

DOES THE SHOE FIT? APPLYING LESSONS LEARNED IN AVIATION TO HEALTHCARE

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Aviation's successful use of Decision Support Systems (DSS) has not been replicated in the healthcare subset of DSS referenced as Clinical Decision Support (CDS). Here the domains of healthcare and aviation are compared and contrasted providing an overview of the adaptation of lessons learned in aviation to healthcare. We propose there are differences in characteristics inherent to the contexts of aviation and healthcare that affect the data necessary for efficient, effective CDS systems. Specifically, ten context characteristics are discussed that jointly and separately affect the availability, quantity, quality and temporal relevance of the data. By providing remedies for overcoming deficiencies and supporting accurate representation of the data perhaps then CDS systems will meet their potential for improved adoption, user satisfaction and patient outcomes.

INTRODUCTION

Although challenges still exist, Decision Support Systems (DSS) developed for aviation over the last 50+ years are generally agreed to have been successful in reducing errors and workload, and improving efficiency. Aviation's successful use of DSS – defined by adoption, user satisfaction, and outcomes – has not been replicated in the healthcare subset of DSS referenced as Clinical Decision Support (CDS). Unmet expectations for CDS have been noted over several years; resulting in the assessment that “systems that are in use in multiple locations, that have satisfied users, and that effectively and efficiently contribute to the quality and safety of care are few and far between” (Wears & Berg, 2005).

Many proponents of CDS look to aviation as a comparison and guide for increased safety and effective patient care (Pronovost, et al., 2009; Wilf-Miron, Lewenhoff, Benyamini, & Aviram, 2003). Both aviation and healthcare domains have a long history of considering electronic aids to decision making. DSS in aviation began in the early 1950s with the U.S. military. Healthcare's CDSS were first described in 1959 and dozens of systems were under development in the 1960s (Dick, Steen, & Detmer, 1997). With over 50 years of decision support experience in both domains, why have CDS systems not kept pace with aviation DSS? Many technical and social factors have been cited to explain the perceived advanced state of DSS in aviation over healthcare (Delaney, Fitzmaurice, Riaz, & Hobbs, 1999; Pronovost, et al., 2009). However, aside from regulatory mandates, training, technical and social issues, we propose there are differences in characteristics inherent to the contexts of aviation and healthcare that affect the data and cognition.

Consideration of these characteristics when designing and implementing CDS may improve CDS adoption, user satisfaction and patient outcomes. This paper presents the results of a literature review where the intent was to identify differences in context characteristics that affect the adaptation of lessons learned in aviation to improve CDS in healthcare. The domains of healthcare and aviation were compared and contrasted by examining three areas of research where calls have been made to apply lessons learned in aviation to healthcare CDS – the use of checklists, Crew Resource Management (CRM) training, and Situation Awareness (SA)

measurement. This paper provides an overview of the adaptation of lessons learned in aviation to healthcare; then presents the ten context characteristics that emerged within two categories – characteristics of the environment and characteristics of the “patient” (aircraft or human). The description of the ten context characteristics is followed by a discussion of the effects of the context characteristics on the data and interventions available; and concludes with recommendations for CDS systems.

REVIEW OF CHECKLIST USE, CRM AND SA APPLICATION TO HEALTHCARE

Extending Lessons Learned in Aviation DSS to Healthcare CDS

Proponents of using aviation as a guide to improving health care typically cite one of three areas where lessons learned in aviation can be applied to healthcare: 1) The use of checklists, 2) Crew Resource Management (CRM), and 3) Situation Awareness (SA). These three areas are quite dissimilar in practice, but share the common goal of supporting or improving cognitive processes.

Checklist Use in Aviation and Healthcare. An early study in aviation recognized that limits in the capability of humans to acquire and process information can consistently cause pilot errors with the potential for “fatal” consequences (Drinkwater, 1967). Checklists were developed in aviation to reduce errors in normal situations including, preflight, starting and landing; and non-normal situations – including emergencies. While paper checklists have been used successfully, electronic checklists developed for aviation have shown clear benefits over paper versions (Boorman, 2001).

McDonald (1976) reported on an early adaptation of checklists as a diagnostic aid for use in healthcare. Citing Drinkwater's (1967) study as having “obvious implications for the performance of physicians under the peak informational loads of busy practice settings” McDonald drew an analogy between pilots “keeping watch for random and infrequent events” and a physician's “watch for pathologic events.” McDonald studied protocols to generate recommendations; computer support using checklists and protocols was deemed a success as measured by physician's detecting and responding

to twice as many events when they were given the computer recommendations.

In spite of the early foray into the use of checklists to support diagnosis and treatment, some researchers believe that diagnostic checklists are “neither clinically helpful or widely used” (Schiff & Bates, 2010). An example of checklist use failure to provide meaningful benefit is the American Psychiatric Association’s Diagnostic and Statistical Manual of Mental Disorders (DSM) IV use of laundry list type checklists. Diagnosis of some conditions is attempted with a laundry list type checklist where criteria is rated as present or absent. These checklists and ratings have been found to be inadequate; and new assessments have been defined for DSM-V (scheduled for release in 2013); the rationale for these changes is that, “personality pathology is a matter of degree” and “behavior can be intermittent and changeable over time” which can make accurate diagnosis difficult (American Psychiatric Association, 2011). Checklists are not effective when the data are unavailable, ambiguous and/or uncertain.

Crew Resource Management (CRM). CRM training is another aviation research area with calls for applying lessons learned to healthcare settings. CRM originated from a 1979 NASA workshop that identified the primary cause of aviation accidents as human error due to failures of interpersonal communication, leadership, and decision making (Helmreich, Merritt, & Wilhelm, 1999). CRM programs were soon developed by airlines to train cockpit crews in communication skills and strategies to manage error by recognizing limitations of human performance – especially under stress due to fatigue, workload and/or emergencies.

While CRM studies are not specifically linked to DSS and CDS systems, the comparisons of CRM training studies reveal parallels and differences in the environments of both aviation and healthcare that are relevant to DSS. The transfer of CRM’s teamwork, communication and reporting principles have reportedly been successful in emergency departments, operating rooms (including anesthesiology), and intensive care units (ICU) (Leonard, Graham, & Bonacum, 2004; Morey, et al., 2002; Woolever, 2005). These healthcare environments parallel the close spatial proximity of aircraft cockpits.

Situation Awareness (SA). SA is a component of CRM that is frequently referenced as a separate field of research; including when calling for adaptations of lessons learned in aviation to healthcare. The most common definition of SA is the one given by Endsley (1988) as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future.” Poor SA accounts for a large percentage of aviation errors attributed to human error (Endsley, 2001).

Although there are multiple calls for improving SA in healthcare (Singh, Peterson, & Thomas, 2006; Wright, Taekman, & Endsley, 2004), few studies have actually measured SA in healthcare (Hogan, Pace, Hapgood, & Boone, 2006) Some calls for the measuring of SA to improve healthcare acknowledge there may be limitations based on differences in the domains. These limitations include the lack of continuous patient monitoring and communication between team members in ambulatory settings; in addition, while

aviation has “gold standards” for responses to circumstances, because of uncertainties a correct diagnoses in a clinical situation may be reached by multiple routes, making simulations and measurement difficult (Singh, et al., 2006). The availability, quantity and quality of data due to measuring, monitoring and communication issues, as well as certainty of intervention outcomes, impacts SA at the perception, comprehension and projection levels.

CONTEXT CHARACTERISTICS

Ten context characteristics that affect the cognitive support required for a successful DSS can be extrapolated from examining the domains of aviation and healthcare. These context characteristics can be classified into two inter-related categories: Environmental characteristics and patient characteristics.

Environment Characteristics

On the surface there are many similarities between aviation and healthcare environments. However, a closer look reveals that environment characteristics create differences in the availability, quantity and quality of data. The following five environment characteristics reflect the similarities and differences that can affect the application of lessons learned in aviation to healthcare: 1) Setting variability; 2) spatial proximity; 3) stress, fatigue and time pressure; 4) multiple conditions and measurements; and 5) transitions of care.

Setting Variability. Aviation and healthcare both have diverse settings where the “patient” can be monitored and interventions performed. Healthcare settings vary widely with roles that are not exclusive to a single setting. For example, the role of physician or nurse can be associated with tasks in multiple settings: surgery, ICU, emergency department, care center, clinic, etc. Like healthcare, the aviation domain also has diverse settings (airport, air, maintenance buildings); however, while the aircraft can be monitored everywhere at any time, the roles appear to be tightly linked to the settings (e.g., a cockpit crew’s setting is generally restricted to the cockpit).

Spatial Proximity. Crew Resource Management (CRM) studies reveal how the context characteristic of spatial proximity supports tracking the actions and responses of other team members and provides immediate feedback and acknowledgement. A spatial division can affect communication accuracy, sufficiency and timeliness. Studies reporting successful application of CRM principles to healthcare are typically settings where events can be monitored with close temporal and geographic boundaries (i.e., emergency departments, operating rooms, intensive care units). In contrast to team environments, a visit to an individual practitioner’s office is generally not closely monitored and errors in decisions or lapses in communication may not be visible or even recognized and/or reported. Differences in location necessitate oral or written communication which may be delayed or misinterpreted with little to no feedback or acknowledgement.

Stress, Fatigue and Time Pressure. Checklist, CRM and SA researchers all acknowledge the need to overcome/ or compensate for the complex, highly intense environments inherent to both the aviation and healthcare domains. Physical and environmental stressors (e.g., sleep deprivation, noise, or temperature) or psychological stressors (e.g., perception of threat/danger or lack of control) can increase human errors (Orasanu & Backer, 1996).

In both domains, error conditions may result in the need to respond immediately without sufficient time to consider all options. Within healthcare, the sources of time pressures may differ: In a trauma or emergency situation patient conditions may change quickly with the need to assess and respond immediately; while in an ambulatory settings high patient loads often result in significant time constraints on the provider's ability to consider a single patient.

Multiple Conditions and Measurements. Both aviation and healthcare domains are complex environments where multiple conditions exist simultaneously. Multiple measurements must be interpreted and integrated for assessment and action.

Transitions of Care. Both aircraft and humans experience transitions of care between providers; however, there are differences in variability and communication for continuity of care. In-flight air traffic control (ATC) transfers of an aircraft are predictable: Handoffs between ATC centers occur with no expectation of variance from predetermined settings. In contrast, during the course of treatment, a human patient may be transferred from one setting to another (e.g., on admission, between hospital units, discharge to home or care facility etc.) where communication is not always predictable or automatic. In addition to transfers between settings, multiple providers (e.g., primary care, specialists, and nurses) collect, analyze and communicate information regarding the care of the patient. Effective and efficient communication of information or access to information cannot always be assumed in healthcare.

“Patient” Characteristics

Comparisons of aviation to healthcare show a surface similarity when considering environmental characteristics. However, significant differences become apparent when maintaining and/or remedying the health of an aircraft versus the health of a human “patient.” Here we discuss 5 context characteristics that have significant impact on design and implementation when applying lessons learned in aviation to healthcare decision support systems: 1) Autonomy and compliance; 2) identity and history; 3) structure transparency and adaptability; 4) predictability; and, 5) temporality of conditions.

Autonomy and Compliance. Aircraft and humans obviously differ in their ability to choose and be self-directing. As an engineered system, an aircraft cannot decide whether or not to allow in-flight control or accept preventive maintenance or repairs; however, a human patient often has the right to refuse treatment or may not fully comply with treatment instructions. Patients may not comply because of concerns about the treatment costs and time commitment, and/or the

patient may not understand the actions required or the implications of non-compliance. Personal goals, values and preference also affect patients' acceptance of treatment (Brennan & Strombom, 1998).

Identity and History. The task of identifying and/or obtaining a history can differ significantly between aircrafts and humans. Typically, identifying an aircraft is a simple procedure; commercial and military aircraft records can often be electronically shared between locations and contain unique identifiers for the aircraft and its components; flight logs are maintained and maintenance records show services performed and when maintenance is due (Zhang, Zhao, Tan, Yu, & Hua, 2011).

Although providing healthcare also requires identifying the patient and obtaining the patient history – including previous interventions, conditions or observations – the process may be complicated by multiple factors: a) Ambiguous or uncertain identity due to lack of identification or intentional deception (a person may “borrow” a friend or relative's insurance card to receive benefits); b) access to patient records is slow and/or difficult because the records are paper-based or in incompatible systems; c) in some cases records simply do not exist; d) the historical information patients themselves give to providers is often unreliable and/or incomplete (Clay, Halasyamani, Stucky, Greenwald, & Williams, 2008).

Structure Transparency, and Adaptability. Consistent with their natures as engineered and natural systems, aircrafts and humans inherently and obviously differ in their transparency or ability to see and comprehend internal structures and processes (Durso & Drews, 2010). While engineered aircrafts conform to design and function within designed tolerances with predictable resistance to stressors, human are highly variable and adaptable. In addition, the hazards and conditions in an aviation environment are generally visible with predictable outcomes. Humans vary in psychological and physiological structure. Environmental hazards/threats may not be visible (e.g., stressors, genetic dispositions, and exposure/resistance to diseases/pathogens).

Predictability. The third level of SA – prediction – is often more difficult to obtain in healthcare than aviation. Prediction is problematic in two ways: first, it may be difficult to determine an accurate diagnosis and thus predict the outcome without intervention; second, even with an accurate diagnosis it is often difficult to predict the outcome of available interventions and therefore determine the most appropriate intervention.

Predictability is complicated by the *likelihood* of an event or condition; the probability distribution can be a binomial or a multinomial distribution with deterministic or probabilistic outcomes. In aviation, under normal operating conditions, actions and consequences are predictable and deterministic. Conversely, in healthcare diagnoses are often more probabilistic than deterministic.

Temporality of Condition. Events/conditions occur over time. In aviation conditions develop over time; however, mechanical issues will generally not resolve over time without intervention. In contrast, patient conditions develop over time and may resolve over time without intervention. There are also

differences in the temporal nature of feedback from an intervention. When controlling an aircraft or performing maintenance the result of the intervention is almost instantaneous; the aircraft responds or the replaced part immediately fixes the issue. In healthcare, the feedback from an intervention may be immediate or delayed by hours, weeks or months and varies from patient to patient.

DISCUSSION

Clinical Decision Support (CDS) requires appropriate quantity and quality of data in order to be useful (McDonald & Abhyankar, 2011). The context characteristics presented above jointly and separately affect the availability, quantity, quality and temporal relevance of the data. Consideration of the context characteristics and their effect on data aid in understanding the quality of the data and lead to several recommendations for adapting lessons learned in aviation to Clinical Decision Support Systems (CDSS).

Quality of Data and Interventions

The quality of data can be assessed by its accuracy, certainty and level of ambiguity. In aviation, the direct measurement and real-time communication of data increases availability while reducing the uncertainty and ambiguity of the data. The same quality and quantity of data are not generally available in healthcare. Ambiguity and uncertainty can stem from multiple characteristics of the healthcare data: a) Latent measures – as opposed to the many *direct* measurements in aviation, in healthcare assessments of internal system components are *inferred* from single point measurements such as vital signs and lab results; b) inconsistent measurements may stem from conditions that are intermittent and/or changeable over time, or failure to consistently obtain measurements; c) subjective data – conditions are often a matter of degree – measuring mere presence or absence is often insufficient; however, ratings on a scale are also problematic since they can be subjective in terms of reporting and interpretation; d) reliability – the source of the data may be deemed unreliable.

Accurate data transformed into information combined with knowledge enables prediction of an outcome and the formulation of an intervention plan. The number of options and availability for action along with the existence of standards of “best practice” differ between aviation and healthcare.

Standard practices, including those supported by checklists, reduce the ambiguity and uncertainty associated with routine and emergency intervention options in aviation. Conversely, even though standards and best practices exist in healthcare, the nature of healthcare data leads to uncertainty and ambiguity when determining the best *intervention*; even the definition of *evidence-based medicine* “makes allowances for *missing, incomplete, or low-quality evidence* and requires the application of clinical judgment [*italics added*]” (Sim, et al., 2001).

Recommendations

Clearly there are differences in context characteristics that affect adaptation of lessons learned to support CDS. CDS systems must recognize that efficient and effective cognition requires access to data and information that accurately reflects the quality of the data in a timely and secure manner. In the spirit of the Five Rights of Medication Administration, we propose the following Five Rights of CDS Data: Right data, right amount, right form, right time, and right users.

Right Data. A CDS requires accurate patient identification, historical data and intervention options. A CDSS must support the use of data and information whatever the source (human interface or electronic monitor). Missing data should be made salient with appropriate remediation recommendations. The CDSS should directly and indirectly monitor for errors. In addition, when transferring care, a CDSS should support active communication of data (push to other providers) and availability of information to support communication between all parties (e.g., name and contact information for the patient representative and the entire care team). A CDSS must also promote the most up-to-date best practice guidelines and protocols.

Right Amount. A CDSS should anticipate that some conditions allow for thoughtful, thorough investigation of data and consideration of options, while other conditions require immediate access to only the most relevant and time-critical data, diagnosis and intervention options. At all times the system should reduce information overload by anticipating the workflow to minimize irrelevant stimuli and make salient the most relevant information.

A CDSS must be able to track data for a single condition over long periods of time. Timeline displays should be adjustable to the temporal nature of the data – short or long term.

Right Form. Given the potential for missing, uncertain and ambiguous data, a CDSS must carefully represent the quality of the data. Aspects of the data such as the source (patient, clinician, labs, electronic monitor, etc.), variability, frequency and time should be stored with the data. Any variance, uncertainty and/or ambiguity of the data should be salient in the presentation (e.g., use of colors and/or textures to denote uncertainty, or the use of confidence intervals or depiction of normal ranges to reflect variance). The probabilistic nature of diagnoses and interventions should be reflected when suggesting diagnoses and representing simulations

Right Time. There are multiple facets of time relevant to CDS: 1) A CDSS should provide access to all relevant data from any appropriate location at any time. 2) Time to access data and the processing speed of the CDS system are critical. 3) In addition, the system should automate creation of common data displays and provide reuse of configurations for time savings for the user.

Right Users. There are multiple issues with users of CDS systems. Data security and user authentication is of vital importance. In addition to insuring appropriate access to the data, a CDSS should *support communication between team members in the appropriate context* of relevant data, diagnosis

and/or intervention and action required. Relevant information should be presented to the right people at the right time in the context of the communication – eliminate the recipients' need to search for referenced information. Synchronous and asynchronous sharing of the action required/requested and the rationale and supporting data may promote the ability to detect and report irregularities in data, diagnoses and prescribed interventions (Wilf-Miron, et al., 2003).

If these five rights cannot be met then the system must support efforts to correct the data or accurately represent the quality of the data and the compromised status of any guidelines, protocols or predictions of outcome.

Conclusions

Aviation's enviable safety record provides good reasons to apply lessons learned to healthcare. The similarities and parallels of the environment context characteristics naturally lead to comparisons; however, the design, implementation and use of clinical decision support must acknowledge that differences in both environmental and "patient" context characteristics create variances in the availability, quantity and quality of the data. By providing remedies for overcoming deficiencies and supporting accurate representation of the data perhaps then CDS systems will meet their potential for improved adoption, user satisfaction and patient outcomes.

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