Effective medical center finding during COVID-19 pandemic using a spatial DSS centered on ontology engineering

Zahra Rezaei · Mohammad H. Vahidnia

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Abstract The global spread of the coronavirus has generated one of the most critical circumstances forcing healthcare systems to deal with it everywhere in the world. The complexity of crisis management, particularly in Iran, the unfamiliarity of the disease, and a lack of expertise, provided the foundation for researchers and implementers to propose innovative solutions. One of the most important obstacles in COVID-19 crisis management is the lack of information and the need for immediate and real-time data on the situation and appropriate solutions. Such complex problems fall into the category of semi-structured problems. In this respect, decision support systems use people’s mental resources with computer capabilities to improve the quality of decisions. In synergetic situations, for instance, healthcare domains cooperating with spatial solutions, coming to a decision needs logical reasoning and high-level analysis. Therefore, it is necessary to add rich semantics to different classes of involved data, find their relationships, and conceptualize the knowledge domain. For the COVID-19 case in this study, ontologies allow for querying over such established relationships to find related medical solutions based on description logic. Bringing such capabilities to a spatial decision support system (SDSS) can help with better control of the COVID-19 pandemic. Ontology-based SDSS solution has been developed in this study due to the complexity of information related to coronavirus and its geospatial aspect in the city of Tehran. According to the results, ontology can rationalize different classes and properties about the user’s clinical information, various medical centers, and users’ priority. Then, based on the user’s requests in a web-based SDSS, the system focuses on the inference made, advises the users on choosing the most related medical center, and navigates the user on a map. The ontology’s capacity for reasoning, overcoming knowledge gaps, and combining geographic and descriptive criteria to choose a medical center all contributed to promising outcomes and the satisfaction of the sample community of evaluators.

Keywords Spatial decision support system (SDSS) · Geographic information system (GIS) · Spatial databases · Knowledge management · Coronavirus · Ontology

Introduction

One of the most serious issues in COVID-19 crisis management is a lack of information, which necessitates real-time data on the situation and the provision
of appropriate solutions. Information and knowledge management has been critical in helping decision-makers to make strategic decisions not only for governments but also for people throughout the world (Wang & Wu, 2020). Knowledge management, in this respect, considers the link between information with information, information with activities, and information with an individual to realize knowledge sharing. Knowledge management is common as one of the strategic assets of any organization, and in the pandemic period, it affects people too (Yigitcanlar et al., 2021). Although knowledge management is of particular importance as one of the planned benefits of any organization, it has attracted more attention due to the inefficiency of conventional methods, providing more opportunities for creative and innovative solutions to COVID-19 crisis management (Odih, 2021). As a result, information sharing is just as crucial as knowledge application, to the point where a lack of proof of public engagement makes developing a co-created urban space for all a challenging task (Lim et al., 2021). Finding the proper medical center during a coronavirus outbreak is an issue that needs such knowledge to maintain people’s health and avoid disease transmission. Because of their intricacies, such problems are categorized as semi-structured problems due to a lack of expertise and knowledge.

According to definition, a decision support system is a computer system that assists decision-makers in dealing with unstructured or semi-structured problems through direct interaction with relevant data and problem analysis models (de Lima et al., 2019). Today’s decision-makers are increasingly confronted with issues influenced by geographic and spatial constraints. The availability of geospatial information is among the basic to manage a disaster (Van Oosterom et al., 2006). Indeed, without accurate and timely geospatial information, there is no possibility to manage the crisis optimally. In the COVID-19 epidemic crisis, local restrictions and intensive care have been put in place during this period aiming to maintain public health and helping break the disease chain. Also, some decisions to serve and assist patients require geospatial information, justifying the need for location-based, web-based, or Internet-of-thing (IoT) based technological solutions in this area (Dong et al., 2020; Garg et al., 2020).

Spatial Decision Support Systems (SDSS) are responses to Geographic Information system (GIS) deficiencies in decision support (Coutinho-Rodrigues et al., 2011). SDSS includes a Decision Support System (DSS) and a Geographic Information System (GIS). This combination requires to include three main components: a database management system, a library of related models (which manage the description of relationships, features and predict the outcome of decisions), and a user interface (which help users to interact with the computer system and analyze the results) (Crossland et al., 1995). In many people’s decisions about COVID-19, the human mental and perceptual abilities alone are not enough, highlighting the need for SDSSs that benefit knowledge management capacity. Ontology engineering is one of the most effective approaches to model knowledge about complicated semantics and a DSS relying on logical inference (Sure et al., 2009). By offering the macro and diverse perspectives, using ontology leads avoid wasting time and money, providing strategic solutions in project knowledge management, and making better use of its knowledge management achievements (Rezgui, 2006).

Ontologies effectively define the structure of knowledge for different domains (Lacy, 2005). They are a formal technique of describing classes of objects and the relationships between objects. Their ability to express nested relationships makes them a foundation for high quality and coherent data modelling. In medicine, the ontologies’ adaptation is often to find the cause of diseases by categorizing the relationships between the symptoms and different diseases (Haen-del et al., 2018; Schriml et al., 2012, 2019). Ontologies are also used for semantic web mining, patient information processing, and diagnosing complex issues (Aufaure et al., 2006; Dutta & DeBellis, 2020; Panigutti et al., 2020; Ryerson et al., 2017; Sharma et al., 2017).

Spatial analysis and decision-making make up a significant portion of coronavirus studies during this period. COVID-19 confirmed cases and attributed deaths in Africa were shown spatial and statistical credibility by Adekunle et al. (2020). They created spatial variants of clusters to investigate the relationship between COVID-19-related mortality and confirmed cases. Policymaking that could restrict disease spread explored, in addition to these challenges. Dangermond et al. (2020) explored the role of GIS during the COVID-19 crisis to examine explanatory parameters such as population, economy, climate, health and
quality of health care, place of residence, exports and imports, and environmental conditions. To analyze the influence of disease control measures, they classified effective systems into interactive systems, real-time data systems, systems linking to medical information systems, geographic dashboards, interactive applications, and simulation programs. Since the first detection of the disease in China in late 2019, the effects of the coronavirus have changed global patterns of disease and mortality, leading to the demonstration of strengths and limitations of health care systems and social security networks. In this respect, strategies are implemented to provide fast and accurate statistics and maps of the disease. Although these maps and the daily mortality statistics of COVID-19 are used as a political and social tool, researchers emphasize its effectiveness in tracking disease progression and appropriate responses by authorities (Rosenkrantz et al., 2021). As a result of deploying the GIScience strategy, several flaws were discovered, notably by using online mapping and location-based technology (Drew et al., 2020; Oliver et al., 2020). However, accurate tools have displayed that COVID-19 would have a long-term effect on global health. de León-Martínez et al. (2020) presented a comprehensive analysis of the social, environmental, and health factors of outbreaking COVID-19 in the Mexican indigenous population. In this study, the best way to address the issues and consequences of the COVID-19 crisis is to improve the health system with a community-based approach. In this study, all the necessary information about recognizing risk factors, including spatial, environmental, health, etc. information is discussed. Potential ideas are also presented in indigenous communities, hoping to find better solutions.

The major contribution of this study is the development of a web-based spatial decision support system (SDSS) with ontology-based knowledge management for finding the proper medical center in the event of a COVID-19 pandemic. The solution offered to the public in identifying medical centers is appropriate to the level of symptoms and clinical problems of users, spatial constraints, and preferences of individuals. Semantic capacities can lead to decisions that would be in the best interest of the medical staff and the people at the time of the outbreak of the disease. In terms of the importance of research, it can be claimed that simply displaying information about medical centers on a map and providing charts and illness data are insufficient for a patient to make an informed choice in many cases. In reality, innovative servicing mechanisms are intended for quick, reliable, and intelligent decision-making. Mao and Li (2011) suggested designing and implementing ontology-based web SDSSs to support various spatial decisions. They discuss that the handling of geospatial data, resources, and GIS analysis are efficiently performed on the internet in this way. Ontology languages such as Web Ontology Language (OWL) provide enhanced search and services and flexible architecture to solve the spatial semantic barriers in various fields (Cardoso & Pinto, 2015). On the other hand, integrating geospatial solutions into the health and clinical care command system provides a much more accurate response capability, especially at crisis events (Goniewicz et al., 2020; Hertelendy et al., 2021). Although ontology-based DSS has been used in various fields such as enhancing supply chain resilience, diagnosis of plant diseases, crime investigation processes, site selection (e.g., Dzemydiene & Kazemikaitiene, 2005; Lagos-Ortiz et al., 2017; Malezewski & Jelokhani-Niaraki, 2012; Sherimon & Krishnan, 2016; Singh et al., 2019)), to the best of our knowledge, it has not been studied to find treatment centers, especially in the COVID-19 pandemic. As a consequence, this strategy is employed in this study, and the aftereffects are assessed through developing an experimental system.

Therefore, the main objectives of the upcoming research are: first, to develop an ontology to provide knowledge in the field of symptoms of COVID-19 and its relationship with the facilities of different medical centers; Second, the development of an ontology-based decision support system that can effectively match the preferences of users and their spatial constraint with the symptoms of the disease and the treatment facilities of the medical centers; and finally, evaluating the proposed approach with the opinions of volunteers in a community of specialized fields such as medicine and nursing, as well as ordinary people.

Materials and methods

A knowledge base is a repository for knowledge in a specific domain that uses meta-models to discover a model base. In practice, the knowledge base is divided into a database of facts and logical rules. The
fact database contains data generated from the model base and other information about the application of different models. The rule database contains various decision rules adopted based on the opinions of different experts. It can also incorporate rules that are automatically derived from prior experience (Ferretti & Montibeller, 2016).

Spatial Decision Support Systems (SDSS), which support geospatial information analysis and decision making, are currently of great interest to researchers. Research on DSS comes from two separate domains: the GIS community and the DSS community. The synergy between these two research communities leads to the most advanced and practical solutions in SDSS development. The needs of geographic information scientists and high-level decision-makers are well provided by combining these two paradigms. The Web has recently brought a new dimension to SDSS in such a way that Web SDSS is being developed in a variety of areas (Maina et al., 2014; Sugumaran & Sugumaran, 2007).

As mentioned in the previous section, applying SDSS technologies in various areas of complex issues (such as healthcare, property management, environment, crisis management, etc.) can be beneficial and constructive. In this study, in order to control the prevalence of COVID-19, web-based SDSS and ontology-based solutions have been used, considering the complexity of information related to COVID-19 disease and its spatial nature. For this purpose, an ontology is first designed and developed. In this ontology, different classes and properties are created regarding the symptoms of the disease, the type of medical centers, and their location in the city. Symptoms of the disease such as fever, cough, sore throat, and many other cases, according to the knowledge experienced so far in Iran and the tips provided by the World Health Organization are designed. Medical centers are also classified according to special facilities, having a laboratory, having a pharmacy, and similar items. This ontology will then be the basis of a web-based DSS that will lead to finding the right medical center. One of the goals of this design is to use only open-source solutions (Agrawal & Gupta, 2017). Therefore, The ontology will be designed in Protége based on the OWL language (Olantiwo et al., 2018) and will be revoked in the system using the package called Owlready in Python to interpret users’ queries logically (Lamy, 2017). The system will also use a PostGIS spatial database to store and retrieve treatment center location data when needed. Web design also uses technologies such as HTML, CSS, Bootstrap, OpenLayers, and JavaScript to create a dynamic map-based user interface. Technologies such as Werkzeug and Flask will also be used to build the web server and communicate with the client (Mitchell, 2008). The following is a description of this design and implementation.

Ontology and logical reasoning

The designed ontology is an explicit and formal description of classes of concepts such as medical centers and the symptom of COVID-19, and properties describe each of these concepts. The medical center classes can be treated as spatial objects that contain a set of non-spatial information. As a result, extra location or descriptive data for a center might be stored in a geographical database and retrieved following ontological reasoning (Vahidnia & Alesheikh, 2014). In this respect, the World Wide Web Consortium (W3C) standard knowledge representation language for authoring ontologies, i.e., Web Ontology Language (OWL), is used in this study. Because of using ontologies in the proposed system, in addition to representing knowledge and its complicated relationships, the ability to handle reasoning on this knowledge is also feasible (Corcho et al., 2004). Ontologies use a logic-based manner through Description Logic (DL) to retrieve information and provide reasoning capabilities. In this study, Protege is employed as an OWL ontology development environment. In addition, reasoning over the designed ontology is handled by the HermiT reasoner (Abbru, 2012). Using reasoner not only eliminates logical inconsistencies in ontology but also responds to queries to the user such as "Which treatment center is right for my location and symptoms?" will be applicable. In this research, an attempt is made to provide specific services in a user interface, according to the user’s characteristics. A set of rules and features have been created at the top level of ontology that ultimately equips the system with reasoning power. The general structure of the ontology hierarchy and subclasses is shown in Fig. 1. The designed ontology root class includes the classes of disease symptoms, the distance to medical centers, and location. Object Properties and Data Properties and standards of
establishing the domain ontology could equip the system with a reasoning engine discussed in more detail in the implementation section.

System architecture

Due to the expected functions of the SDSS, it should regard a client–server architecture under the web. In this architecture, health center information related to coronavirus with features such as location, names, and addresses has been considered for storage in a PostgreSQL database. In addition, a component for ontology-based and reasoning is provided which can be queried about semantics behind the model. An attempt was made to provide specific services in the user interface based on the user’s characteristics. The interface was required to communicate with the knowledgebase component. OWL capacities are used on the server-side to interpret the clinical signs of users, related medical facts, and other user preferences in selecting medical centers.

A simple way to demonstrate the issue that the ontology-based web SDSS will address can be explained as follows: First, get the user preferences and symptoms; Next, create an ontology instance based on the characteristics provided; Finally, If the user conditions are satisfied based on ontology reasoning, then response and support the user with the best choice for the clinical center on a map. In other words, on the client-side, the user can select the desired spatial priorities and disease symptoms and the distance factor to the desired medical centers. By analyzing and considering the user’s clinical symptoms and their location priorities, the system directs the user to a suitable medical center and access its address, telephone and location.

Protégé provides simple and visual tools for creating OWL ontologies, which was employed in this work. This software also uses ontological analysis to produce derived classes, check model consistency, and infer additional information. In this context, defining classes and subclasses and constituting object and data properties are straightforward. Classes describe domain concepts, and each class can have subclasses. Figure 2 illustrates the system architecture and its main components. HTML, CSS, Bootstrap, OpenLayers, and JavaScript programming languages are utilized in the developed system to create a dynamic web page that collects user preferences on the client-side as a new instance to be entered into the ontology on the server-side. The OpenLayers library is used to guarantee that the underlying OpenStreetMap and geographica data are properly rendered, and the Bootstrap library features are employed to improve the web page’s visual appeal. On the server-side, there is a PostgreSQL database of medical centers. The database and the knowledge base are consumed by the DSS business logic written in the Python programming language. The web server in this architecture establishes communication with clients using Flask and Werkzeug technologies. The PostgreSQL database also incorporates storage of information parsed during the ontology retrieving process. The OWLready package loads ontology entities and automatically removes them from RAM if they are no longer needed through a decision-making process. This library allows the program to handle intricate knowledge details plus parse and update the OWL ontology. A temporary ontology is formed after the ontology is loaded and classes and features are accessible in a Flask application. Next, a new instance is added to the ontology based on the input parameters that the user has requested. After that, HermiT is used to reasoning on the ontology, and the most relevant class is inferred. Finally, the user receives the decision’s outcome as well as the mapping results.

Evaluation method

Generally, a community that make a collective intelligence can be used to evaluate a system’s performance. In this study, 15 volunteers—specialist physicians, medical staff, nurses, and patients—with varying degrees of experience in health and medicine are chosen in order to assess the effectiveness
and productivity of the system that has been developed. Next, we provide this community access to use the program’s different features. We would set up a survey form in the Telegram messaging system and request that participants submit their own viewpoints of using the system in the four categories of completeness of clinical symptoms in the system, consideration of user preferences, functionality and usefulness of the introduced center, and comparative diagnosis by a specialist physician into the channel. The expected outcome is for the response to be a nominal variable with a constrained range of attributes such as weak, medium, good, and excellent. The volunteers need to consider the characteristics and symptoms of the disease and the spatial constraints for finding a medical center in this survey. The survey statistics are then compiled for the final assessment once the linguistic terms have been turned into their corresponding numerical values.

Results and discussion

Ontology engineering of medical centers

In this study, ontology includes the main classes of common and important symptoms of COVID-19, other clinical symptoms, distance to medical centers, and location of these centers. Attention was paid to specific or the most common symptoms of coronavirus
using ontology. Different classes of clinical symptoms and the need to attend related medical centers, including laboratories, clinics, hospitals, etc., are among the determinants. In addition, user preferences and spatial characteristics of the user are considered based on description logic. For this purpose, it was necessary to define the object properties between classes. For example, the isBaseSymptom property is defined between the MedicalCenter and DiseaseSymptom classes. That is, it is defined which center has the necessary facilities to respond to which symptoms. Equipped hospitals, for example, are suitable for responding to the common symptoms of COVID-19, but people with milder symptoms should be referred to clinics. Features in the ontology can be defined in different ways such as symmetric, asymmetric, transitive, reflexive, irreflexive, functional, and inverse functional. Defining these features leads to automatic logical deduction and the discovery of new relationships. For example, the hasDistance property contains examples of the distance or proximity of a reflexive property. If a medical center is close to the person, the person is also mutually close to the center. As another example, the hasLocation property is a functional property. That is, a medical center accepts only one of the urban locations, such as north, east, south, west, or center, and no more. Parts of the ontology are presented, both as a representation of the hierarchy of classes and subclasses, and as graphs of their relationships in Figs. 3 and 4. A fraction of the OWL/XML output of the implemented ontology to be utilized in the decision support system has been depicted in Fig. 5.

Developing an ontology-based web decision support system

According to the description of the designed architecture and built-in components, ontology-based web SDSS was implemented. When users connect to this system, they encounter a form in the client section. In this form, the user’s clinical condition such as fever, cough, body aches, age group, etc., and residential area are sent to the server by request. On the server-side, in the ontology section, the classes, subclasses, attributes, and logical rules are matched to the requested query, and the reasoning operation is performed. Based on the reasoning of the user’s request, the appropriate treatment centers are determined and sent back to the user in the client section as a response. Figure 6 shows some code accomplished in Python, JavaScript, and HTML with the help of libraries like Flask, Bootstrap, OpenLayers, and OWLready. Figure 7 also illustrates screenshots from the system user interface indicating user requests and responses. In this web form, the user provides his clinical symptoms as well as the medical center’s geographical priority. On the answer page, the result of the best decision is displayed along with the location on OpenStreetMap and information such as the name, address, and description of the health center.
Evaluation of efficiency and productivity

The system has been evaluated by being available to several volunteer users to assess the efficiency of the designed system. Among the volunteer users, several medical staff was invited to cooperate to could be getting better conclusions regarding the accuracy and efficiency of the system. By considering effective parameters regarding the system performance in identifying an appropriate health center corresponding to the user’s clinical symptoms and by considering the characteristics and spatial priorities of the user regarding the lack of access, they gave answers to some survey questionnaire.

Based on this, the opinions of different users were collected according to their different views and levels of knowledge in the field of medical sciences and treatment. The evaluations performed on the system are shown in Table 1. In addition to the comments received from users, in the last column, a comparative opinion of a specialist physician regarding the performance of this system according to users’ transactions was taken and included in the final summary. Due to different opinions, only a few experts and acquaintances in the field of treatment and medicine did not welcome the treatment centers introduced to the user. These people suggested that parameters such as the capacity of medical centers, insurance companies under the contract, previous user feedback from social networks should also be considered by the system. On the other hand, the vast majority of users had a positive opinion about the ability of this system in terms of appropriate medical centers. Because the ability of this system to infer based on clinical signs, user location and preferences, are the most important items that each person considers and leads to user satisfaction. At the same time, in critical situations and urgency, quick decision-making is an important advantage of the system. On the other hand, the logical argument that an ontology brings is more reasonable than a long-term review of user feedback and scattered searches on Google and other search engines. Finally, in a comparative study of the opinions of specialist physicians regarding the performance of

![Graph of entities and their relationships in COVID-19 medical center finding support system](image-url)
Then, in order to statistically analyze user feedback on the use of this system, quantification charts of evaluation indicators were performed. The desired indicators are completeness of clinical symptoms in the system, consideration of user preferences, functionality and usefulness of the suggested center, and comparative diagnosis by a specialist physician. In the feedback quantification process, a high opinion was considered equal to 200, a good opinion equal to 100, an average opinion equal to 50, and a poor opinion equal to 0. According to the results, the strength of the system is the functionality and usefulness of the suggested center, which has obtained the highest score according to Fig. 8. According to the separation of user types in Fig. 9, the level of satisfaction of normal users of this system is in the highest range. Also, the users’ satisfaction rate of the healthcare staff is above average. These results show the proper efficiency of the system in helping people and medical staff in these critical situations.

Discussion

Numerous research has been conducted in the area of geospatial information technology to combat the COVID-19 pandemic. Our investigation shows that the findings of previous technological research have been mainly focused on issues such as obtaining spatial statistics to provide choropleth maps of the prevalence of disease, developing online tools to assist counseling for illness prevention and treatment, the interactive maps’ depiction of pertinent medical facilities and navigational aids, and providing intelligent location-based services to prevent individuals from coming into contact with patients. The focus on medical center equipment
in the face of the corona virus was one of the key distinctions between the current research and other studies. Patients with COVID-19 cannot be admitted by several Iranian hospitals. However, even after admission, there are many levels at which services are provided. For instance, serving patients who require special care or those with urgent digestive issues is different from serving those who are healthier. This study demonstrated that, under such circumstances, an intelligent DSS makes it easier to select a medical center. Knowledge management relying on ontology engineering was another way that this research differed from earlier ones. We went beyond only representing the location information of medical centers on geographic dashboards, querying over huge databases, and displaying charts and statistics. The power of reasoning in the ontology, resolving the contradictions in the existing knowledge, and the combination of spatial and descriptive constraints all brought promising results and the satisfaction of the sample community of evaluators.

Conclusion

Co-occurrence of COVID-19 outbreak in the world with the information technology era and communication has created a new opportunity in the new management system for organizations to get themselves more agile in outbreak duration, transition, and post-peak of the crisis outbreak gained appropriate experiences through transition management and crossing with health. In the study, an ontology-based spatial decision support system was designed and implemented to help manage the coronavirus crisis for both the public and the authorities. Thanks to the logical deduction provided by the system business logic and knowledgebase, the decision support system makes it possible to find the most appropriate medical center for users. Important decision-making criteria were the individual’s clinical symptoms and priorities concerning the medical center location. The main benefit of such a system encompasses avoiding unnecessary movement of people while facing this disease or suspicious symptoms in unrelated health centers that
prevent overcrowding in these centers and avert the spread of illness to others. Many open-source components were communicated together to bring reasoning and mapping capabilities into existence in the proposed architecture. In this respect, the ontology was explicitly constructed and consumed as basic knowledge and semantic.

For future studies, it is first suggested that the presented ontology be further completed. As the surveys showed, other classes and features about health centers such as contracted insurance companies, admission time periods, and other facilities can be defined. Another issue for future research is the combination of decision support systems and

![Figure 7](https://example.com/f7.png)

**Fig. 7** User request registration page in the client part of the system (a) and the posted result to the user from the server-side (b)
recommendation systems. In recommendation systems, previous user feedback and finding similarities between a person’s symptoms and those of other people will be effective in recommending a health center. Such a system, while having the necessary intelligence, will require less user input information. Another way is to add more advanced location-based services. Spatial analysis, routing, and user navigation with minimal exposure to crowded areas are a prime example during the COVID pandemic.
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**Declarations**

**Conflict of interest** The authors have no competing interests to declare that are relevant to the content of this article.

**Ethical approval** This research does not involve individual participants in the study, and thus ethical approval is not required.

**Informed consent** The authors have given the informed consent to publish this article and therefore informed consent is not applicable.

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**Fig. 9** The sum of the scores assigned to each criterion by different types of users
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