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A systematic mapping study of decision support systems in health informatics

Rabia Ali Alkhazmi ,1* and Hiba Abdullah Ateeya Abdullah 2

1 Department of Computer Engineering, Higher institute of science and technology, Tarhuna, Libya.
2 Department of Computer Engineering, College of technical sciences, Derna, Libya.

Abstract

The act of choosing the correct option among many available alternatives is called decision-making. Many factors should be considered to make the right choice. The decision may or may not be decisive depending on the contrast of the considered factors. When providing healthcare services, it is important to make the correct decisions to ensure providing efficient, low-cost, fast and accurate services. Many factors should be considered to make such decisions, and some have no contrast to make decision making easier. Thus, computer systems are proposed to support the decision making to ensure better service quality. Patient related information and the techniques used to communicate such information are known as Health Informatics. Health Informatics are mandatory for a decision support system designed to support the healthcare service provision related decision.

The rapid development in software engineering and the high availability of computers in every healthcare facility encourages scientists and engineers to build decision support system in health informatics. Those led to a huge number of studies proposed in this field making it hard for future studies to choose the appropriate guidelines for them. Thus, this study provides a systematic mapping for existing studies that can be used as guidelines for future research.

Keywords: Systematic Mapping; Decision Support Systems; Health Informatics; Decision-making

1. Introduction

Scientists have always been dreaming of creating an "Electronic Brain" ever since the computers' modern history, [3]. The rapid progress of computers gave them the ability to execute very complex algorithms and processing numerous data in a very short period to support decision making task.

1.1. Decision Support Systems

Decision-making can be defined as the problem of choosing the correct option among many alternatives. Complex decisions require a lot of investigation in order to make the appropriate choice either because of the similarity of the available options, the huge number of factor affecting the decision-making or the importance of making the correct decision. Improving the quality of decision made by humans motivates the development of different models that presents knowledge in logical, algebraic or statistical variables. Models interact with these variables using equations or logical rules and may be improved by uncertainty explicit representation. When it is impossible to represent the interactions in a functional form, probabilistic terms are used to describe these interactions purely. Decision Support Systems (DSS) are computer-based systems that have a role in the process of making a decision [1]. The fundamental components of a decision support system are database management system, model-base management system and dialog generation system. The database management system is the data storage area of the DSS, enormous amounts of data related to the problems that the decision support system is built for are stored in the database management system, and it should be able to provide the stored data types and the scheme to access these data. Model-base management

* Corresponding author: Rabia Ali Alkhazmi

Department of Computer Engineering, Higher institute of science and technology, Tarhuna, Libya.

system transforms data stored in the database management system into useful information for the decision making process.

1.2. Health Informatics

Recently, it has become difficult to imagine providing healthcare services to a patient without the use of a computer. This led to an enormous amount of accumulated data that was realized to be useful not only at the time of healthcare service provision but for later patient care too. The use of information and technologies used for communication within the healthcare field is known as Health Informatics (HI). Because of the complexity of the process and the numerous amount of data utilized in the healthcare field, clinical decision support systems rely on health informatics to achieve the required tasks [4].

1.3. Systematic Mapping in Software Engineering (SE)

With the numerous studies in the field of decision support systems in health informatics, it is very important to provide an overview of the conducted studies in this field using Systematic Mapping (SM), which is carried out through classifying and counting these studies according to their categories to assist researchers acquire an overview of the existing computer decision support systems in health informatics as guidance for their studies.

Summarizing and providing an overview of a study field is very important as this field matures because of the huge increment in the number of studies in it thus, systematic mapping is used in the field of software engineering to categorize and provide visual summaries of the studies included in the mapping in order to structure these studies and their results.

A systematic mapping study reviews a particular topic in software engineering to classify the studies in that domain. In order to achieve that, very high-level Research Questions (RQs) are selected to contrast different categories in each sub-domain of the domain being studied. Thus, researchers in the software engineering field are interested in the systematic mapping results as it provides an overview of the studies conducted on a specific topic.

1.4. Systematic Mapping Process

Guidelines for conducting systematic mapping in software engineering are propose. The key steps to perform a systematic mapping using these guidelines are the definition of research questions, search conduction, inclusion and exclusion criteria and data extraction table. A summary of the systematic mapping procedure using these guidelines is shown in figure 1.

Research questions help illustrate each sub-domain of the topic, by answering these questions for each study included, an overview of that topic is concluded so that a researcher may use the statistics of each review question's answer or combine statistics from multiple answers to create a custom overview of the topic depending on the required information.

In order to retrieve a list of studies alongside with their essential details for further processing during the systematic mapping process, a search must be conducted in the databases of related digital libraries. The keywords used in the search phrases are identified from the research questions.
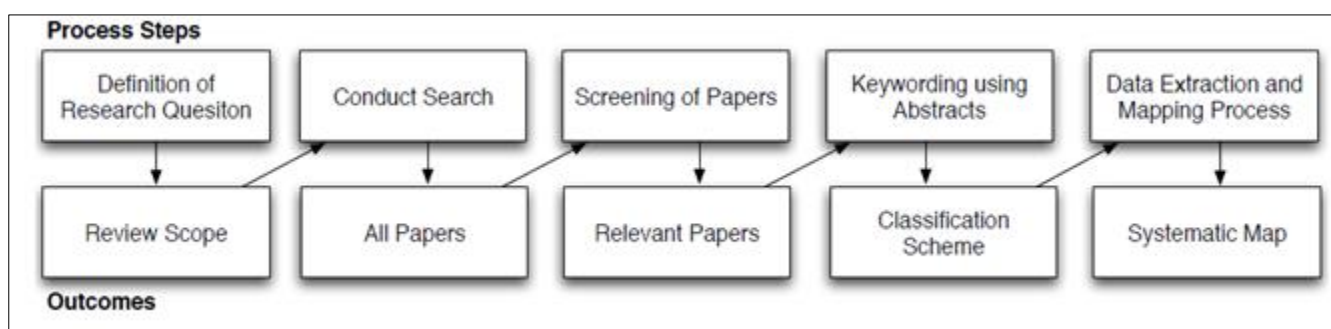
Figure 1 Systematic Mapping Process

Inclusion and exclusion criteria, which are concluded based on the research questions, are used to evaluate the studies resulted from the search conducted in order to decide whether each study is included in the mapping or not.

Data extraction table contains all the included studies alongside with the answers to the review questions regarding each study. Again, the data extraction table is designed based on the review questions. The contents of this table are used to generate the statistics and graphs resulting from the mapping process.

The structure of the remainder of this study is as follows: Section 2 presents background knowledge. Section 3 demonstrates the process used to conduct this systematic mapping. Section 4 illustrates the results of the systematic mapping. Section 5 discusses the information concluded from the mapping results. Section 6 presents recommended future works.

2. Background

The main reason behind using a clinical decision support system in a healthcare facility is to provide better quality and safer services for each patient and improve the efficiency of the healthcare facility. Clinical decision support systems have shown significant improvement in both the outcomes of a patient and the cost of the healthcare process Byrne et al. (2011).

According to the methodology used to build the clinical decision support system, clinical decision support systems can be categorized into one of two categories, knowledge-based and non-knowledge-based systems.

The knowledge-based systems are usually, but not necessarily, consisted of a group of if-then clauses to replicate the thinking of an experienced professional in the field that the CDSS is interfering with. Non-knowledge-based systems are based on machine learning algorithms that are a form of artificial intelligence. This category of clinical decision support systems attempts to find patterns in the available clinical data and/or use past experiences for practicing to learn the best suitable decision for the case being investigated.

Information and communication technologies used within the healthcare field are known as Health Informatics (HI)). It is mandatory for a clinical decision support system to use health informatics to achieve its goals except for the very rare case where patient's information is entered directly into a stand-alone system. The data required by a clinical decision support system might be patient's information, lab test results, sensors connected to the patient, images or any combination of these data types.

Patient information used by a CDSS may be stored in Electronic Health Records (EHR) or may be provided directly by the user of the clinical decision support system. This information may include symptoms, historical data and personal information of the patient. EHR of a particular patient may be used to support decisions related to that patient or any other patients by using machine learning to find a pattern that matches the information provided about the patient under investigation to support the decision to be taken by the CDSS use. Using available data to classify patients suspected to have swine flu by learning the pattern in the currently available data to suggest the class that the patient under investigation fits into out of three classes according to the probability of having this disease.

Some decision support procedures require processing images such as X-rays, MRIs and biopsy results, thus, some CDSSs use image processing and/or computer vision algorithms to extract data from these images for further processing by the CDSS in order to complete the requested tasks, Bhaskar et al. (2016). The retinal disorder is very serious for people with diabetes and may lead to blindness. Thus, the CDSS proposed) uses image processing to predict any retinal disorder by using a handheld device and mobile camera to enable the patient taking necessary actions to avoid any development. The stages of image processing employed in this CDSS are shown in figure 2.

A CDSS may interfere with the workflow, drug prescription, diagnosis or any of combination of these healthcare services. Interfering with the workflow means that the CDSS assists the user of the system to make the appropriate workflow following this step to provide the optimal healthcare process. Avoiding drug-drug and drug-food interaction, optimal dosage and side effects alerts are the benefits of a prescription interfering CDSS while diagnosis interfering systems are used to provide more accurate diagnosis of the disease.

The input data is processed by the CDSS to assist the user to come up with the appropriate decision regarding the task that the CDSS is designed to be used for. The output of the CDSS may be a suggestion, classification or warnings and alerts Suggesting a workflow, prescription or a diagnosis may assist the user of the CDSS making the optimal decision with less effort, time and cost even if the user does not follow the suggestion as it is and decides to modify it. According to the lack of healthcare services quality in the rural areas of Bangladesh and the wide availability of the internet service.
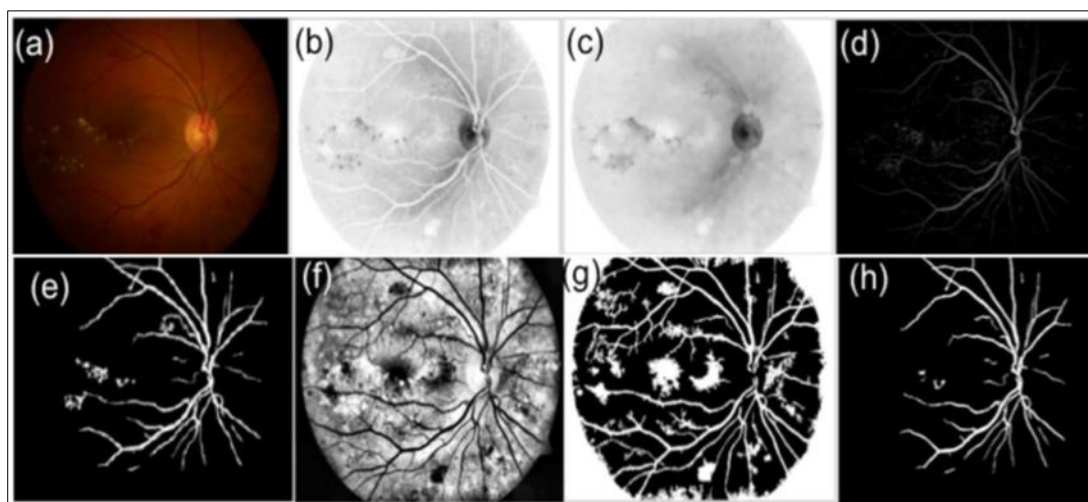
Figure 2 Exudates detection stages using image processing

Warnings and reminders are the simplest interventions of the CDSS and are usually distributed into different levels depending on how important is the warning or the reminder is. These warnings and reminders may be triggered by an action taken by the user of the CDSS or by processing the data of the patient.

Although patients are the primary beneficiaries of using a CDSS by receiving faster, more accurate and less expensive healthcare services, a CDSS may be used by clinicians, patients or both. A user of the CDSS is defined as the person who is responsible for providing the required data to the CDSS and interacts with the output of it.

3. Methodology

3.1. Systematic Mapping Process

3.1.1. Research Questions

In order to choose useful relevant research questions, we need to set up the goals of this study. These goals are:

- G1: To classify the clinical decision support systems proposed according to the methodology used to build the system.
- G2: To determine the benefits of the proposed CDSS by studying the type of decisions it supports.
- G3: To identify the types of inputs used by the CDSS to perform the required tasks.
- G4: To study the criteria used in the CDSS to interact with the decision making process.
- G5: To identify the user who interacts with the CDSS.
- G6: To determine the top countries investigating the field of using decision support systems in health informatics.
- G7: To study the pattern of the proposed studies.
- RQ1: What are the methodologies used to develop the proposed CDSS? The aim of this question is to find the methodologes used by developers to build the proposed.
- RQ2: What decision types does the proposed CDSS support?
- This question is proposed to discover the types of decisions that are being supported by the clinical decision support systems proposed in the studies included in this systematic mapping.
- RQ3: What are the inputs required by the CDSS?
- This question aims to investigate the inputs provided to the proposed CDSS, in order to perform the required task.
- RQ4: What are the outputs of the CDSS?
- The purpose of this question is to understand the techniques used to support the decision making and how these systems provide the output to the user of the system.
- RQ5: Who are the users supposed to interact with the CDSS?

- This question inspects the user who interacts with the proposed CDSS. This will provide an overview of the users that the proposed systems are targeted to and the distribution of the users among the proposed systems.
- RQ6: Where are the studies conducted?
- The aim of this question is to find the top countries interested in the clinical decision support systems.
- RQ7: When are the studies conducted?
- This question investigates the year when the study is published through.
- RQ8: Where are the studies published?
- The purpose of this question is to find the top journals and conferences that published related studies to achieve the goals planned for this study.

3.1.2. Studies Search

For the purpose of finding studies relevant to our topic, three academic digital libraries were searched which are IEEE Xplore, ACM Digital Library, Science Direct, Wiley and Springer. The initial search phrases are based on the subject of the study (decision support systems in health informatics), then, PICO (Population, Intervention, Comparison, Outcomes) is used to improve these phrases. As each digital library has a different search engine, search phrases are different for each library. The search phrases used and the number of studies for each library is shown in Table 1.

Table 1 Search phrases used for each digital library

| Library	Search Phrase	No. of Studies
IEEE Xplore	(("Document Title":decision AND (p_Title:support OR "Document Title":aid OR "Document Title":making) AND (p_Title:health* OR "Document Title":clinic*)))	317
ACM Digital Library	"query": { acmdlTitle:(+decision +(Support aid make making) +(healthcare health clinic clinical)) }	527
Science Direct	TITLE("decision" AND ("support"OR"aid"OR"make"OR"making") AND ("health"OR"healthcare"OR"clinic"OR"clinical") AND ("computer"OR"system")	258
WILEY	TITLE(decision AND (support OR aid OR make OR making) AND (healthcare OR health OR clinic OR clinical) AND (computer OR system)	177
Springer	TITLE(decision AND (support OR aid OR make OR making) AND (healthcare OR health OR clinic OR clinical) AND (computer OR system)	957
Total		2236

3.1.3. Inclusion/Exclusion Criteria

Studies are excluded in two stages; the first stage is based on titles of the studies and their abstracts while the second stage is based on quality assessment during full-text reading. It is important to mention that the inclusion/exclusion criteria were applied by the author and the supervisor of the study. A study is excluded in the first stage only when both vote for exclusion while all remaining studies are processed through the second stage to ensure unbiased exclusion of the studies. The inclusion criteria are:

- The study is in the field of computer decision support in health informatics.
- The study presents the model used for decision support and the output of that model.
- The study is published between 2007 and 2016. This study is conducted in 2017.

The criteria used for study exclusion are:

- Articles that present summaries of conferences.
- Studies presented in a language other than English.
- Books and gray literature.
- Studies that their full-text is inaccessible.
- Duplicate studies.

The number of studies that are included or excluded for each step is illustrated in figure 3.
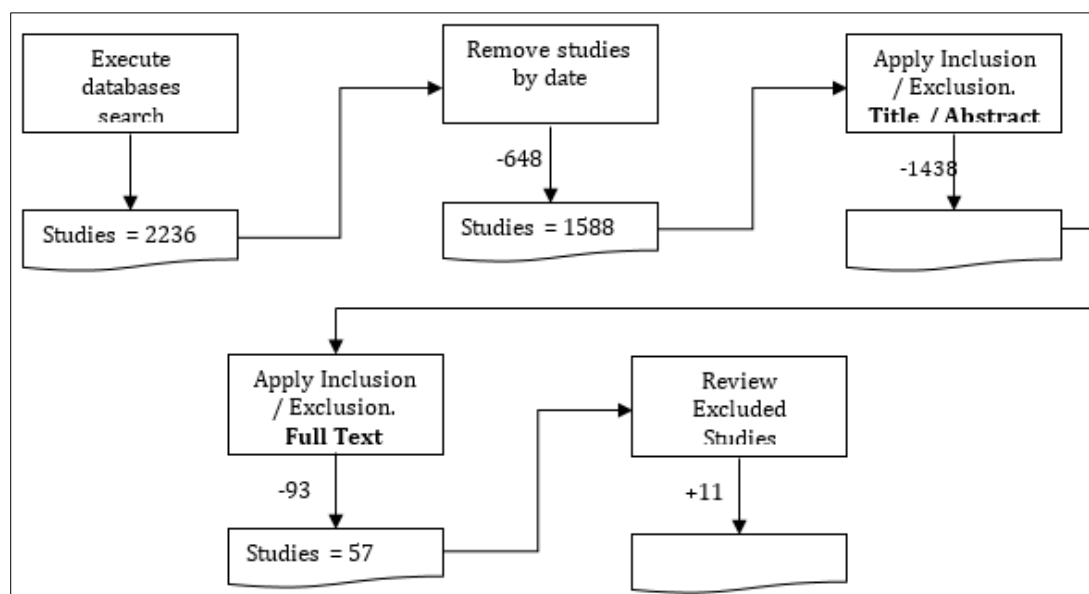
Figure 3 Study selection procedure

3.1.4. Data Extraction

In order to provide tabular data for the mapping, the template shown in Table 2 is used to extract required data from each study included. To simplify the data visualization process, each data extraction field is split according to the possible metrics available in that field.

**Table 2** Data fields to be extracted from included studies

Data item	Description
D1: Index	The ID of the study.
D2: Title	The title of the study.
D3: Author list	The full name of all the authors of the study.
D4: Year	The year that the paper was published in (RQ7).
D5: Venue	The name of the venue that published the paper.
D6: Summary	A short review of the study.
D7: Methodology of the proposed CDSS	The methodology of the proposed CDSS (RQ1).
D8: Who uses the CDSS	The type of users that the CDSS is aimed to (RQ5).
D9: What are the outputs of the proposed CDSS	The output provided by the proposed CDSS (RQ4).
D10: Data provided to the CDSS	The input types of the CDSS (RQ3).
D11: Decisions interfered by the CDSS	The tasks that the CDSS interfere with (RQ2).
D12: The country where the study is conducted	Where the study was conducted (RQ6).

4. Mapping Results

4.1. What are the methodologies used to develop the proposed CDSS? (RQ1)

There are two categories of the decision support systems that are knowledge-based and non-knowledge-based, The knowledge-based decision support systems are usually consisted of IF-THEN rules that represent the experience of an expert in that field to be applied in order to support the decision-making procedure while non-knowledge-based systems are based on machine learning which attempts to learn from existing data in order to make reliable predictions

in the future when new data is presented. These two categories result in three methodologies used to build the CDSS that are knowledge-based, non-knowledge-based and hybrid systems that include both categories in their methodologies. The methodologies employed by the proposed clinical decision support systems in the included studies are illustrated in figure 4.
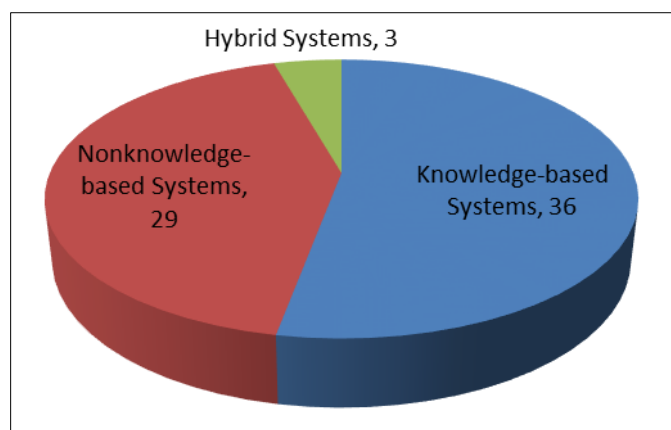
Figure 4 Distribution of methodologies used to build CDSSs

The illustration shows a very close number of studies that propose knowledge-based (53%) and non-knowledge-based (43%) systems and relatively few studies that propose hybrid systems (4%).

Another important way to look at the methodologies, used to build the proposed clinical decision support systems, is the distribution of these methodologies over the investigated duration. The number of proposed studies per each methodology is illustrated for every year included in this systematic mapping study is shown in figure 5.
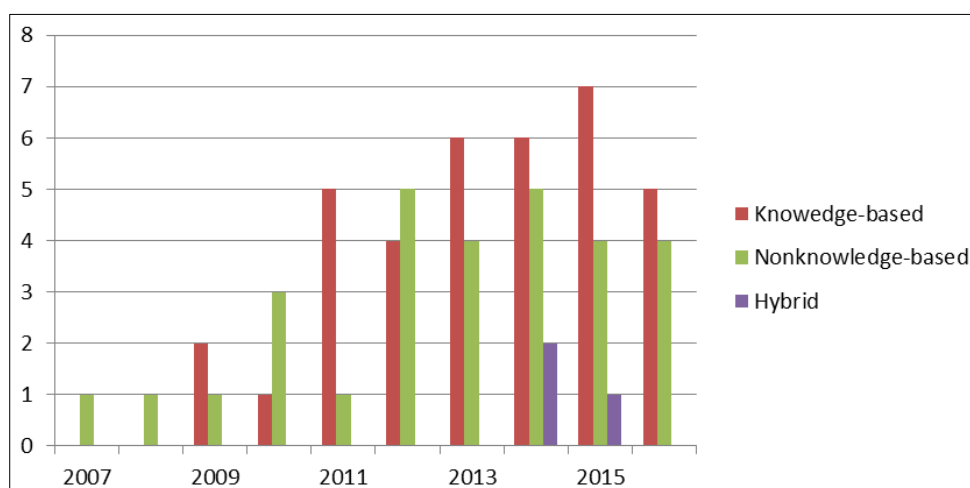
Figure 5 CDSS methodologies used over time

4.2. What decision types does the proposed CDSS support? (RQ2)

A CDSS may support the decision making of one or more of the decision types regarded to the health informatics, those are, the workflow following the current step, writing a prescription and diagnosis of the disease, Supporting decisions for the following workflow assists providing faster and less-expensive, Prescription writing assistance may be done by avoiding errors or providing correct medicines with optimal dosages,. Diagnosis may be a tough task according to the huge number of the known diseases and the similar symptoms of many of them. Thus, a clinical decision support system is a very useful tool for accurate diagnosis using fewer resources, Figure 6 shows the summary of the decision types supported by the clinical decision support system proposed in the studies included in this study.
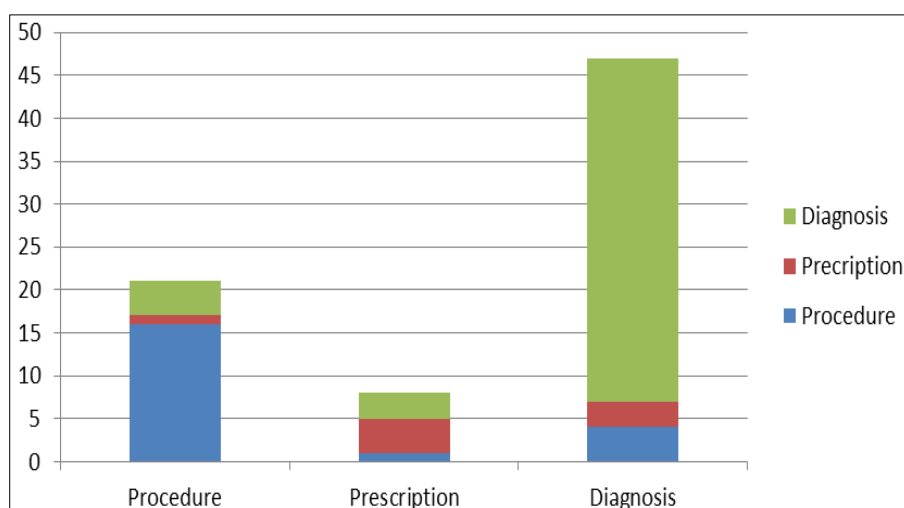
Figure 6 Decision types supported by the proposed CDSSs

4.3. What are the inputs required by the CDSS? (RQ3)

Any decision support system requires inputs in order to perform the required tasks of decision support. These data may be retrieved from a storage area, sent to the DSS in real time or entered manually by the user of the system. In this study, we focus on the forms of data used by the clinical decision support system in order to perform the required decision support tasks. These data forms may be patient data, lab test results, sensors, images or any combination of those data forms. Patients' data may be historical data stored in the EHR or real-time data entered by the user to the CDSS directly to be processed once or to be processed and stored Lab tests contain crucial information for the clinicians as well as the clinical decision support systems that assist reaching more accurate decisions.
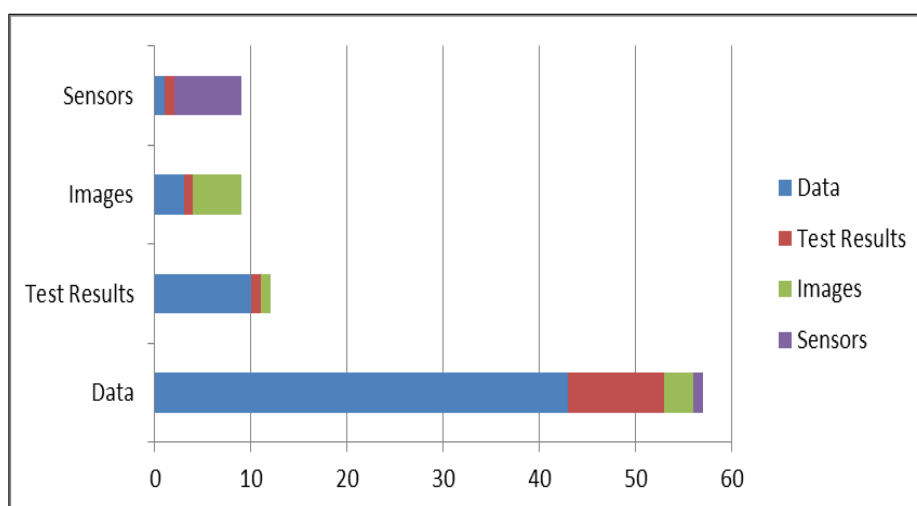

Figure 7 Inputs to the CDSSs

The distribution above shows that fifty-seven out of the sixty-eight (84%) studies proposed clinical decision support systems that require patient's information in data format as input, forty-three of these studies use only this kind of input while ten systems used these data alongside both the lab test results and the data as inputs to the system while the remaining clinical decision support systems use only one system with lab test results. It is also noticeable that the clinical decision support systems with sensors connected to them as inputs do not use any other form of inputs with images and lab test results.

4.4. What are the outputs of the CDSS? (RQ4)

The output of the clinical decision support system is provided to the user of the system, in order to support the decision-making task, by offering a suggestion, a matching class or a warning. A decision suggested by a clinical decision support

system may be used as a guideline for the user of the system, i.e. the user has the final decision to make, but the provided suggestion makes it easier to reach such decision.
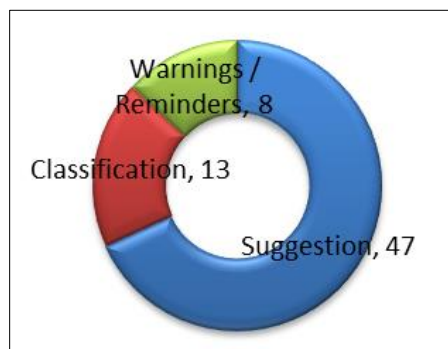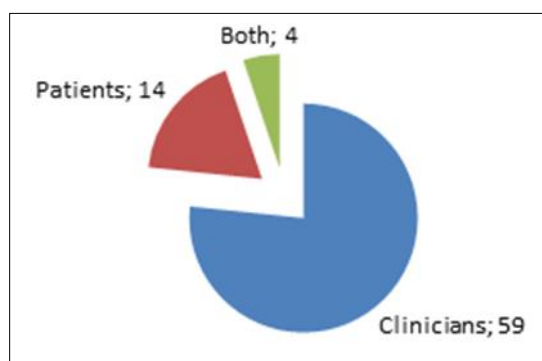

Figure 8 Decision Support Means distribution of the proposed CDSSs

Most of the clinical decision support systems proposed in the studies included in this mapping support the decision of the user by providing a suggestion (69%) while the remaining studies propose an equal number of clinical decision support systems that provide either classification (18%) or warning and alerts (13%).

4.5. Who are the users supposed to interact with the CDSS? (RQ5)

The user of the CDSS is the person responsible for providing the data required by the CDSS, to complete the required decision support task, and/or to interact with the outputs from the system. The clinicians, patient or both may use a CDSS. Figure 9 shows the users found to be interacting with the system proposed in the studies included in this mapping.


Figure 9 Users of the CDSSs investigated by this study

The users of the clinical decision support systems are mainly clinicians, where (81%) from the clinical decision support systems proposed in the studies included in this mapping, while (14%) of these clinical decision support systems are to be used directly by the patients and only two studies (5%) propose clinical decision support systems that are used by both the clinicians and patients simultaneously.

4.6. Where are the studies conducted? (RQ6)

It is important to mention that five, out of sixty-eight, studies do not mention the country it is conducted in. The United States of America has the highest number of contributions in this area of study with total of fifteen (26%) studies during the investigated interval. India, on the other hand, also has a fair number of studies with nine studies (16%) of the total number of included studies. South Korea, China and Canada have superiority over other countries regarding the number of studies proposed during this interval.
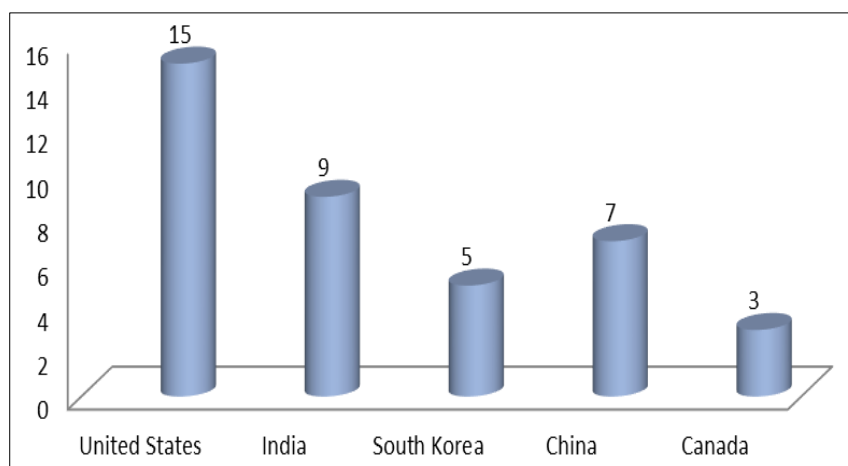
Figure 10 Top 5 study counts by countries

4.7. When are the studies conducted? (RQ7)

To illustrate the interest in CDSS studies, the total number of studies for each year is calculated. Figure 11 shows how studies included in this study are distributed over the last ten years.
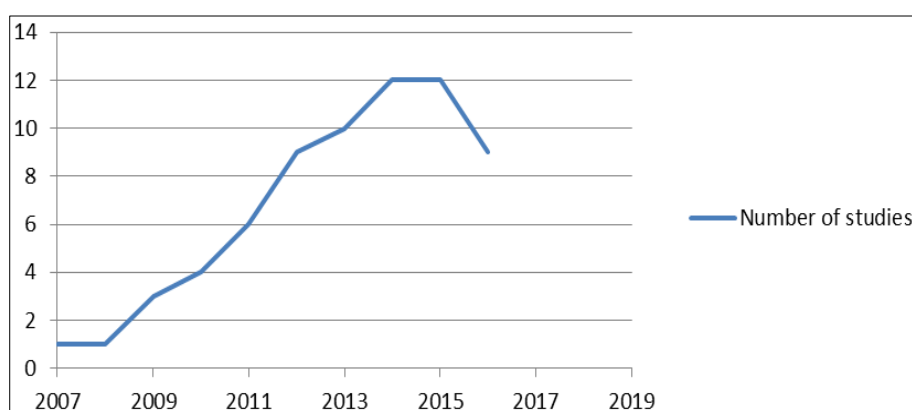
Figure 11 Distribution of included studies over the investigated period

Another important illustration is the number of studies proposed in each country over the investigated interval. Figure 12 shows the distribution of studies proposed in the investigated range grouped by top five countries where these studies are carried out in.
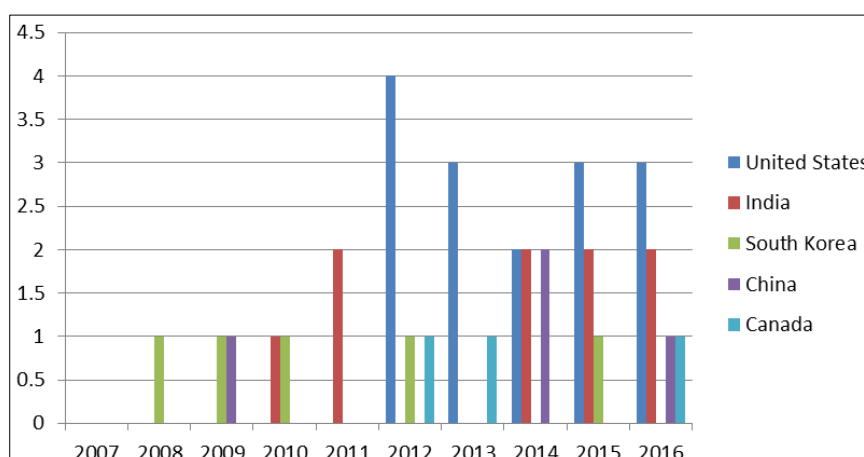
Figure 12 Proposed studies over the investigated interval by countries

4.8. Where are the studies published? (RQ8)

In order to recognize the publishers who, have the most studies published through, the studies are grouped depending on the publisher that the study is published through. Conferences with the highest number of studies published in the investigated interval are shown in Table 3.

Table 3 Top conferences that studies are published through

Conference	Number of studies
Annual International Conference of the IEEE Engineering in Medicine and Biology Society	4
IEEE International Conference on BioInformatics and BioEngineering	3
IEEE International Conference on e-Health Networking, Applications and Services (Healthcom)	2
IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology (WI-IAT)	2
International Conference on Intelligent Systems Design and Applications	2

Journals with the highest number of published studies alongside with the number of studies published by each journal are shown in Table 4.

Table 4 Top journals that studies are published though

Journal	Number of studies
IEEE Journal of Biomedical and Health Informatics	4
Pergamon Press, Inc.	3
Plenum Press	3
IEEE Journal of Translational Engineering in Health and Medicine	2
Journal of Computational Science	2
BMC Medical informatics & decision making	3

5. Discussion

The knowledge-based, as well as the non-knowledge-based methodologies, are used with similar frequency in the studied interval to develop decision support systems using health informatics.

The clinical decision support systems proposed in the included studies depend on many input types to perform the required task. Patient's information is found to be *the most used type of inputs as it is also the main part of the health informatics* Decisions are supported by different means. Mostly, clinical decision support systems included in this study are found to *provide a suggestion in order to assist the user of the system making decisions*.

 Classification and warnings/reminders are found equally frequent in the included studies but less popular when compared to the suggestion provision mean. Providing matching class to the patient under investigation assists the user making the correct decision depending on the class proposed while warnings and alerts assist user-avoiding errors by prompting a warning or alert, in case the action taken by the user does not comply with the guidelines set by the clinical decision support system being used.

Although patients are always the beneficiates of a CDSS, most of the proposed clinical decision support systems investigated in this systematic mapping found to be used by the clinicians to assist them providing efficient services. Few clinical decision support systems are found to be used by the patients themselves while both clinicians and patients use only two of the investigated clinical decision support systems.

Top countries interested in studying clinical decision support systems are United States of America and India with significant superiority over other countries according to the studies included in this systematic mapping study. Moreover, South Korea, China and Canada have some obvious interest in this field too. The close numbers of studies published by the top publishers as well as the narrow margin between these top publishers and the rest show that the study field of decision support system in health informatics is getting wider interest and studies are being published under many topics.

By studying the number of studies proposed in each year during the investigated interval, it is evident that this area of study is getting more and more interest recently. The more EHR available and the easier access to computers especially with the existence of the internet lead to this interest to provide faster, cheaper and yet more efficient medical services to the patients by using computer systems to support the decision-making process. Although the United States of America has the highest number of studies proposed over the entire investigated interval, India and South Korea noticed to have an earlier interest in clinical decision support systems than the United States.

The limitation of this systematic mapping study is the number of digital libraries searched for studies related to decision support systems in health informatics. Although the studies returned from these searches provide enough resources for the mapping study, a higher number of studies used in the mapping process may provide results that are more accurate.

6. Conclusion

In this systematic mapping study, fife digital libraries are searched for studies published between Jan. 2007 and Jan. 2017, as this study is conducted in 2017. Inclusion/exclusion.

The results of this mapping study show that the interest in applying decision support systems in health informatics is growing rapidly. Interest is almost equal in knowledge-based and non-knowledge-based systems, but a recent interest in hybrid systems also exists. Clinical decision support systems rely on many types of inputs but the most used input type used in these systems is patient's information while some other clinical decision support systems may combine more than one input type to achieve the required tasks except the clinical decision support systems that use sensors as inputs which are found to use only this type of inputs and does not combine types with images and lab test results.

In summary, the proposed clinical decision support systems are found to be developed for a specific task with limited capabilities that are specifically set to achieve the required task only. In future work, it is recommended to search more libraries in order to provide more resources for the mapping study to increase the accuracy of the results.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare no competing interests.

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