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Special article

# Clinical decision support systems and infection prevention: To know is not enough

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Clinical decision support (CDS) systems are an increasingly used form of technology designed to guide health care providers toward established protocols and best practices with the intent of improving patient care. Utilization of CDS for infection prevention is not widespread and is particularly focused on antimicrobial stewardship. This article provides an overview of CDS systems and summarizes key attributes of successfully executed tools. A selection of published reports of CDS for infection prevention and antimicrobial stewardship are described. Finally, an individual organization describes its CDS infrastructure, process of prioritization, design, and development, with selected highlights of CDS tools specifically targeting common infection prevention quality improvement initiatives.



The data demand for infection preventionists (IPs) has increased exponentially in recent years. In response, IPs have adopted electronically assisted surveillance technology to streamline surveillance responsibilities, with nearly one-fourth of organizations in California using such tools in a 2010 report.[1] Arguably, these surveillance tools emphasize the data collection and surveillance responsibilities of the IP but may have limited utility in actively preventing infections or directly impacting patient care.

Clinical decision support (CDS) systems are algorithm- or rule-based tools designed to provide "computer-generated clinical knowledge and patient-related information intelligently filtered or presented at appropriate times, to enhance patient care."[2] Although CDS systems are more commonly associated with electronic medical records (EMRs) and automation, early decision support systems were paper-based. In a recent multilogistic regression systematic review of 70 studies evaluating CDS systems, decision support tools provided on an electronic platform were significantly associated with improved clinical practice.[3] As recently as 2006, a statewide survey reported that although CDS was used at 38% of the respondents' organizations, only 29% were computer-based.[4] For the purposes of this article, all CDS systems referenced are computerized unless specifically denoted otherwise. This article outlines attributes of successful systems, provides examples of successful infection prevention– and antimicrobial stewardship–oriented CDS tools, and describes one organization's approach to CDS development with IP-oriented successes and failures.

Although there is some obvious overlap between a semiautomated electronic surveillance system and a CDS system, the latter is a more interactive relationship between the system, user, and patient. As an example, the surveillance system described by Chen et al[5] that notified IPs in real time with pertinent patient results warranting isolation classifies as decision support. An essential element of an effective CDS system resides in the ability of the end user (eg, ordering provider, nurse, or IP) to immediately act on the information provided. In this example, the notification of significant results would be optimized by interoperability with the computerized provider ordered entry or EMR system to procure an isolation order. Most semiautomated electronic surveillance systems that use CDS are described as noninterruptive. The term noninterruptive refers to a workflow or tool that provides new information in a worklist or queue to be reviewed at a time convenient for the end user. Although this may be acceptable for routine surveillance activities, immediate notification may be important with new patient results indicating a need for isolation precautions. In a recent study, emergency department physicians were more susceptible to interruptive CDS when an alert notified

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them that a patient in their department required contact isolation precautions than when similar information was made available for review at a time of their choosing.[6]

Applying models to medical decision-making is not a 21st century concept. One of the earliest examples came in 1961, when Warner et al[7] evaluated a mathematical model for determining the likelihood of congenital heart disease. Importantly, the role of the user was also recognized early as essential to adoption and successful utilization. In 1976, in one of the earliest descriptions of an effective CDS system to improve patient care, McDonald observed that "computerized protocols will only be useful to the extent that they reflect the physician's actual decision logic."[8] To that end, CDS can operate in a variety of ways: it can function as a standalone system or be integrated within an EMR system. Similarly, CDS may require manual data entry or function by pulling and collating clinical data from disparate sources. Finally, systems can function actively (eg, alerting the end user or stopping the end user from further action, also known as hard stop) or so passively as to require the user to actively seek out the tool for advice, as in the non-interruptive scenario previously described.[9] CDS as part of the EMR is an ideal circumstance, but it is not readily available to all. Even with such integration, the challenges do not start and stop before the system or tool is activated (go live). Indeed, in a recent summary of Kaiser's experience with their EMR system, the authors noted that CDS tools for antimicrobial stewardship required a significant time investment when such tools are developed in house (as many are), and they further estimated that no such development is attainable until 6-18 months after an EMR system is fully operational and in use.[10]

## COMMON CHARACTERISTICS OF SUCCESSFUL CDS SYSTEMS

Although most reports regarding CDS technology target topics other than infection prevention, most describe successful and detrimental attributes of the tool or to the design process itself that can be easily extrapolated. Bates et al[11] summarized their experience in designing effective CDS tools at Brigham and Women's Hospital in a collection of 10 commandments that are summarized in Table 1. These characteristics broadly fit into 2 major categories: technical elements of design and the integration of human factors into the pursuit of improved patient outcomes.

Included in the technical aspects of design and repeated throughout nearly all systematic reviews is the issue of processing speed or the length of time it takes for a computerized system to gather and analyze data and provide usable information or action items to the end user. To be readily accepted by users at the bedside, the technology must function at the speed of the business, and in health care that speed is very fast. With obvious overlap to human factors, a CDS system that fails to function expeditiously becomes an interrupter, and interrupters are worked around. Indeed, providing the necessary information in a timely manner and at the point of care (during the provider-patient interaction) accounted for half of the critical elements of successful systems in a meta-analysis of 70 CDS-oriented studies published in 2005.[3] At the Regenstrief Institute, where >1,300 CDS algorithms or rules are operating as part of a dynamic CDS system in place since 1974, the developers acknowledge that even a 20-second delay in treatment recommendations is too long. Their solution is to execute a portion of the time-consuming rules overnight prior to the scheduled outpatient encounter and to store that data for rapid retrieval the next day.[12]

At its most rudimentary level, human factors engineering is the "evidence-based design for supporting people's physical and cognitive work."[13] Human factors focus on understanding the manner in which a task or series of tasks is performed (workflows) and identifying ways to optimize outcomes within the environment. When technology is an integral part of a multimodal workflow, it can be especially important to build the technology with an eye toward integration within workflows. CDS design and implementation teams include end users as part of their teams to apply knowledge of existing workflows into the design process. By doing so, they solicit feedback during the design process to optimize usability and are better able to conduct extensive usability testing prior to releasing tools into the clinical environment.[11,14,15] Human factors are not limited to the software challenges of system design. A sufficient hardware infrastructure (eg, high-functioning computers, tablets) is essential for integrating CDS into existing workflows.[14,15]

Determining success or failure of a CDS initiative presents its own challenges. A 2012 publication in the *Journal of the American Medical Informatics Association* proposed a framework for quantifying the relative success of CDS. The authors describe 5 metrics, 2 of which are technical and 3 of which are based on end-user response by which an organization can evaluate the effectiveness of their intervention. These include the frequency in which an alert fires inappropriately (false-positive rate) and ascribed clinical urgency of the alert to the clinical condition and whether the ordering provider overrides the alert, selects an inappropriate course of action, or adheres to the CDS recommendations and how long it takes

**Table 1**
"'Ten commandments' for Successful Design, Implementation and Use of Clinical Decision Support Systems" adapted from David W. Bates and colleagues in the *Journal of the American Medical Informatics Association* with overlaying themes of technical and human factors[11]

1. It must be fast. Speed, or the time it takes for the CDS system to gather and process the data and return meaningful information or actionable recommendations to the end user.
2. Keep the CDS system simple. Guidelines can be complicated and not readily adaptable to automated systems. Overly complicated systems are more susceptible to technologic fails, and too much information may overburden the end user.
3. Require the user to enter data only when it is essential. Asking end users to enter data already documented (eg, in the EMR) is double documentation and poorly received by users. If it is necessary, get end user acceptance early in the design process by explaining the necessity and the inability to gather the data elsewhere.
4. Routinely maintain and evaluate the CDS system. When guidelines change, the CDS tool built on those recommendations needs to change as well. Retire CDS tools when no longer needed.
5. Identify latent needs and inform the end user. Latent needs are supplemental recommendations in the CDS tool. As an example, if the primary output of CDS is to recommend vancomycin for treating a specific positive culture, a latent need to order therapeutic drug monitoring can be provided at the same time.
6. Build the CDS system to fit the existing workflow and seek input from end users early in the design process to understand their natural workflows better.
7. Understand that usability is essential and nuances matter to end users. Professionals that design or customize CDS tools and clinician end users may both use the same computer program but in very different ways. End users must be involved in the design and development phase from concept to completion.
8. Do not stop, change course and
9. Physicians will not stop. Stopping refers to not allowing the end user to complete their desired course of action and sometimes may be referred to as a hard stop. Offering clinically appropriate alternatives (drug A instead of drug B) and override options (eg, requiring the user page infectious diseases for preapproval for a medication order to be filled) allows the end user to complete their task.
10. Measure and share success. When a CDS tool is implemented it inherently changes how end users do their job. Measuring how end users are responding to the CDS tool and sharing data on the (ideally improved) clinical outcomes reinforces the value in their efforts and builds trust for future development.

*CDS*, clinical decision support; *EMR*, electronic medical record.

for the user to implement the recommendations.[16] Importantly, the authors do not propose minimal standards or thresholds for these metrics.

## CDS FOR ANTIMICROBIAL STEWARDSHIP AND INFECTION PREVENTION

Although CDS is well-described in a variety of health care–related disciplines, its practical application to infection prevention and control has been limited and is predominated by antimicrobial stewardship. In fact, as part of a recent meta-analysis, Cresswell et al[9] summarized key findings of 41 systematic reviews of CDS systems, none of which explicitly included infection prevention. Most infection prevention–related publications pertaining to CDS systems focus on antimicrobial stewardship programs. In the mid-1990s, researchers at LDS Hospital in Salt Lake City were one of the first groups to describe a robust, real-time CDS system for antimicrobial stewardship that had first been used in 1988. They not only noted the significantly improved patient outcomes with fewer drug reactions, fewer drug doses of excessive therapy, and lower costs but also noted in the context of a time-motion study that such a system was more efficient than an infectious diseases specialist.[17,18]

In a landmark study, Samore et al[19] evaluated the effectiveness of CDS for primary care antimicrobial stewardship by randomizing 18 communities to receive CDS (paper-based or electronic-based via handheld technology), community education alone, or no intervention at all. Communities in the CDS arm were less likely to receive prescriptions for antibiotics overall and less likely to be prescribed macrolides than either control arm. In a more recent, family practice-level–based quasi-experimental trial wherein CDS was deployed with quarterly audits and provider-level feedback, overall antimicrobial use declined significantly, but a more statistically significant improvement was observed with avoiding the use of broad-spectrum antibiotics.[20]

McGregor et al[21] at the University of Maryland Medical Center were the first to evaluate the effectiveness of a CDS system for antimicrobial stewardship in the context of a randomized controlled trial. A previously established antimicrobial management team was supplemented with CDS randomized at the individual patient–level according to medical record number. Patients in the CDS arm were twice as likely to receive the intervention, required 1 less hour of review per day for review, and netted an overall additional, annualized direct cost savings of >$336,000.

Aside from antimicrobial stewardship, a number of authors have described using decision support tools for infection prevention. Baillie et al[22] reported on the effectiveness of an intervention aimed at reducing indwelling urinary catheter use in a multihospital setting. Their CDS development was 2 phased, with phase 1 using a generic, noncustomized (also called plug-and-play) reminder system from the EMR vendor that required 7 clicks on the part of the end user and achieved the desired result (discontinuing the Foley catheter) only 2.2% of the time. Feedback from their multidisciplinary group suggested that the low compliance rate was caused by the complexity of the CDS interface. Therefore, in phase 2, they redesigned the alert by using an in-house developed alert that required 2 clicks and was successful in persuading the end users to discontinue the Foley 15.2% of the time ($P < .001$). Unfortunately, false starts such as this, when the initially released CDS tool is cumbersome (7 clicks) or not readily accepted by the user, can sometimes kill an otherwise well-intentioned performance improvement initiative.

In a before-after study at a medium-sized community hospital, researchers evaluated the effectiveness of a CDS tool on head of bed (HOB) elevation for mechanically ventilated patients. Per hospital policy, nursing was required to document the HOB elevation every 4 hours. If the documented HOB was <45°, the alert fired, recommending an increased elevation for the patient and requesting documentation for any contraindications. Although they saw a statistically significant improvement in the mean degree of elevation after the intervention, they also noted a discrepancy of 4° between the documented incline (as measured by the bed scale and recorded by the nursing staff) and the observed incline, as measured by the serial prevalence measurements performed by a member of the investigative team by using a protractor.[23]

At Intermountain Healthcare, patients identified by a CDS tool as being at high risk for colonization with methicillin-resistant *Staphylococcus aureus* (MRSA) are flagged at the nursing station as needing a surveillance culture. These patients were 5 times more likely to be colonized than low-risk patients in the same medical unit, and results were available on average within 16 hours. In addition to highlighting the success of this risk-based alert, the authors also categorized and described 52 implementation issues. These included erroneous alerts as a result of hospital account changes, test patients or inaccurate data entry, server downtime, alerts firing prior to patient arrival to the unit, eliminating duplicate testing from recent prior admissions, and alert acknowledgement issues.[24]

CDS systems can have unintended consequences; however, these occurrences are often not shared in the published literature. One such case was reported in a 2010 randomized controlled trial in which the authors described a near hard-stop intervention for the dual prescribing of warfarin and trimethoprim-sulfamethoxazole. Such prescribing is not recommended because of the compounding anticoagulation effect of the antibiotics on warfarin. The organization implemented a CDS tool that notified the ordering provider that the order for the drug(s) could not be processed and recommended contacting the pharmacy department if both drugs were medically necessary. Although the intervention group (receiving the CDS) was significantly less likely to inappropriately order the 2 drugs in combination, the study was suspended by the institutional review board when 4 patients in the intervention arm experienced delayed treatment when it was clinically necessary.[25]

## NORTHSHORE

NorthShore University HealthSystem (NorthShore) is a 4-hospital, University of Chicago–affiliated health system located in the northern suburbs of the Chicago metropolitan area. In addition to the 4 hospitals, NorthShore operates >100 ambulatory care centers and a home health and hospice service. The system has used an integrated EMR since 2003, which functions in all of these described service areas and provides the patient with a patient-provider interactive communication tool for tasks such as scheduling visits, reviewing laboratory results, and contacting established care providers. The Clinical Decision Support Committee at NorthShore was formed in 2009 and is comprised of physicians (n = 5), health information technology (HIT) and clinical analytics developers (n = 9), EMR trainers (n = 2), nurses (n = 3), a pharmacist (n = 1), and a quality improvement specialist (n = 1). The committee meets monthly to evaluate and prioritize newly requested CDS tools, review early design and development, update the status of CDS tools under development, and evaluate the effectiveness of tools in production. The mission of the committee is to facilitate the right information, to the right person, at the right time. The process by which a new request for decision support is proposed, prioritized, tasked, developed, tested, released, and evaluated is complex, yet structured. Regardless of where the concept for such a tool originates, the end user submits a request for service that is evaluated by the HIT department. HIT staff work with the end user to fully understand and describe the concept of

the proposed tool and estimate the resources required for such a build. Together, the end user and HIT staff identify additional clinical areas that may be impacted by such a change to solicit feedback and address potential unintended consequences proactively. The result of this initial effort is a proposal to the Clinical Decision Support Committee that describes the problem and proposes ≥1 potential solution for the committee's consideration.

The committee evaluates proposals against 6 organizational focus areas and a surrogate measure intended to reflect the complexity of the requested build. Each of the 7 metrics is weighted equally and ranges from zero (no benefit or impact) to 4 (maximum benefit and importance). These priorities include the frequency in which the problem or issue needing to be resolved occurs (where 0 is annually and 4 is daily) to estimate the potential patient impact this would have and the probability of improved efficiency or workflows for end users (none to substantial) in reducing redundancies and improved documentation. Also included are the probability of a severe clinical outcome occurring without developing and deploying a CDS tool (0% to >5% risk), the potential financial benefit for the organization (none to millions), regulatory necessity (none to required), and overall organizational priority (none to large). Finally, the perceived complexity of the build is scored by the HIT staff on the committee, with minimal complexity contributing zero to the total score and maximum complexity deducting 3 points from the total score. Although the process can seem somewhat subjective, scoring is complete by consensus of the committee and usually after a robust discussion between the requestor(s) and among committee members themselves. Once prioritized, the project is placed in the queue, and once HIT resources are assigned, projects proceed through ≥1 design session involving HIT and clinical staff. Projects are then brought back to the committee while still in their early stages of development to assess propensity for success, workflow considerations, and training needs. CDS tools are then brought back to the committee for a review and analysis of their functionality and impact on clinical care approximately 3 months after their release to production or any period thereafter if their utility is no longer assured or is in question.

The solution to a perceived CDS need is not always an alert or pop-up that notifies the user of a recommended action. At NorthShore, alerts are often supplemented with an order built into the alert to guide the user toward the desired action. For example, duplicate orders for the same laboratory test on the same day may trigger an alert with a single click option that allows the ordering provider to cancel ≥1 test. Similarly, some decision support tools may use required documentation, whereby the ordering provider is required to complete required fields as part of the order to describe their rationale for placing orders inconsistent with recommended best practice. For circumstances warranting a reminder but not necessarily immediate action, best practice information can be sent via the EMR mailbox to the ordering provider, prompting the user for further action, such as a reminder for cosigning a trainee's documentation. By leveraging multiple platforms, EMR-based CDS alerts can be deployed outside the EMR, such as when a patient with a history of violent behavior registers in the NorthShore emergency department, a page is automatically sent to the hospital's security services. Messages can also be incorporated unobtrusively into a clinician's patient list as a column that indicates a patient's risk of something important (eg, MRSA colonization) or a gap in their care (eg, due for influenza vaccine). Three examples of NorthShore CDS tools for infection prevention and control performance improvement initiatives are subsequently described.

In 2008, NorthShore embarked on a comprehensive performance improvement initiative to reduce unnecessary Foley catheter utilization. The details of the initiative and unintended consequences of the improved process measures on overall infection rates are reported elsewhere.[26] Part of the improvement effort included the development and release of a CDS tool that required physicians to write an order with clinically approved justification for catheter insertion, reminded nurses and ordering providers that their patient had a Foley catheter every 48 hours, and required documentation for ongoing use in an effort to encourage providers to discontinue the catheter when no longer medically required. When the CDS tool was initially released, the various alerts fired for all ordering providers and immediately on admission to the unit for nursing staff, which averaged 10 alerts per patient per day. At the request of nursing, to allow the nursing intake and assessment on admission to proceed with fewer interruptions, the alert was modified to allow a lock-out period of 4 hours after admission or transfer, after which the alert fired an average of 1.5 times per patient per day. The proportion of patients for whom the alert had the desired effect (acknowledgement and rationale for continued use or removal of the catheter) increased from 35.2%-52.2%, and the overall device utilization continued to decrease. The natural progression of this initiative lead to the nursing department using a real-time list of patients currently with Foley catheters to proactively seek out opportunities to discontinue and avoid receiving the alerts.

In 2011, NorthShore researchers published the results of a multivariable analysis detailing the EMR-extractable electronic risk factors for MRSA colonization based on several years of universal screening of all hospital admissions.[27] The model predicted that by testing roughly 50% of the high-risk admissions, NorthShore would capture 90% of MRSA patient days. An alert was developed in the EMR that calculated the risk score of all hospitalized patients in real time. If the patient's risk score crossed the high-risk threshold, an alert fired for the nurse, indicating that the patient needed a surveillance culture to screen for MRSA colonization. In the EMR, the worklist for the unit census included a colored dot next to each patient. Patients who were either low risk or high risk but had had cultures submitted to the laboratory were indicated with a green dot. Patients determined by the model to be high risk, but no culture had yet been submitted, were indicated with a red dot. Dubbed the magic dot, this noninterruptive CDS feature allowed the nurse to monitor their own patients, empowered supervisors to review their areas of responsibility in a single screen, and allowed the IPs to review their unit's performance in real time and provide feedback when needed. Compliance with completing the surveillance protocol has been in excess of 90% since its release in January 2013, and incidence of MRSA infections has remained unchanged compared with the prior, demonstrably successful universal screening program. The annualized estimated cost savings from reduced testing of low-risk patients as a result of this alert is at least $500,000. The dot system has proven to be one of the most popular tools for the CDS Committee.

In 2012, an in-depth review of hospital onset cases of *Clostridium difficile* infection (CDI) at NorthShore as determined by the National Healthcare Safety Network criteria identified an interesting phenomenon.[28] Over 40% of cases had received laxatives or stool softeners in the days preceding (and including) the day of the test for CDI. Such orders were limited to neither select providers nor select services. The issue was brought to the CDS committee and an alert was developed and released in July 2013. When placing an order for the CDI laboratory test on a patient who had received laxatives, the ordering provider received a pop-up that stated the following: The patient was given a laxative in the last 24 hours. Are you sure you want to order this procedure? The provider was then offered the option to discontinue the order. Education was distributed in advance of releasing the decision support to all physicians and included a summary of recommended ordering

practices provided by the infectious diseases department. In addition, a report was generated once weekly and sent to the infection prevention and control department, listing the patients for whom the alert fired, the ordering provider, and what action the ordering provider chose (continue with the test or cancel). IPs reviewed the list and, for ordering providers who placed the order regardless of the alert, messaged the physician via the EMR with a reference to the patient's record, a reminder of the recommended practice, and the opportunity to consult with the hospital epidemiologists if they had any questions or concerns with the recommended practice. Despite the design, communication, and timely feedback, the alert had no significant impact on ordering practices, and the feedback from ordering providers was largely negative. As a result, the alert was discontinued in early 2014. However, this unsuccessful attempt highlighted the issue of laboratory stewardship (getting the right test for the right patient at the right time) as an emerging joint opportunity for CDS and infection prevention and control. A recent prospective review of urine culture orders of critically ill patients at NorthShore revealed that most (48 of 50; 96%) failed to meet clinically relevant criteria for ordering the culture. Inappropriate testing can result in inappropriate therapy, and as such, a CDS tool aimed at reducing inappropriate ordering practices is scheduled for release in 2015.

## CONCLUSIONS

Although infection prevention brings its own perspective to CDS design and success, there are ample universal challenges that have been previously summarized into the following 3 main categories: improving the effectiveness of CDS systems, creating new systems, and disseminating knowledge. On the technical scale, work remains in improving the interface between the CDS and end user. This can best be addressed by including end users in the design process and allowing for sufficient usability testing prior to production release to ensure adequate uptake. Information management to improve CDS functionality is an ongoing challenge. Improving specificity of the alerts, prioritizing recommendations to the right end user (the provider apt or able to implement the recommendation), and adjusting alerts based on patients' ever-increasing comorbid conditions are all opportunities for improvement.[2] Finally, as organizations advance in their CDS development for infection prevention, it is imperative that we share our collective knowledge to advance the field. By leveraging the increasing availability of electronic health data, CDS offers the promise to guide us toward better, more real-time interventions to ultimately reduce the risk of health care–associated infections in our patients and improve the overall quality of care.

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