



# Identifying and Preventing Technology-Induced Error Using Simulations: Application of Usability Engineering Techniques

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## Abstract

In this paper, we describe a framework for the analysis of technology-induced errors, extending approaches from the emerging area of usability engineering. The approach involves collection of a rich set of data consisting of audio and video recordings of interactions of healthcare workers with health information systems under simulated conditions. The application of the approach is discussed, along with methodological considerations and issues in conducting such studies. The steps involved in carrying out such studies are described along with a discussion of our current work. It is argued that health care information systems will need to undergo more rigorous evaluation under simulated conditions in order to detect and prevent technology-induced errors before they are deployed in real healthcare settings.

“Mistakes are a fact of life. It is the response to the error that counts.” – Nikki Giovanni

## INTRODUCTION

Medical errors are a significant cause of death and disability in North America (Baker et al. 2004a; Baker & Norton 2004b; Institute of Medicine 2000). Current Canadian estimates suggest approximately 185,000 hospital admissions are associated with an adverse event each year (Baker et al. 2004a: 1678). Similar studies have been conducted in other countries with

analogous results (i.e., United States, Australia) (American Hospital Association, 1999; Wilson et al. 1999). In recent years, health information technology has been touted as being an effective method for reducing the overall incidence of medical error (Institute of Medicine, 2000). For example, a number of studies have shown that physician order entry, decision support and medication administration systems can decrease the number of certain types of medical errors (Bates et al. 1998). However, more recent research findings indicate such health information technologies may in fact increase rather than decrease the incidence of certain types of medical errors (Koppel et al. 2005; Kushniruk et al. 2004). This has led some researchers to suggest technology can introduce new types of medical errors arising from the technology itself or from the nature of the interaction between the technology and the clinician in real work contexts (technology-induced errors) (Ammenwerth & Shaw 2005; Horsky et al. 2005; Koppel et al. 2005; Kushniruk et al. 2004).

This new research has called into question previous work that has asserted the value of health information technologies in reducing medical error. It has also led to the development of new research aimed at examining technology-induced error in health informatics and has led to consideration of differing research methods and designs that could be used to study technology-induced error. In this paper, we will describe the use of research methods arising from the usability engineering literature and

their application in the study of technology-induced error for evaluating health information systems. We will begin by providing a discussion of the emergence of usability engineering as an approach that can be applied to the study of technology-induced error. Following this we will present a description of our methodology for evaluating health information systems based on this approach.

## ORIGINS OF USABILITY'S IMPORTANCE IN HEALTH INFORMATICS

The usability of healthcare information systems has emerged as a critical issue in health informatics. Usability can be defined as a measure of how efficient, effective, enjoyable and safe a computer system is to use (Preece et al. 1994). Many studies have documented the importance of usability in terms of its impact upon the adoption and appropriation of health information systems (physician order entry, clinical documentation) by health professionals (physicians and nurses) (Ash et al. 2003; Sicotte et al. 1998). Studies have underscored the fact that a system will not be used by health professionals in everyday practice unless the system is usable (Ash et al. 2003; Murff & Kannry 2002).

There are many documented cases of organizations that have implemented and deployed health information systems that were later "turned off," boycotted, or were not used to their fullest extent because of health profession dissatisfaction with the health information system (Galanter et al. 1999; Massaro 1993a; Massaro 1993b; Tjora 2000). Such research led to the exploration of the underlying causes for such health professional discontent where the usability of a health information system was concerned (Kushniruk et al. 1996). Many of these works have attempted to identify and quantify the reasons for health professional dissatisfaction with such systems in hopes that they would lead to improvements in system design and improved success in terms of health professional adoption and appropriation of health information systems (Murff & Kannry 2002).

## APPLICATION OF USABILITY TECHNIQUES IN HEALTH INFORMATICS

During the 1990s, methods for assessing usability emerging from the field of usability engineering began to be applied in the design of health information systems (Kushniruk et al. 1996). During this period, usability engineers began to concern themselves with making systems easier to use and learn by attempting to improve their safety, utility, effectiveness and efficiency. Early health information systems were very large, costly to develop and implement, and difficult to use (Shortliffe & Blois 2001). Researchers responded by attempting to understand those aspects of health information system design that make systems difficult to use in real world health care contexts (Tang & Patel 1994; Kushniruk et al. 1996). Although it has

been found that there are a number of benefits associated with health information systems use (Bates et al. 1998), some investigators have found that system usability could have a significant and sometimes unintended impact on users' cognitive processes. For example, the particular layout and organization of information presented on a computer screen (i.e., in an electronic health record) to a user (a physician) can have significant impact on how the user interacts in real world work contexts with colleagues and patients. For example, Kushniruk et al. (1996) found that the use of some electronic health records could lead health professionals to become "screen-driven," basing their selection of diagnostic questions posed to patients on the way that information is presented to them by a particular computer system. In some cases, this led to suboptimal diagnostic performance by physicians. In a later study, the impact of the screen layout of information in electronic health records was found to have a profound impact on what data was actually recorded by physicians in doctor-patient interactions, particularly as compared to analysis of data collected by physicians using paper records (Patel et al. 2000). These research findings were used to provide feedback into the design and deployment of health information systems in a process of formative evaluation and iterative systems development, including the design and refinement of Columbia University's PatCIS patient information system and the MED vocabulary (Cimino, Patel & Kushniruk 2001). As a result of usability testing, it has been shown that user satisfaction and adoption of these systems can be improved (Kushniruk & Patel 2004). Such findings have also led to an industry tendency to evaluate a health information system's usability as part of the process of system selection and procurement by healthcare organizations (Ash et al. 2003).

In summary, new methods from the usability engineering literature, some pioneered in health informatics, have been applied to the improvement of user satisfaction with health information systems in order to make user interactions with a computer system more efficient, effective and enjoyable in hopes that it would improve the adoption and appropriation of the health information system (Kushniruk 2002).

## USABILITY AND ITS APPLICATION TO THE STUDY OF TECHNOLOGY-INDUCED ERROR

With recent concerns raised over the potential negative impact of poorly designed information technology on facilitating medical errors (Horsky et al. 2005; Koppel 2005; Kushniruk et al. 2004), usability engineering methods (i.e., usability inspection and usability testing) have been applied in the assessment of health information system safety in order to identify and prevent costly medical errors that may arise from the use of health information systems (i.e., technology-induced error) before they are deployed in real world contexts. Specifically, such methods have begun to be applied to the assessment of the

impact of specific user interface features and design choices on medical error (Kushniruk et al. 2004).

There are two major methodological approaches, borrowed from the usability engineering literature, that can be used to evaluate technology-induced error in the health informatics. One approach is termed usability inspection, where systems and their user interfaces are systematically reviewed by analysts who apply design principles to assess their usability. In healthcare, such an approach has been applied by Zhang and colleagues (2003) to analyze the usability and error potential of devices such as infusion pumps. The other main approach is known as usability testing. Usability testing, unlike usability inspection, involves the recording and analysis of the actual process of use of healthcare systems by real users carrying out specific tasks using a computer system. Such an approach has the potential of allowing investigators to identify exactly where errors occur in the dynamic context of system use by representative users carrying out representative tasks for which the system was designed. The application of usability testing to the study of medical error has the potential to provide a powerful methodological approach for identifying technology-induced medical errors, relating usability problems to the occurrence of medical error, and predicting technology-induced medical error prior to system release (Kushniruk et al. 2005). Additionally, the approach is easily extensible to the study of a wide range of healthcare systems and can be carried out by typical healthcare organizations in a highly cost-effective manner given the steadily decreasing cost of basic computer and video equipment required. In the next section of this paper, we will describe how usability testing can be applied under simulated conditions which are representative of real world work situations to assess technology-induced error.

### TOWARDS A NEW METHODOLOGY FOR ANALYZING HUMAN INTERACTION WITH HEALTH INFORMATION SYSTEMS TO IDENTIFY AND PREVENT MEDICAL ERROR

As described above, our approach to analysis of technology-induced error typically involves conducting simulations of real healthcare situations. There are a number of motivations for incorporating simulations as part of usability testing when studying technology-induced error: (a) simulations allow for detailed analysis of the process of use of a system prior to its release in hospitals and other organizations, and therefore can be used to predict and prevent technology-induced medical errors before a system is deployed (b) such an approach is of low risk to patients (i.e., no patients are receiving actual care in the evaluation) (Kushniruk et al. 2004; Kushniruk et al. 2005), and (c) such evaluation during any or all of the various stages of system development


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(from early system design to customization phases) could greatly reduce the risk of death and disability to patients once a health information system is deployed.

Methods based on simulations have been used in health informatics to study human-computer interaction in a number of research domains including the study of usability, doctor-patient interactions involving technology, health professional decision making, testing of new devices and medical error (Kushniruk et al. 2004; Kushniruk 2001; Patel et al. 2000). The advantage of using simulations is that they can effectively mimic real world situations involving patient care (i.e., aspects of task urgency and complexity). There are a number of differing types of simulations, including computer-based simulations that attempt to mimic human behaviour (Gaba 2004) and simulations that are developed to test specific system components (Kushniruk et al. 2004). In our work, we utilize a category of simulations that involve real users interacting with systems in simulated environments as they perform realistic tasks, such as entering a medication order. Such simulations can be effectively used to develop, pilot test and evaluate systems across the continuum of the system development life cycle from requirements specification to customization. This may also include use of “standardized patients” who play the part of a patient when observing healthcare professionals using a system while interacting with a patient (as described by Kushniruk et al. 1996).

There are a number of steps that can be carried out in conducting simulation-based studies of technology-induced error in health care (as illustrated in Figure 1 and described below). Although there may be some variation in the overall

**Figure 1. Steps in the Usability-Based Assessment of Technology-Induced Error in Healthcare.**



	Activities
Step One	Select representative users
Step Two	Select representative tasks
Step Three	Develop scenarios
Step Four	Select equipment and recording methods
Step Five	Collect video, computer screens and audio data
Step Six	Qualitatively code transcripts and quantify qualitative data

method employed, the development of simulations in our work has typically involved consideration of each of these steps to ensure the generalizability, applicability and value of the findings in informing health information systems development, design and implementation. Initially, the objective of the evaluation needs to be carefully considered prior to designing the study. (Objectives may include testing for technology-induced error arising from programming, assessing usability of the user interface, assessing changes in health professionals' workflow, etc.)

Our methodological approach involves techniques adapted from the area of usability engineering and also the application of simulation of real work contexts, as described in the steps below.

### Step 1: User Selection

This crucial step involves the identification and selection of representative users for studying interaction with a particular health information system. Users should be representative of those individuals who will use the system. This may involve prescreening of health professionals in terms of their level of disciplinary, domain and technology expertise (Kushniruk & Patel 2004). It has been shown that as few as 10 users can provide significant feedback about the quality of a health information system, along with specific feedback to designers regarding improvements (Lewis 1994; Nielsen 1993).

### Step 2: Task Selection

This stage involves the selection of representative tasks that the users (health professionals) are expected to undertake when using the system under study. A range of tasks could be selected. For example, in the study of errors induced by use of a medication order entry system, this may include presenting users (i.e., physicians) with written descriptions of patient cases (that might include, for example, a prescription list for the patient in the case). The actual patient cases can vary from routine to atypical. Some studies may also involve use of actors playing the role of a patient presenting with a medical problem (i.e., an extension of the standardized patient approach used for assessing residents' interviewing skills in medical education). Users in such studies (i.e., physicians) are observed as they interact with both the simulated patient and the computer system under study (as will be described in a subsequent step) in order to carry out a task. For example, the task in such studies might include instructing the users (i.e., physicians) to carry out an interview with the patient while using the system under study to arrive at a diagnosis and treatment plan (Kushniruk & Patel, 2004).

### Step 3: Scenario Design

Scenarios used to drive usability testing can range from simple written medical case descriptions that are given to users to read, to more elaborate scripts to guide actors in playing roles in

simulated doctor-patient interactions (Gaba 2004; Kushniruk et al. 2004). Attention should be paid to the attributes or qualitative dimensions of each scenario. Researchers should consider varying levels of scenario complexity, urgency and time constraints in scenario design (Kushniruk & Patel, 2004). Scenarios should also be representative of the range of situations encountered by users from the routine to the atypical to ensure the health information system's limits or boundaries are sufficiently tested (Kaner et al. 1999; Patton 2001).

### Step 4: Equipment and Recording Methods

The complexity of the equipment required for simulations varies from low-fidelity to high-fidelity simulations (Gaba 2004; Kushniruk & Patel 2004). A low-fidelity simulation roughly approximates the nature of the real world situation that the simulation is supposed to represent. For example, a simple low-fidelity study may involve presenting physicians with a short written case description of a patient and asking them to enter prescription information about the patient into a physician order entry system while recording the interaction with simple video or audio devices. A high-fidelity simulation would reproduce more closely the real world situation being studied. For example, a simulation may involve actors playing the roles of patients and staff in a clinic in the study of how physicians use of a patient record system. Such a study may involve multiple recording devices to precisely document all user interactions (i.e., audio and video recording of all verbalizations, computer activities and the hospital room or clinic environment in order to document actions).

### Step 5: Data Collection

As health professional users carry out the tasks created for the study (i.e., entering medications into a physician order entry system), the process of their interaction with the system under study is recorded in its entirety. We recommend that users' verbalizations be audio recorded. This may involve instructing users to "think aloud" while carrying out a task and tape recording their verbalizations (Ericsson & Simon 1993). Audio data is for the most part a primary source of data providing information about what is being focused on and considered by the users during simulations. Other forms of data can include computer screen recordings of users' interaction with a computer system (obtained by outputting the computer screens into a VCR, using a PC-video converter, or alternatively by using screen recording programs such as HyperCam). In addition, users' physical behaviours can be video recorded. Video data and computer screen recordings can provide additional insights and key findings when triangulated with audio data. Increasingly, the role of computer screen recordings and video data has been demonstrated to inform and contextualize information and can provide additional insights and understanding of underlying

cognitive processes and the effects of computerization upon them. For example, in a recent study examining the relationship between medical error and system usability by Kushniruk and colleagues (2004), video recordings of computer screens were collected in conjunction with audio data consisting of users' verbalizations as they interacted with the system under study. In this study, audio data indicated users believed they had entered the correct prescription when using an electronic prescribing program, while the corresponding video data and computer screen recordings revealed usability issues led users to unknowingly enter incorrect prescriptions. A more detailed description of the approaches, techniques and equipment for conducting such studies in a cost-effective manner is outlined in Kushniruk and Patel (2004).

### Step 6: Data Analysis

The data collected in step 5 (i.e., audio, video and computer screen recordings of users' interactions with a system) can be analyzed to identify: (a) usability problems, (b) medical errors and (c) the relationship between usability problems and medical errors. This typically involves having the audio portion of the data first transcribed in its entirety and then applying coding schemes to facilitate identification of aspects of the user's interaction with the system that are of interest to the investigators. We have employed a number of coding schemes for identifying usability problems, including application of categories for identifying user interface problems (data entry problems, display problems, navigational problems) and problems with the content of a system (information being out of date, defaults

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for medication dosage presented by the system being inappropriate). In addition, the actual occurrence of medical errors made by a health care professional (i.e., entering an incorrect medication) are also identified from analysis of the video and audio recordings of a user's interaction with the system under study.

An example of a coded transcript illustrating the relationship between usability problems and technology-induced medical error is given in Table 1. In the example, a physician user enters a medication into a medication order entry system. In Table 1 the audio portion of the subject's "thinking aloud" is given in the left-hand column. The corresponding human-computer interactions are recorded using video and are given in the second column. In this example, the user enters a medication (Tylenol), its dosage (two tablets) and frequency (q6h). The system responds with a menu that has defaulted to an inappropriate frequency. However, the user's final action is to submit the order and consequently the wrong frequency is entered into the system. This is indicated in the third column as a usability problem

("default frequency is inappropriate") and as a medical error shown in the fourth column ("wrong frequency recorded in system"). This approach can be used to identify the relationship between specific usability problems and medical errors.

Qualitative data (coded verbal transcripts and coded observations from video data or recorded computer screen information) can be converted into quantitative data by (Barbour 1998; Sandelowski 2000) tabulating the frequencies for each coded category (usability problems and medical error) in the transcribed data, and then inferential statistics can then be applied (Patel et al. 2000). For example, the

**Table 1. An example of a coded segment illustrating a medical error related to a usability problem (i.e., an inappropriate default).**

Audio	Video	Usability Problem	Medical Error
<p>"I am entering an order for Tylenol number three q6h prn [i.e., every six hours as needed].</p> <p>Okay, it looks fine and I'll enter the prescription now."</p>	<p><b>User Action:</b> Clicks on Tylenol number three from drug drop-down menu list.</p> <p><b>User Action:</b> Clicks on two tablets from the dose drop-down list.</p> <p><b>User Action:</b> Clicks on q6h from the frequency drop-down list.</p> <p><b>System Response:</b> Default of q4h reappears for frequency.</p> <p><b>User Action:</b> Clicks OK for ordering prescription.</p>	<p>Default frequency is inappropriate</p> <p>After input of q6h (i.e., frequency every 6 hours), the default of q4h reappears (i.e., frequency of every 4 hours). However, the user does not notice the system's response (with the inappropriate frequency).</p>	<p>Wrong frequency recorded in system.</p>

number of medication errors that occur when physicians use a medication order entry system during simulation testing can be quantified. Each category of usability problems identified in the users' interactions with the system (using the coding scheme) can also be quantified (problems related to specific issues such as appearance of inappropriate dosage defaults on a menu, navigational problems with the user interface, etc.) and related to the occurrence of actual medication errors (see Kushniruk et al. 2005).

### EXAMPLE: USE OF SIMULATION IN THE STUDY OF TECHNOLOGY-INDUCED ERROR

In our current work, we have found that simulation methods provide a powerful approach for the analysis of errors resulting from user interactions with healthcare information systems. For example, in a recent study we conducted involving a physician order entry system, a simulation was used where physicians' interaction with a prescribing program were video and audio recorded and then transcribed (Kushniruk et al. 2005). Specifically physicians were asked to "think aloud" as they entered prescriptions from written text into a handheld prescribing program. They were also given scenarios (in the form of short written cases) to respond to and enter prescriptions for. The transcriptions from these sessions were coded to identify usability problems using a theoretically based coding scheme (identification of navigational problems, display visibility problems, etc.) as well as being coded to identify actual medication errors (incorrect dosages entered into the system). The statistical correlation between the occurrence of coded usability problems and medication errors was calculated in order to determine the predictive power of the usability coding in identify potential occurrences of medication error. From this study, it was found that 100% of the actual errors in medication entry made by physician users during the simulation could be predicted by the occurrence of independently coded usability problems.

We are currently following up with naturalistic study to determine if the error rates observed in the laboratory are the same or different in the naturalistic (clinical) setting. One approach we are using here is application of a remote tracking system we have developed known as the "Virtual Usability Laboratory" (VUL), which allows for tracking of computer screens as users interact with a system under study (described in detail in Kushniruk & Ho 2004).

### CONCLUSIONS

In this paper, we have described our work in the development, refinement and application of a new approach to the assessment of technology-induced errors based on the study of human interaction with a health information system under simulated conditions. The approach builds on previous work in the area

of usability engineering (Kushniruk et al. 1996) and leads to a rich collection of qualitative as well as quantitative data. In addition, the approach can be used throughout the system development life cycle, from analysis of user needs (as a basis for system design) to assessment of the impact of health information systems upon technology-induced error. Results from such study can guide and provide focus for the improvement of health information systems before they are deployed in real world clinical settings.

There is a need to develop and employ new research methods that identify sources of technology-induced error before a system is deployed in an organization. Usability-based methods (involving simulations) allow one to determine the specific origin of errors while providing systems designers with feedback about how best to redesign a system to prevent technology-induced errors. Work on health information systems quality is needed to prevent errors before they occur; however, previous studies (Koppel and colleagues 2005) have focused on technology-induced error identified after the system under study has already been deployed in real work settings. There is a need to evaluate systems before they are used in real clinical situations and to develop best practices based on ongoing health information systems research throughout systems development to inform system designers and develop design standards that reduce the likelihood of technology-induced error, as has been done in other industries such as aviation. After all, what passenger or commercial pilot would fly in a plane that hasn't been properly tested for the presence of technology-induced errors?

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