route finding algorithm such as Dijkstra's algorithm. Regarding the former, most travelers on tourist-oriented trips select this route in the winter and summer seasons due to several advantages such as its various tourist facilities (e.g. restaurants), interesting places, and pleasant climate compared to other routes. Meanwhile, in the latter, there are no tourist attractions. Although, the former route has a high level of traffic and is somewhat more difficult to travel in winter as well as being longer than the 'Semnan route', given its other advantages and assuming that time is not of great importance to tourist travelers, this route is the best choice. Thus, the result illustrates the capability and accuracy of the personalized user-centric algorithm based on a tourist travel model verified in a real-world situation.

After considering the results achieved by experts and drivers, it shows that the 'Haraz route' has a lot of tourist characteristics in reality which are very considerable for tourist travelers. It was found that in practice almost all tourist drivers select 'Haraz route' to go to Mashhad. Finally, the aforementioned assessment shows that both the user model and the context model function properly in the road network. They are able to precisely represent the real situation of the GIS road network in a computer for optimum user-centric path finding. Moreover, the model verification confirms that the result corresponds with the user's preferences and context conditions and it thus suggested that the proposed system will prove valuable in both a GIS environment and the real world.

5. Discussion

The results of the personalized ontology-based route planning system using a multi-criteria decision making technique have been successfully modeled in this work. In this study, a personalized optimum path system was derived from user's preferences and a context model, which

[1] For interpretation of color in Fig. 7, the reader is referred to the web version of this article.

play major roles in ubiquitous GIS and ITS environments in order to realize user friendliness for user-centric applications. Furthermore, a flexible user-centric technique incorporating an ontology-based approach and a multiple criteria decision making technique is suggested to provide a reliable approach to address evaluation problems. Additionally, although this method of integrating ontology-based approach and multi-criteria decision making technique was applied to a GIS route finding evaluation, the model verification suggests that the proposed system is feasible and applicable to real settings. Moreover, the personalized route finding algorithm provides accurate decision making by choosing crucial criteria, and by establishing an effective decision strategy.

The advantages of the method are summarized in the following. First, the algorithm is able to effectively compare and quantify the importance of non-quantification criteria associated with the user model and context model. This is particularly important given that the most significant criterion of tourism-oriented personalized evaluation is always non-quantification. Furthermore, many relevant criteria are not currently available in digital form such as average congestion on streets. Additionally, some criteria are virtually impossible to encode, such as whether a route is "scenic". The relative importance of these criteria varies among individuals, and drivers may not know themselves what they value most in routes. Moreover, the personalized ontology-based impedance model actually provides a richer description of a road segment of a GIS road network and can improve accuracy of the route finding algorithm. The structured hierarchical structure, which is the fundamental part of the AHP ontology of this study, can help the decision maker to decompose the complex route finding evaluation problem into simpler components and thereby facilitate understanding. Finally, one of the major advantages of the proposed architecture is that it helps to integrate assessments of decision makers and the real situation. In an actual situation, decision makers are unable to assess the real personalized route planning analysis without adequate knowledge and experience. In this study, after formulating a domain specific ontology and producing initial criteria by experts, the AHP evaluation produced efficient criteria that are important for a personalized system.

While the advantages of the ontology-based multiple criteria decision making technique are clearly evident, there are also a number of limitations with this research that should be addressed for future assessments. Despite AHP popularity, this method is often noted for its inability to sufficiently handle the inherent uncertainty and imprecision associated with the mapping of the decision-maker's perception to exact numbers (Deng, 1999). In the formulation of the AHP, human judgments are represented as numbers. On the other hand, in many practical cases, a user favorite model is uncertain and decision-makers might be unable to assign exact numerical values to the evaluation judgments. Since some of the service evaluation criteria are qualitative, it is very difficult for experts to express the strength of their preferences and to provide exact comparison judgments. A new fuzzy AHP ontology-based method, which derives criteria weights from inconsistent fuzzy comparison process, has been described. Additionally, there is a limitation due to the large number of criteria in the hierarchical structure, which makes the proposed approach cumbersome. However, the proposed architecture is nevertheless significant since an effective evaluation AHP ontology-based personalized system is not yet available.

6. Conclusion

In this paper, a user-centric impedance model of each road segment for a personalized route planning analysis using AHP and an ontology-based approach was proposed. To address this research issue, various efficient criteria that affect personalized impedance modelling were identified and then combined into a single impedance function. This impedance model covers situational and personal user preferences in the route finding process. Thus, the personalized route planning yields optimal satisfactory routes according to the user and context models. In addition, richer descriptions of the road segments provided by the appropriate impedance model can improve the accuracy of route finding. Additionally, this approach could model subjective criteria such as whether a route is 'scenic'. As noted earlier, ontology-based multiple criteria decision making is employed to model the real world domain. The ontology-based multiple criteria decision making is not only able to model such knowledge, but also able to reuse and share it within group users. Furthermore, the domain-specific ontology offers a solid foundation for extending or maintaining the domain knowledge.

It is expected that this new approach can be implemented to develop new graph algorithms relies on semantic web technology that operate on new semantic graph structures. Moreover, sharing various user's models and experiences as well as ontologies could be a fruitful subject for future study. Application of fuzzy AHP is suggested given that in many practical situations the weighting criteria are uncertain and decision makers might be unable to assign exact numerical values to the comparison judgments. Finally, after defining an initial version of the ontology, it should be evaluated and debugged through practical applications or use in problem-solving methods or through discussions with experts in the field. Thus, revision of the initial ontology seems inevitable. This process of iterative design will likely continue through the entire lifecycle of the ontology.

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References

Chunithipaisan, S., James, P., & Parker, D. (2004). Network analysis from heterogeneous datasets – case study in the London train network. In *Proceedings of MapAsia 2004*, China. Available at: http://www.gisdevelopment.net/application/utility/transport/ma04167.htm.

Clemen, R. T. (1996). *Making hard decisions: An introduction to decision analysis* (2nd ed.). Belmont: Duxbury Press.

Deng, H. (1999). Multi-criteria analysis with fuzzy pairwise comparisons. *International Journal of Approximate Reasoning, 21*, 215–231.

Dey, A. K., Abowd, G. D., Brown, P. J., & Davies, N. (1999). Toward a better understanding of context and context-awareness. In *Handheld and ubiquitous computing,* pp. 304–307.

Farbey, B., Land, F., & Targett, D. (1993). *How to assess your IT investment: A study of methods and practice*. Oxford: Butterworth-Heinemann.

Fink, J., Kobsa, A., & Nill, A. (1998). Adaptable and adaptive information provision for all users. Including disabled and elderly people. *The New Review of Hypermedia and Multimedia* 4, 163–188. http://www.ics.uci.edu/~kobsa/papers/1998-NRHM-kobsa.pdf.

Forman, E. (1990). Multi criteria decision making and the analytic hierarchy process. In A. Carlo & B. Costa (Eds.), *Readings in multiple criteria decision aid* (pp. 295–318). New York, NY: Springer.

Gallo, G., & Pallottino, S. (1986). Shortest path methods: A unified approach. *Mathematical Programming Study, 26*, 38–64.

Gauch, S., Chaffee, J., & Pretschner, A. (2003). Ontology-based personalized search and browsing. *Journal of Web Intelligence and Agent Systems, 1*(3–4), 219–234.

Guarino, N. (1998). Formal ontology in information systems. In *Proceedings of the 1st international conference on formal ontologies in information systems FOIS* (pp. 3–15). Trento, Italy: IOS Press.

Jarrar, M., Demey, J., & Meersman, R. (2003). On using conceptual data modeling for ontology engineering. *Journal on Data Semantics, 1*, 185–207.

Järvelin, K., & Wilson, T. D. (2003). On conceptual models for information seeking and retrieval research. *Information Research* 9(1) Paper 163. Available at: http://InformationR.net/ir/9-1/paper163.html.

Jun, C., Koo, J., & Koh, J. (2004). Developing a water pipe management system in Seoul using the GIS. International archives of photogrammetry. *Remote Sensing and Spatial Information Sciences, 35*(2), 290–293.

Kobsa, A., Koenemann, J., & Pohl, W. (2001). Personalized hypermedia presentation techniques for improving customer relationships. *The Knowledge Engineering Review* 16(2) 111–155. http://www.ics.uci.edu/~kobsa/papers/2001-KER-kobsa.pdf.

Kwon, O., & Kim, M. (2004). MyMessage: Case-based reasoning and multi-criteria decision making techniques for intelligent context-aware message filtering. *Expert Systems with Applications, 27*(3), 467–480.

Natalya, F. N., & Deborah, L. M. (2001). Ontology development 101: A guide to creating your first ontology. Stanford Knowledge Systems Laboratory Technical Report KSL-01-05, Stanford Medical Informatics Technical Report SMI-2001-0880.

Pearl, J. (1988). *Heuristics*. Reading, MA: Addison-Wesley.

Qodsipoor, H. (1999). *Analytical hierarchical process*. Tehran, Iran: Amikabir University publisher.

Reuter, A., & Zipf, A. (2005). GIScience – where next. In S. Fotheringham & J. P. Wilson (Eds.), *Handbook to GIS*. Blackwell.

Riecken, D. (2000). Personalized views of personalization. *Communications of the ACM, 43*(8), 27–28.

Rogers, S., Fiechter, C.-N., & Langley, P. (1999). An adaptive interactive agent for route advice. In *International conference on autonomous agents* (pp. 198–205).

Rothengatter, T. (1993). Road user attitudes and behaviour. *Behavioural Research in Road Safety, III*, 128–133.

Saaty, T. L. (1980). *The analytic hierarchy process*. New York: McGraw-Hill.

Sadeghi Niaraki, A. (2002). Defining the cost model of Iran roads network in GIS. Thesis of GIS Master of Science, Faculty of Geodesy and Geomatics Engineering, K.N. Toosi University of Technology (pp. 49–53).

Sadeghi Niaraki, A., Varshosaz, M., & Behrooz, H. (2004). Implementation of the resulting cost model of road network in the Geographic Information System (GIS). In *International congress for photogrammetry and remote sensing; ISPRS congress*, pp.1272–1280.

Shadewald, J., Hallmark, K. S., & Souleyrette, R. R. (2001). Visualizing system-wide economic impacts of transportation projects. *Journal of Urban Planning and Development, 127*(4), 158–168.

Shen, X., Tan, B., & Zhai, C.X. (2005). Implicit user modeling for personalized search. In *Information and knowledge management*, CIKM (pp. 824–831).

Short, M. (2000). My generation: Third generation wireless mobile communication. *Electronics and Communication Engineering Journal, 12*(3), 119–122.

Thirumalaivasan, D., & Guruswamy, V. (1997). Optimal route analysis using GIS. http://www.gisdevelopment.net/application/Utility/transport/utilitytr0004a.htm.

Ziliaskopoulos, A. K. (1993). *Time-dependent, shortest-path algorithm for real-time intelligent vehicle highway system applications*. Transportation Research Record No. 1408, pp. 94–100.

Zipf, A. (2002). User-adaptive maps for location-based services (LBS) for tourism. In *Information and Communication Technologies in Tourism,* pp. 329–338.

Zipf, A., & Jost, M. (2006). Implementing adaptive mobile GI services based on ontologies. *Computers, Environment and Urban Systems, 30*(6), 784–798.