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Modeling the longitudinality of user acceptance of technology with an evidence-adaptive clinical decision support system ☆

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ABSTRACT

This paper presents multiple innovations associated with an electronic health record system developed to support evidence-based medicine practice, and highlights a new construct, based on the technology acceptance model, to explain end users' acceptance of this technology through a lens of continuous behavioral adaptation and change. We show that this new conceptualization of technology acceptance reveals a richer level of detail of the developmental course whereby individuals adjust their behavior gradually to assimilate technology use. We also show that traditional models such as technology acceptance model (TAM) are not capable of delineating this longitudinal behavioral development process. Our TAM-derived analysis provides a lens through which we summarize the significance of this project to research and practice. We show that our application is an excellent exemplar of the "end-to-end" IS design realization process; it has drawn upon multiple disciplines to formulate and solve challenges in medical knowledge engineering, just-in-time provisioning of computerized decision-support advice, diffusion of innovation and individual users' technology acceptance, usability of human-machine interfaces in healthcare, and sociotechnical issues associated with integrating IT applications into a patient care delivery environment.

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1. Introduction

Evidence-based medicine is the "conscientious, explicit, and judicious use of current best evidence in making medical decisions about the care of individual patients" [25]. There has been a general consensus that continuous, comprehensive practice of evidence-based medicine has tremendous potential to improve quality of care and reduce practice variation. However, there is also a widely acknowledged gap between clinicians' awareness of these care standards and their consistent application of the standards in practice. Clinical decision support systems (CDSS)—in particular, evidence-adaptive decision support systems—provide decision aids with a knowledge base constructed from and continually adapting to new research and practice based evidence of medicine [29]. Such decision aids address a current need in healthcare decision support for tools that use reliable patient data, decision models and problem solving methods to address challenges in performance requirements, data and knowledge forms and generalizability to other application areas [27]. However, while there is evidence that CDSS can improve clinician guideline compliance, and thus patient health [16,26], widespread use of such systems has not become available due to numerous technological, behavioral, and organizational barriers. These facts motivate the present research.

Clinical Reminder System (CRS) is a research-oriented clinical information system iteratively designed and developed through a 7-year joint effort by researchers from the H. John Heinz III College at Carnegie Mellon University (CMU) and medical practitioners at the Western Pennsylvania Hospital (WPH). CRS is an evidence-adaptive CDSS that aims to improve the quality of patient care by providing clinicians with just-in-time alerts and advisories based on best known evidence-based medicine guidelines and individual patients' health descriptors and treatment conditions. Of the four functions that a computerized CDSS may provide [21]—administrative support, managing clinical complexity and details, cost control, and decision support—CRS is designed to supply all except cost control.

CRS has been developed in the context of increased pressure to use electronic health records (EHR) to improve quality of care and patient safety, in the form of recommendations from professional organizations such as the Institute of Medicine and Federal mandates contained in the American Reinvestment and Recovery Act of 2009. However, adoption rates for EHRs in the U.S. are low compared to other industrialized

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countries [13]. Additionally, while CDSS technologies demonstrate great potential to improve quality of care and patient safety in laboratory and clinical trial settings (e.g., [4]), once deployed for routine use in the field, they often fail to obtain adequate usage by medical practitioners and consequently fail to achieve those anticipated benefits on clinical performance and patient outcomes [24]. For example, through a systematic review, Shojania et al. [34] found that computerized medication safety alerts are overridden by clinician users in 49% to 96% of cases including those for preventing severe drug–drug interaction events. In a more recent review, Shojania et al. [28] reported that point-of-care CDSS reminders have produced much smaller clinically significant improvements than those generally expected. Factors contributing to this missing link between the deployment of CDSS and the achievement of long-term end user adherence remain underexplored.

To enlarge the research base of knowledge regarding adoption and clinically relevant use of CDSS and EHR generally, CRS has operationalized research-based methods and models via a carefully designed application that has been evaluated in clinicians' day-to-day patient care routines. This process has generated research insights into reengineering the system's technological designs to improve its usability as well as informing tailored behavioral interventions for addressing the user resistance encountered. As an exemplar of the "end-to-end" IS design realization process, the CRS project draws upon multiple disciplines including decision science, computer science, information systems, and behavioral and social sciences to formulate and solve challenges in (1) medical knowledge engineering; (2) just-in-time provisioning of computerized decision-support advice; (3) diffusion of innovation and individual users' technology acceptance; (4) usability of human-machine interfaces in healthcare; and (5) sociotechnical issues when integrating technological systems into the reality of a patient care delivery environment. The CRS project hence embodies a "methodological pluralism" approach called by researchers [14] which demands extreme additional attention be paid to medical practitioners' work contexts, their preferences and constraints, and the social and organizational environments in which technologies and users are situated.

The purpose of this paper is twofold: to summarize a new understanding of the importance of rigorous and adaptive clinical IT design to bridge academic research and practice generated through our previously published work based on developing, evaluating, and iteratively improving CRS, and to use this understanding to frame novel insights provided by CRS regarding the behavioral underpinnings of technology acceptance that may inform more useful and usable technology designs as well as more effective diffusion strategies and use policies. We achieve the first goal by reviewing the research contributions of the CRS project: analysis of longitudinal usage rates and causes of dissatisfaction with an early version of the application, and, with a re-engineered version of CRS, user interface analysis to identify navigational patterns and opportunities for usability improvements, and social network analysis to reveal the nature of users' social interactions the relationship to individual clinicians' system utilization. We achieve the second goal by introducing a new model of technology adoption that addresses the limitations of the well-known technology acceptance model (TAM) through accommodation of the longitudinal course of acceptance behavior formation, development, and institutionalization relying on "actual system use" as computer-recorded objective usage instead of self-reported surrogates.

2. Materials and methods

2.1. CRS functionality

The Clinical Reminder System (CRS) is capable of managing workflow and clinical documentation as well as generating decision-support reminders at the point of care. To provide administrative support, CRS allows clerical staff to register new patients and manage patient appointments. When patients arrive in the clinic, clerical staff use CRS to track workflow activities such as patient check-in, encounter in progress, and patient check-out. To enable clinicians to manage all necessary patient information using a single system, CRS has evolved into a "lite" EHR system. The EHR features of CRS provide comprehensive patient data management support such as documenting clinical observations, tracking progress notes, prescribing medications and ordering laboratory tests. To minimize data entry and to collect electronically collect up-to-date patient health conditions, CRS is interfaced with other hospital information systems to retrieve laboratory test results (in real time) and patient demographic information and historical disease diagnoses (in batch mode, performed periodically).

In addition to storage, management, and retrieval of patient data, CRS implements evidence-based medicine guidelines to generate "just-in-time" alerts and advisories to improve medical practice of four chronic diseases: asthma, diabetes, hypertension, and hyperlipidemia; and five preventive care categories: breast cancer, cervical cancer, influenza, pneumonia, and steroid-induced osteoporosis. Such alerts and advisories, or reminders, provide clinicians with decision support aid in (1) managing clinical complexity and details, and (2) clinical diagnosis and treatment plans. The reminders that CRS generates take the form of recommendations to have certain tests performed, to receive vaccinations, or to discuss the pros and cons of alternative treatments. Fig. 1 contains an extended view of CRS' main workspace.

The most recent, web-enabled version of CRS is implemented using C# and ASP.Net technology and an Oracle 10 g database. All guideline-based, reminder generating algorithms are implemented as web services using a homegrown ontology. CRS is available at http://crs.sph.umich.edu:8088/.

2.2. CRS research directions

As a prelude to our discussion of new research results related to system usage, we summarize the primary research contributions of CRS. To enable effective and efficient medical knowledge engineering, we designed and implemented a novel guideline ontology model that enables structured acquisition and automated execution of evidence-based medicine guidelines. The Guideline Representation and Execution Model (GREM), built upon several existing guideline ontologies such as Guideline Interchange Format, is discussed in detail in [40].

We conducted a longitudinal, quantitative usage analysis to assess the dynamics in the utilization rates of CRS. The main variable constructed from computer-recorded usage data is "the percentage of patient encounters in which CRS was used to generate clinician directed reminders." The longitudinal usage data were analyzed using a novel developmental trajectory analysis model (DTA). This model embodies a semi-parametric, group-based statistical approach for identifying distinct trajectory groups within a population and relating the group membership probabilities to a set of covariates of interest [19]. Based on the quantitative analysis results, we further collected and analyzed qualitative data from multiple sources in order to explain the low utilization rates observed (approximately 35% on average), and the developmental usage trajectories identified. These empirical, field-based user experiences of CRS within the context of clinical practice enabled us to identify a number of positive and negative themes that varied across usage trajectory groups. A summary of the quantitative and qualitative usage analysis is described in ref. [39].

The technology acceptance model, which provides a framework for understanding usage results such as those described above, is based on theory of reasoned action (TRA). TRA posits that an individual's consciously intended behavior is determined by behavioral intention: a function of the person's attitudes towards the behavior; and subjective norm: influence the person receives from his or her significant others [2]. In extensions to TAM, the subjective norm construct has traditionally been measured using self-reported, general perceptions of other's influence to use software in question. As such, self-reports are incapable

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