A Review on Clinical Decision Support Systems in Healthcare

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Abstract

Expert systems are widely used in healthcare for predicting and diagnosing diseases. Several efforts have been made to help diagnose diseases, and to identify their codes, signs and symptoms. However, abnormal findings, social circumstances and external causes of diseases in the psychological arena are a huge burden of illness in the community and still a complicated task. Several intelligent techniques based on different rules are used in developing CDSS. Therefore, further investigation on the current state of the field is required in order to identify the related issues and the future directions. This study intends to analyze the current state of the expert systems’ development for psycho-diagnostics. That provides a comprehensive background of the available methods, techniques and issues related to CDSS.

Keywords: CDSS, Healthcare, Expert System, Psychological Assessment, Review of Literature

1. Introduction

Psychological assessment is a process of evaluating and measuring the psychological factors, biological and social relations in a person or group with possible psychological disorders, while the diagnosis is the process of determining whether the affect person meets all specific criteria for psychological disorder [1]. Therefore, the diagnosis is an aspect of the overall process of psychological evaluation. Psychological problems are a huge burden of illness in the community [2]. That they are increasingly identified among general population [3].

However, the lack of single universally-acknowledged pathogenesis in the past leads to unreliability among clinicians in diagnosis [4]. Although, several efforts have been spent to help diagnosis, code diseases and signs, symptoms, abnormal findings, complaints, social circumstances and external causes of injury or diseases in the psychological arena, it is still a complicated task. Furthermore, the psychiatrist are not available everywhere especially in the rural areas. Consequently, medical experts system is urgently needed to give a support for the psychiatrist in determining definitive diagnosis or a range of alternative diagnosis [3].

Expert systems are widely used in healthcare either predicting or diagnosing diseases. They are useful and crucial in complex issues and when the medical experts are unavailable [5-6]. The computer technologies in solving complex problems based on defined theories and historical information offers a great opportunity for using an existing experiences and theories in illnesses diagnosis. They could have roles in supporting patients’ assessments, diagnosis and treatments in clinical settings [7].

According to [8] Clancey and Shortliffe [9] provided a definition for the using of the computer technologies in supporting the illness diagnose, which is: ‘Medical artificial intelligence is primarily concerned with the construction of AI programs that perform diagnosis and make therapy recommendations. Unlike medical applications based on other programming methods, such as purely statistical and probabilistic methods, medical AI programs are based on symbolic models of disease entities and their relationship to patient factors and clinical manifestations’ [8].

Nowadays, studies concentrate on the clinical decision support systems rather than the Artificial Intelligence in Medicine (AIM) systems. That is used to support the medication prescribing, in clinical laboratories and educational settings, for clinical surveillance, or in data-rich areas like the intensive care setting [8]. However, psychiatric problems and disorders is time consuming for the doctors and
result in a huge burden to the health care delivery system [10]. Therefore, decision support systems play a major role in health care, while the problem is that few systems are available to support the psychiatric disorders [3].

Clinical Decision Support Systems (CDSS) make electronic systems valuable to the clinicians in order to improve the quality of health care [3, 11]. The systems offer significant advantages to the clinical staff, directly from their use [12]. However, the use of CDSS is not as widespread [11, 13].

This study intends to present and review the current state of the CDSS and methods used in psychodiagnostics. The paper is organized as follows: Section two presents the decision support systems in health care centers, the use of CDSS, the values added by these systems, related issues, and the key requirements for developing CDSS systems. Section three provides a background of the psychological problems and disorders, and how they can be diagnosed. The review is concluded in section four.

2. Clinical Decision Support Systems

The decision support systems DSS use knowledge and theories from diverse areas [14], to support a complex decision making and problem solving. It allows the decision makers to build and explore the implications of their judgments [15]. That the DSS provides evidence-informed recommendations to support clinical diagnoses [16].

Nowadays, computer based systems have been increasingly adopted by health care professionals to record patient data, which is encouraged by carrots and sticks policies of governments and organizations than by inherent benefits from these systems [17].

A number of these tools are being used [18], which they are useful in administrative, data management and in clinical experiments [3]. They minimize the times, efforts, errors, and enhance the accuracy of the diagnosis. Moreover, these tools offer a great opportunity of using the previous experiences regardless the attendance of the experts, the time, and the geographical areas. On the other hand, they allow the psychiatrist especially the novice to learn more from existing experiences, evaluate their capabilities, and enhance their performance of diagnoses.

The clinical decision support system CDSS synthesize and integrate patient specific information, perform complex evaluations and present the results to clinicians in a timely fashion [19]. Clinical Decision Support Systems are information systems developed to support and enhance the clinical decision making [20]. Sim et al. [21] defined it as a “software that is designed to be a direct aid to clinical decision-making in which the characteristics of an individual patient are matched to a computerized clinical knowledge base, and patient-specific assessments or recommendations are then presented to the clinician and/or the patient for a decision”. However, the fundamental roles of the clinical experts are used in the DSS, and therefore, the system provides only a decision support making and do not indicate the decision to be taken [22].

Bouzguenda [23] listed four main challenges in CDSS that have been discussed in the literature [24-28], which are:

- The clinical data that must be entered is already exists elsewhere in a digital form.
- The CDSS must consider an appropriate decision making by health professionals to a patient considering their clinical context. Moreover, different information should be provided such as symptoms, medical history, family history and genetics.
- CDSS has to be connected with Computerized Prescriber Order Entry (CPOE) which assists the doctor in preparing the prescripts.
- The CDSS has to be integrated with the CPOE in the medical workflow management system. That the clinical user must stop clinical process on the current system, switch to the CDSS or CPOE, and reenter data necessary into the CDSS that may already exist in another healthcare system.
Frize et al. [29] suggested three criteria for developing CDSS successfully. These criteria are:

- **Input to the CDSS**: one of the CDSS’s failures caused by the data and information entry [30-31]. That is, the system requires the least amount of physician time and be able to update itself [32].

- **Human-Computer Interaction**: one of the main critical components of a successful CDSS is the human-computer interaction. That is the system’s access has to be easy and secure. Moreover, the speed is one of the main factors in the success of CDSS, it is utmost important for physicians. Including the time of logon to the system and time to acquire the information desired, the systems should be design to use least amount of the users’ time [33]. That is, 70% of doctors intended to use the system if it lengthened patient consultations by 2 minutes compared to only 23% if the time added was 5 minutes [34].

- **Output**: CDSS should be an added value to the clinics by improving the quality of care and reducing the cost of care delivery. Moreover, the CDSS must fit the workflow of the physicians, provide useful information, and the output type and format based on the physicians requirements. That is, clinics have different work habits and different requirements, which make the CDSS’s development more complicated and crucial for deployment success. Finally, the number of provided information should be simple and effective [32-33].

### 2.1. DSS Methods for Supporting Healthcare

The main idea of CDSS is a set of rules derived from medical professionals applied on a dynamic knowledge. However, several decision support systems’ methodologies are used to provide a support for healthcare professionals. In the following, six main techniques are discussed:

#### 2.1.1 Bayesian Network

The Bayesian network is a knowledge-based graphical representation that shows a set of variables and their probabilistic relationships between diseases and symptoms. The variables are conditional probability base that is the probability of event given the occurrence of other events. The rules allow computing the probability of the event supported by more readily available information and it consistently processes options as new evidence is presented. However, Bayesian network is used to compute the probability of the presence of possible diseases given their symptoms.

The main advantage of the Bayesian Network is that involves the knowledge and conclusions of experts in the form of probabilities. The assistance in decision making as new information is available and is based on unbiased probabilities that are applicable to many models. However, there are difficulties to get the probability knowledge for possible diagnosis and not being practical for large complex systems given multiple symptoms.

#### 2.1.2 Neural Network

Neural Networks is a non-knowledge-based adaptive CDSS that uses a form of artificial intelligence. It is known as machine learning that allows the systems to learn from existing knowledge and experiences. Neural Network exists of nodes and weighted connections that transmit signals between the nodes. The nodes are distributed on three main layers: Input (data receiver or findings), Output (communicates results or possible diseases) and Hidden (processes data). Large amount of data results more efficient results.

The using of Neural Network avoids programming the systems and provides inputs from experts. Moreover, Neural Network able to proceed with incomplete data that provides educated guesses about missing data and get improved with every use due to its adaptive system learning. Finally, it does not require large databases for the outcomes with its associated probabilities. However, the problem of training which is time consuming leads to use the system ineffectively. The Neural Network system derive its own formulas for weighting and combine data based on
based on the statistical recognition patterns over time. This could be difficult to interpret and doubt the system’s reliability.

2.1.3 Genetic Algorithms

Genetic Algorithm is a non-knowledge-based method proposed in the 1940s at the Massachusetts Institute of Technology based on Darwin’s evolutionary theories that dealt with the survival of the fittest. The algorithm rearranges to form different re-combinations that are better than the previous solutions. In this algorithm, the system goes through an iterative process to produce an optimal solution. The fitness function determines the good solutions and the solutions that can be eliminated. However, this method lacks of transparency in the reasoning involved for the decision support systems making it undesirable for physicians. Moreover, the using of genetic algorithm requires many components such as multiple drugs, symptoms, treatment therapy and so on available in order to solve a problem.

2.1.4 Rule-Based System

Rule-based system intends to capture knowledge of domain experts into expressions that can be evaluated. Once an enough rules are compiled into a rule base, the current working knowledge can be evaluated against the rule base by chaining rules together until reach a conclusion. A rule-based expert system makes the storing of large amount of data easy, and the rules help to clarify the logic that used in the decision-making process. However, it is difficult to transfer the experts’ knowledge into distinct rules, and many rules can be required for a system to be effective.

2.1.5 Logical Condition

The methodology behind logical condition is fairly simplistic; given a variable and a bound, check to see if the variable is within or outside of the bounds and take action based on the result. Mainly, the logical conditions are used to alerts and reminders to individuals across the care domain. These alerts help the physician to increase their compliance with several guidelines, but it is become risky when too many alerts that could overwhelm doctors, nurses, and other staff and cause them to ignore the alerts altogether.

2.1.6 Causal Probabilistic Network

Causal network methodology is mainly based on cause and effect. The nodes represent the items such as symptoms, patient states or disease categories, whereas, the connections between nodes indicate a cause and effect relationship. Causal network based system intends to trace a path from symptom nodes all the way to disease classification nodes, using probability to determine which path is the best fit. This method helps to model the progression of a disease over time and the interaction between diseases. But, it is not always the case that medical knowledge knows exactly what causes certain symptoms, and it can be difficult to choose what level of detail to build the model to.

2.2. CDSS Applications

Expert systems are applied to perform and assist many clinical tasks. Table 1 shows the common applications of CDSS, followed by list of systems and typical examples in table 2:

- **Alerts and Reminders**: the expert system provides real time alerts and warnings to the medical staff. It is connected to the patients' monitoring devices, which makes the medical staff aware about any changes to the patient status. Moreover, these applications can be used to provide tasks lists for clinicians.

- **Diagnostic Assistance**: Knowledge base systems can be used to assess the patients’ data and provide the possible diagnosis. It is useful for inexperienced clinicians, and in the complex or unrelated cases.
• **Prescription Decision Support**: it is known as specialized CDSS, which is one of the most widely used CDSS. It is used to check for drug-to-drug interactions, dosage errors, and drug contraindications. Moreover, these applications enable automated script generation and electronic transmission to the pharmacy.

• **Information Retrieval**: it is used to locate and retrieve an appropriate and accurate data that could be used for diagnosis or treatment planning. The system works as search queries and allows assessing the importance, applicability, or utility of the retrieved information.

• **Image Recognition and Interpretation**: Expert systems are now capable of interpreting clinical images ranging from simple x-rays to MRIs or CT scans. The greatest benefit can be seen when examining a series of images where a system may detect minute changes over time.

• **Therapy Critiquing and Planning**: the system identifies the inconsistencies, errors, omissions, or potential contradictions by examining the treatment plans. It assesses the proposed treatments against the patient data and known standards of care. It is a rule base to compare the treatment plans and knowledge base of treatment protocols and guidelines.

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Link</th>
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<tbody>
<tr>
<td>DXplain</td>
<td>Internal Medicine Expert System</td>
<td><a href="http://dxplain.org/dxp/dxp.pl">http://dxplain.org/dxp/dxp.pl</a></td>
</tr>
<tr>
<td>GRIP</td>
<td>Glucose Regulation for Intensive Care Patients</td>
<td><a href="http://grip-glucose.sourceforge.net/">http://grip-glucose.sourceforge.net/</a></td>
</tr>
<tr>
<td>POEMS</td>
<td>Post-operative Expert Medical System</td>
<td><a href="http://www.openclinical.org/aisp_poems.html">http://www.openclinical.org/aisp_poems.html</a></td>
</tr>
<tr>
<td>VisualDX</td>
<td>Image-based Clinical Diagnosis Support</td>
<td><a href="http://www.logicalimages.com/prodVDx.htm">http://www.logicalimages.com/prodVDx.htm</a></td>
</tr>
</tbody>
</table>

2.3. **Target Area of Care**

Berner [35] classified the CDDS based on the stages of the care processes: preventing, diagnosis, treatment, and monitoring. That is, the classifications were performed based on the used technologies are not understandable to the end users. The new classification was developed based on three main factors, which are:

- The target area of the CDS, its primary needs and the problem needed to be solved.
- The way of delivering the information, to whom and how the information is presented.
- The amount of the user’s control on the system, accessing and responding.
<table>
<thead>
<tr>
<th>EM</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ACUTE CARE SYSTEMS</strong></td>
<td></td>
</tr>
<tr>
<td>Dugas et al. [36]</td>
<td>Decision support in hepatic surgery</td>
</tr>
<tr>
<td>Sawar et al. [37]</td>
<td>Post-operative care decision support</td>
</tr>
<tr>
<td>Miksch et al. [38]</td>
<td>Parenteral nutrition planning for neonatal ICU</td>
</tr>
<tr>
<td>NéoGanesh 1996 [39]</td>
<td>ICU ventilator management</td>
</tr>
<tr>
<td>SETH 1993 [40]</td>
<td>Clinical toxicology advisor</td>
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<tr>
<td><strong>LABORATORY SYSTEMS</strong></td>
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<tr>
<td>GERMWATCHER [41]</td>
<td>Analysis of nosocomial infections</td>
</tr>
<tr>
<td>HEPAXPERT I, II [42]</td>
<td>Interprets tests for hepatitis A and B</td>
</tr>
<tr>
<td>Acid-base expert system [43]</td>
<td>Interpretation of acid-base disorders</td>
</tr>
<tr>
<td>MICROBIOLOGY/PHARMACY [44]</td>
<td>Monitors renal active antibiotic dosing</td>
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<tr>
<td>PEIRS [45]</td>
<td>Chemical pathology expert system</td>
</tr>
<tr>
<td>PUFF [46]</td>
<td>Interprets pulmonary function tests</td>
</tr>
<tr>
<td>Pro.M.D.- CSF Diagnostics [47]</td>
<td>Interpretation of CSF findings</td>
</tr>
<tr>
<td><strong>EDUCATIONAL SYSTEMS</strong></td>
<td></td>
</tr>
<tr>
<td>DXPLAIN [48]</td>
<td>Internal medicine expert system</td>
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<tr>
<td>ILLIAD [49]</td>
<td>Internal medicine expert system</td>
</tr>
<tr>
<td>HELP [50]</td>
<td>Knowledge-based hospital information system</td>
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<tr>
<td><strong>QUALITY ASSURANCE AND ADMINISTRATION</strong></td>
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<tr>
<td>COLORADO MEDICAID UTILIZATION REVIEW SYSTEM</td>
<td>Quality review of drug prescribing practices</td>
</tr>
<tr>
<td>MANAGED SECOND SURGICAL OPINION SYSTEM</td>
<td>Aetna Life and Casualty assessor system</td>
</tr>
<tr>
<td><strong>MEDICAL IMAGING</strong></td>
<td></td>
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<tr>
<td>PERFEX [51]</td>
<td>Interprets cardiac SPECT data</td>
</tr>
<tr>
<td>Lindahl [52]</td>
<td>classification of scintigrams</td>
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</tbody>
</table>
Berner [35] provides a list of examples on the CDS based on their targets as indicated in table 3.

<table>
<thead>
<tr>
<th>Target Area of Care</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preventive care</td>
<td>Immunization, screening, disease management guidelines for secondary prevention</td>
</tr>
<tr>
<td>Diagnosis</td>
<td>Suggestions for possible diagnoses that match a patient’s signs and symptoms</td>
</tr>
<tr>
<td>Planning or implementing treatment</td>
<td>Treatment guidelines for specific diagnoses, drug dosage recommendations, alerts for drug-drug interactions</td>
</tr>
<tr>
<td>Follow up management</td>
<td>Corollary orders, reminders for drug adverse event monitoring</td>
</tr>
<tr>
<td>Hospital, provider efficiency</td>
<td>Care plans to minimize length of stay, order sets</td>
</tr>
<tr>
<td>Cost reductions and improved patient convenience</td>
<td>Duplicate testing alerts, drug formulary guidelines</td>
</tr>
</tbody>
</table>

2.4. Design and Implementation of CDSS

Several studies discussed the process of designing and implementing CDSS, such as [21, 32, 53-56]. Kawamoto, et al. [57] identified the design characteristics that are associated with the success of CDSS development, which are:

- Computer-based decision support is more effective than manual processes for decision support.
- CDS interventions that are presented automatically and fit into the workflow of the clinicians are more likely to be used.
- CDS that recommends actions for the user to take are more effective than CDS that simply provides assessments.
- CDS interventions that provide information at the time and place of decision making are more likely to have an impact.

Berner [35] states that, attention must be paid to CDSS implementation process, in order to avoid negative affects in addition to the quality assurance.

2.4.1 Workflow Integration

Workflow involves the structure of the system and how its features and processes support the care. Therefore, it should be the first step of the development process, which requires an assessment of where the CDSS requirements are identified, and it has to be taken into account for both designers and programmers. Discovering any problems in the workflow assessment allows avoiding the redesign and re-implementing the CDSS. Moreover, the congruence between workflow and CDSS timing, structure, and design make it more likely to be accepted and effective. Therefore, involving the clinicians in developing the CDSS is very important and crucial for the system success.

2.4.2 Data Entry and Output

Most of the CDS systems related to drug interaction alerts and reminders are integrated into an EMR and draw their patient information from that record. The alerts and reminders are usually provided in the context of computerized provider order entry (CPOE) systems. Some CDSS are independent of the EMR, which makes it challenging to work with different systems. However, if the CDSS is not able to integrate into EMR, the patients’ information has to be entered twice, in the clinic.
records and in the CDS. This is a workflow issue that may lead to failure to use the CDS routinely. Identify the users who enter the data and who receive the advice.

- If the prescription is entered to the system by nonphysician, how it can be handled if the system recommends changing the medicine.
- If the clinician is no longer interacting with the system and the CDSS notify, how will timely response be ensured.

Several approaches addressed the feedback issues, while the user performance issues are required to be addressed as a part of the assessment, design, and planning process and evaluated once the system has been implemented.

### 2.4.3 Standards and Transferability

It has to be recognized that the EMRs with CDSS capability might not be ready to use without additional work. Some local customizations are required to make the CDSS implementation effective. Currently, there is no standard for specific evidence-based guidelines or rules that should be built into CDSS, that allows the users to select their rules and alerts that most applicable to their site. Therefore, there is a need for standards for exchanging information, data quality, and desired functionalities of CDSS. That is approximately, the half of the CDSS development cost is the clinician time in selection and design of content. The using of commercial knowledge bases or models from other sites could save some of the development times, while there are vocabulary differences among sites and different standards for normal laboratory values, medication formularies, or norms for processes of care at different sites and within different CDSS. However, the sites must realize that there is a need for invest a considerable amount of time in understanding the logic of CDSS, and sometimes required to adapt the CDSS to their unique needs.

### 2.4.4 Knowledge Maintenance

The main challenges of knowledge maintenance can be identified in two main aspects. First, maintaining the accuracy of the patient record. There is a high rate of alert overrides shows that the medical records are out of date. The alerts are not accurate and overriding them does not make sense, when the information of the CDSS that is used for triggers inaccurate. Consequently, frequent inaccurate triggers lead the clinicians to ignore the system’s advices. However, the knowledge maintenance is an import process for all CDSS types, and therefore, it’s important to monitor the accuracy of the patients’ records and to address problems encountered.

Second, knowledge embedded within CDSS. Discovering new drugs and diagnoses is a continuous process, and the evidence based guideline change as new evidence is accumulated. Therefore, utilizing the commercial knowledge bases that provide frequent update is required. In other hand, developing an in-house knowledge management process as a part of HealthCare, although still there is a need for commercial knowledge bases.

### 3. Psychological Problems and Disorders

Psychiatric problems are one of the main issues needed to be considered, especially in the developing countries. Because 50% of patients attending primary care setting suffer from psychological problems \[58\]. Most of these cases require a psychiatric treatments rather than medical treatments.

Psychological assessment is conducted in order to identify whether the problems faced by a patient meet all of the psychological disorder criteria. These criteria are defined in the diagnostic manuals: diagnostic and statistical manual of mental disorders (DSM-IV-TR) which is sponsored by American Psychological Association \[59\], and the International Statistical Classification of Diseases and Related Health Problems which is the latest revision released by the world health organization ICD-10 \[60\]. These manuals influenced the psychological assessment process and decisively changed the evolution of the classification of mental disorders. The manual identified the basic criteria for each disorder, in addition to the criteria that could be affected by the disorder.
4. Conclusion

Decision Support Systems play a key role in healthcare centers. They provide assistance in information management and diagnosis. Several techniques and different methods are used to provide a healthcare center with decision support systems for more accurate diagnosis, save times, and overcome the issues of experts’ lack in wide ranges. This study reviews the main techniques and methods used in developing decision support systems to support diagnosis. Moreover, the main requirements and the current issues faced in this field are presented.

5. References


