Due to the increasing rate of medical errors, there is a continuing challenge for clinicians to provide safe and effective care. In this regard, the establishment of clinical guidelines to improve the quality of patient care and reduce medical costs can be very effective. These clinical guidelines, pathways, and protocols can be available to providers in electronic format as clinical decision support systems (CDSS). CDSS is an analytical tool that converts raw data into useful information to help clinicians make better decisions for patients. CDSS can be implemented in the electronic health record (EHR) and alert clinicians when there is a conflict in the care plan or it is necessary to change a patient’s treatment based on uncovered patterns in clinical data. The functions of such systems are diagnosis, interpretation, suggestion, and notification, most of which are presented as reminders and alert systems. With reminders, users can defer follow-up action, but usually must take some action to see the entire message. On the other hand, an alert is intrusive, interrupting whatever the user is currently doing without regard for its importance. The user must take immediate action. For example, reminding the physician to prescribe a specific drug or specific test versus alerting the physician to prevent an adverse drug event or drug allergy. These messages should be timely, relevant, understandable, and without complexity. Thus, paying attention to them leads to a decrease in medication errors and an increase in patient safety.

In this article, an overview of various models of CDSS is provided, as it helps users select an appropriate system based on needs and expectations and in order to make better decisions. Finally, the application of CDSS in healthcare and medical imaging, specifically, is explained as well as challenges of using CDSS.

**Taxonomy of CDSS**

The decision-making process is a spectrum. On one end, there are structured problems, which are also called programmed problems. These are routine problems for which there are standard solutions. In the decision-making process there are fairly systematic phases (intelligent, design, choice, and implementation) to solve such problems. On the other end of the spectrum, there are unstructured problems for which there is no standard solution and none of the three phases of decision-making processes (intelligence, design, and choice) are included. There is only human judgment and intuition as a decision-making
basis. In the middle of the spectrum, there are semi-structured problems for which only some decision-making phases are used to solve and a combination of standard solutions and human judgment is required.10

Accordingly, a variety of definitions have been proposed for CDSS. One considers CDSS a form of computer-based support for managers who are faced with semi-structured problems. Others introduce CDSS as a computer-based interactive system, which uses data and models in order to assist decision makers in terms of solving unstructured problems. But another defines CDSS as a comprehensive and useful term for a variety of information systems that support decision making. The above definitions can imply that CDSS is a computer-based system to solve structured, unstructured, and semi structured problems, which with strong collaboration of the users, combines models and data and offers many solutions for decision-makers.10–14 Not only is there no general definition for CDSS, but there is also no comprehensive classification available. Various researchers have proposed different classifications, which are presented in Table 1.13–15

About CDSS architecture, there are various components, which are presented in Table 2. Considering the cases presented in Table 2, data management consists of a data warehouse to encompass medical data and is managed by a database management system. The user interface subsystem is a communication tool between user and system. The model management, including tables, data necessary to establish rules, and predictive models and protocols provides analytical capabilities to the system. The final subsystem is knowledge management that supports all the other subsystems, can operate independently and provide the knowledge necessary to solve specific problems.6,13–14,16–17

Of the models presented here, clinicians may benefit the most from a knowledge driven CDSS in clinical practice. This type of CDSS is equipped with a database, which provides the necessary knowledge for the treatment of diseases using protocols and certain preventive care. It helps clinicians in diagnosis, criticism of care plan, treatment plan, provision of alerts, and image interpretations. The function of these systems is to adjust the current cases with decision criteria, which were derived from statistical analyses performed on previous high volume cases.18

Application of CDSS in Healthcare

In this study, the application of CDSS in healthcare is divided into six areas: diagnosis, disease progress management, care and treatment, prescription, evaluation, and prevention. These application areas and the effects of these systems on these areas are shown in Table 3.8–9,19–62 According to the literature reviewed for this study, clinicians using these systems are able to achieve significant gains such as reducing medical and medication errors, complying with standard treatments and medication guidelines, reducing costs, and ultimately improving the quality of healthcare.

In the diagnosis area, medical imaging plays a major role because it is widely used and affects patient care in every area of hospital.63 Therefore; there are multiple opportunities to provide safer care in medical imaging departments. It should be noted that each type of error can lead to sentinel events.64–66

In the medical imaging chain, from ordered study to communicating results, such systems can help achieve best practices. For example, in the beginning of the chain, CDSS provides evidence based guidelines to assist referring physicians and other providers in making the most appropriate imaging decisions. When acquiring images, these systems can provide alerts and reminders for issues such as contraindications to contrast agents and allergies and can also detect and correct errors potentially leading to adverse drug reactions. Regarding interpretation, application of this system can support radiologists and help them interpret more accurately. It can help reduce errors during image findings, interpretation of those findings to render a diagnosis, and decisions and recommendations about case management. At the end of the chain, in communicating results, these systems can notify timely report turnaround, communication of critical test results, and the need for follow-up examinations.67–69

The American College of Radiology (ACR) has undertaken an initiative to facilitate the use of its Appropriateness Criteria in order entry and decision support applications. These criteria are constantly updated and cover a wide breadth of topics and clinical conditions. Using CDSS in medical imaging by providing evidence-based guidelines can lead to improving the quality of imaging services.30

Beginning in January 2017, referring physicians must use physician-developed appropriateness criteria when ordering advanced imaging for Medicare patients. The new provision was approved April 1, 2014 as part of the Protecting Access to Medicare Act of 2014, or so-called sustainable growth rate (SGR) “patch” bill. It also directs the secretary of the US Department of Health and Human Services (HHS) to identify CDSS tools to help physicians navigate the appropriateness criteria. By November 2015, HHS must specify applicable appropriate use criteria for imaging services, using guidance from national professional medical specialty societies, including ACR, and other provider-led groups. When the law takes effect, physicians who provide imaging services will only be paid for claims that include information about which CDSS was used and documentation that it meets the standard. This could pose a problem for radiology, since it would become their responsibility to make sure ordering physicians used the CDSS properly and reported it.70

CDSS is also a reference tool for radiologists to answer most clinical questions during practice. It can help radiologists navigate to related studies to find
<table>
<thead>
<tr>
<th>Classification levels</th>
<th>Types of CDSS</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Passive</td>
<td>This system aids the process of decision making, but can’t bring out explicit decision suggestions or solutions.</td>
</tr>
<tr>
<td></td>
<td>Active</td>
<td>This system can bring out decision suggestions or solutions.</td>
</tr>
<tr>
<td></td>
<td>Cooperative</td>
<td>This system allows the decision maker to modify, complete, or refine the decision suggestions provided by the system, before sending them back to the system for validation. The system again improves, completes, and refines the suggestions of the decision maker and sends them back to them for validation. The whole process then starts again, until a consolidated solution is generated.</td>
</tr>
<tr>
<td>Conceptual-level</td>
<td>Communication-driven CDSS</td>
<td>This system emphasizes the use of communications and decision models intended to facilitate the solution of problems by decision makers working together as a group. This is often called group decision support systems.</td>
</tr>
<tr>
<td></td>
<td>Data-driven CDSS</td>
<td>This system emphasizes real-time access to large database and manipulation of a time series of internal company data and, sometimes, external data.</td>
</tr>
<tr>
<td></td>
<td>Knowledge-driven</td>
<td>This system provides specialized problem-solving expertise stored as facts, rules, procedures, or in similar structures.</td>
</tr>
<tr>
<td></td>
<td>Document-driven</td>
<td>This system manages, retrieves, and manipulates unstructured information in a variety of electronic formats.</td>
</tr>
<tr>
<td></td>
<td>Model-driven</td>
<td>This system emphasizes access to and manipulation of a statistical, financial, optimization, or simulation model.</td>
</tr>
<tr>
<td></td>
<td>Intra &amp; inter organizational-driven</td>
<td>These systems are driven by the rapid growth of Internet and other networking technologies such as broadband WANs, LANs, WIP, etc. Inter-organization CDSS are used to serve companies, stakeholders (customers, suppliers, etc.), whereas intra-organization CDSS are more directed towards individuals inside the company and specific user groups.</td>
</tr>
<tr>
<td></td>
<td>Web based</td>
<td>This is computerized system that delivers decision support information or tools to a manager or business analyst using a Web browser like Netscape Navigator or Internet Explorer.</td>
</tr>
<tr>
<td></td>
<td>Online Analytical Processing (OLAP)</td>
<td>This is a category of software technology that enables analysts, managers and executives to gain insight into data and view the result in multi dimensional or cube format.</td>
</tr>
<tr>
<td>System-level</td>
<td>Enterprise CDSS</td>
<td>This is linked to large data warehouses and serves many managers in a company.</td>
</tr>
<tr>
<td></td>
<td>Desktop CDSS</td>
<td>This is a small system that resides on an individual manager’s PC. This is often called single-user CDSS.</td>
</tr>
</tbody>
</table>
Clinical Decision Support Systems and Medical Imaging

### TABLE 2. Components and architecture of CDSS based on reviewed studies

<table>
<thead>
<tr>
<th>Wager &amp; Tan</th>
<th>Marakas</th>
<th>Hättenschwiler</th>
<th>Power</th>
<th>Sprague</th>
<th>Components Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>CDSS Network and Architecture</td>
</tr>
<tr>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>Knowledge Management Systems</td>
</tr>
<tr>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>The Model-Base Management System</td>
</tr>
<tr>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>Database Management System</td>
</tr>
<tr>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>User Interface</td>
</tr>
<tr>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td>Users</td>
</tr>
<tr>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A Target System Describing The Majority Of The Preferences</td>
</tr>
<tr>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A Specific And Definable Decision Context</td>
</tr>
</tbody>
</table>

information that is important for patient care. In fact, CDSS can improve quality by decreasing inappropriate, redundant, or unnecessary imaging through provider education, incentives, and restrictions and by increasing patient safety through avoidance of unnecessary radiation or downstream procedures.

### Challenges of Applying CDSS

The use of these systems has challenges and implementation is faced with obstacles such as technical support and issues related to user interface such as patient data coding, interoperability, and human factors. Patient data, for example, must be coded correctly with standard classification in order to be calculated in the inference engine. But choosing the correct code is a time consuming process that doesn’t allow clinicians to focus on the content of the clinical document and also increases the potential loss of the explanatory notes in the text content. To solve this problem, a new clinical data classification based on observation such as SNOMED and UMLS is recommended.71

Another important challenge is the interoperability that can affect the use of CDSS. To make a recommendation, CDSS must have access to complete and updated patient data. However, clinical computerized systems are commonly used for management of the patient data, so many of these systems do not interact with each other. Use of data exchange standards such as HL7 and regional networks such as personal health records would enable loading patient data into a common data repository.71–73

There are other factors that make the use of CDSS a challenge. Given that CDSS has a profound effect on patient care, if not applied properly it can cause damage to the quality of the patient-physician relationship at the point of care. Using computers in front of patients and a lack of face to face interaction can be considered impolite and a cause of patient resistance. On the other hand, clinicians may consider it a threat to have autonomy in their practices because the new generation of CDSS is equipped with evaluation mechanisms that provide the ability to score clinicians. These features can lead to gradual distortion of the patient’s experience; therefore, solving this problem requires designing user-friendly interfaces and training users on the benefits of these systems.74

### Conclusion

The use of CDSS in six application areas (diagnosis, disease management process, care and treatment, drug prescription, evaluation, and prevention) has significant impact on improvement of the process of care and the performance of clinicians. In general, the effects can be divided into three groups. First, improving the quality of care and increasing patient safety by reducing medication errors and adverse effects and compliance with evidence-based clinical guidelines. Second, increasing the cost-effectiveness through faster processing of orders, decreasing repetition of examinations, reducing the drug adverse effect events, and changing patterns of drug use by prescribing cheaper drugs. Third, promoting knowledge through the accessibility of resources and useful information to optimize decision making. Finally, in order to increase the effectiveness of these systems, organizational culture needs to be aligned in such a way as to provide clinicians, as the users of these systems, proper education. 🌟
<table>
<thead>
<tr>
<th>Study Results</th>
<th>Studies Reviewed</th>
<th>Application Areas of CDSS</th>
</tr>
</thead>
</table>
| Improvement in diagnosis performance and interpretation by providing radiologist with evidence based guidelines | - Brain tumor diagnosis  
- Breast cancer detection  
- Renal obstruction detection  
- Coronary artery diagnosis  
- Evaluation of suspected pulmonary embolism  
- Interpretation of myocardial perfusion images  
- Approximal caries diagnosis  
- Distinguish benign from malignant vertebral compression fractures  
- Neuroradiology imaging studies | Diagnosis |
| Effectiveness of CDSS application in the management of the disease process | - Management of asthma and angina  
- Guideline implementation for outpatient cardiac rehabilitation  
- Risk management of CVD in CCU  
- Management of children with fever without apparent source  
- Management of renal anemia | Disease process management |
| Improvement in the quality of health care | - Treatment of diabetes mellitus  
- Treatment of major depression in primary care  
- Treatment of rheumatology  
- Telecare  
- Identification of heparin induced thrombocytopenia  
- Prevention of pneumonia for patients receiving mechanical ventilation  
- Provider ordering behavior  
- Nursing care  
- Treatment of prostate cancer | Care and treatment |
| Medication errors reduction  
Side and adverse effect reduction  
Prescribing costs reduction | - Prescribing behavior for breast cancer patients  
- Medication dosing for patients with renal insufficiency in the long-term care setting  
- Reducing prescription of excessive doses  
- Opioid therapy for chronic non cancer pain  
- Determining the quality of antimicrobial dosing in intensive care patients with renal insufficiency  
- Adequacy of venous thromboprophylaxis in acutely ill medical patients  
- Insulin therapy  
- Prevention of adverse drug reactions in intensive care patients  
- Prescribing costs in primary care | Drug Prescription |
| Improvement in clinician practice based on recommendations | - Assessment of suspected breast cancer  
- Determining the quality of clinical practice - providing a qualitative measure of cardiac care and patient education  
- Mental health clinical practice guideline  
- Evidence-based guidelines for blood ordering in primary care  
- Reducing unnecessarily repeated serology tests in a cardiovascular surgery department  
- Assessment of chronic urticaria | Evaluation |
| Increasing in screening rate  
Reduction in disease infection | - Screening of latent tuberculosis infection  
- Screening of pediatric depression  
- Prevention of venous thromboembolism  
- Screening of osteoporosis | Prevention |
References

13. Sprague RH. Building effective decision support systems.
34. Roukema J, Steyerberg EW, van der Lei J, Moll HA. Randomized trial of a clinical decision support system: impact on the


Mahtab Karami, PhD, is assistant professor of health information management in the department of health information technology and management at the school of allied medical sciences, Kashan University of Medical Sciences in Kashan, Iran. She can be contacted at karami_m@kaums.ac.ir.