Development of a Hand-held Real-time Decision Support Aid for Critical Care Nursing

P. Fortier*, S. Jagannathan*, H. Michel*, N. Dluhy*, E. Oneill*

University of Massachusetts Dartmouth
285 Old Westport Road, N. Dartmouth, Ma. 02747-2300

*Electrical and Computer Engineering Department
*Nursing Department

Email: {pfortier, sjagannathan, hmichel, eoneill, ndluhy}@umassd.edu

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Abstract

In the current health care environment, nurse clinicians must work “faster and smarter” making complex decisions on almost a continual basis. Evidence-based knowledge and standardized guides, such as clinical algorithms, can support clinical nursing decisions, however; effective real-time access is limited. This paper outlines research addressing this problem. In this research, current clinical knowledge is delivered to the clinician via an off-the-shelf handheld computer using wireless access to a central server and data repository. Innovative minimal-set database, data mining and knowledge discovery algorithms using a combination of case based and rule based learning with added confidence measures permitting bi-directional (forward and backwards) inferencing based on individual client data are developed and presented for the hand held device. The technology provides real-time decision support for the multiple cases and sequential decisions characterizing present critical care nursing practice. Nurses will be able to consider a full range of alternative explanations, determine additional data needs, find, isolate and examine patient case outliers for additional diagnostic data or verify the appropriateness of a selected strategy. Once fully developed the system will have the capacity to maintain a history of a series of decisions and outcomes thereby over time improving the case base and rule bases used for decision support. Outcomes of the real time decision support aid include more timely health care, less biased decisions, and improved patient outcomes.

1 Introduction

Computerized decision support systems within health care have been considered since the mid-1950’s however, development in nursing has been limited by a number of factors. Sinclair [71] cited a lack of understanding of nurses’ decision making as well as the fundamental characteristics of nursing knowledge. Schutzman [68] examined hospital environments and concluded that nursing units require complex, portable systems with rapid, seamless connectivity. In addition, the original expert systems were often seen as a challenge rather than a support to professional decision-making. The following provides a review of nurse decision making, the evolution of decision support systems (in particular expert systems) and the changing technologies for knowledge management in acute care environments. Building on this foundation, this research effort envisions an augmented off-the-shelf handheld computer, and expert system capable of real time point of care clinical decisions. These are not final, single point decisions, but sequential decisions, typically made by a series of different nurse clinicians.

Clinical decision making

Clinical decision making is a complex task requiring a knowledgeable practitioner, reliable informational inputs, and a supportive environment. It involves the identification and management of patients’ health needs. Most research in decision making is grounded in either decision analytic theory or information processing models. Analytic models stress achieving optimal decisions systematically and rationally [44]. Optimal decisions are reached by pre-specification of decision alternatives, determining the probability of the alternative occurring, and the utility of the alternatives to the decider.

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While pattern recognition has become an accepted feature of expert reasoning, less is known about novice decision making as patterns in memory are less precise and less complete. Researchers [16,60] found that nurses' intuitive decisions agreed with the decision analytic model 35% of the time. They also argued that the moderate rate of agreement highlights the potential usefulness of decision analysis in practice. Undergraduate and graduate nursing students have reported improvement in decision-making ability after learning decision analysis [53,69].

The second major model, information processing theory (IPT) describes the cognitive behavior of the decision-maker. A major assumption of the theory is that there are limits to human's ability to think rationally. Research findings indicate that humans adapt to these limitations by collecting data selectively, processing data serially, and dissecting problems to simplify them [48]. Clinical researchers using IPT models have theorized that clinical decision making occurs by a hypothetico-deductive method characterized by (a) cue recognition, (b) hypothesis generation, (c) cue interpretation, and (d) hypothesis evaluation [19,76,77]. Early studies concluded that decision making is case specific, with education and experience determining competence.

Nurse researchers offered an alternative explanation to case specificity -- pattern recognition. In pattern recognition, the clinician compares the signs and symptoms of the patient problem with clinical patterns in memory and selects the best match [4,7]. Pattern recognition depends on large stores of well-organized knowledge [22,35]. Effective organization depends on extensive practice in a specific domain or sub-specialty [8,78].

Pattern recognition is now recognized as a central feature of expert performance. Nurse researchers using inductive approaches have described expert performance as the “intuitive grasp of the situation” [6,10,62]. Defining intuition as “understanding without a rationale”, [6] have identified pattern recognition and similarity recognition as essential aspects of intuitive judgment. Intuitive activities include recognizing important aspects of the situation, rapidly identifying similarities, and interpreting the situation based on previous knowledge [7,13]. Several disciplines agree that expertise has three essential components: a sizable body of knowledge, an effective indexing system holding a large number of patterns, and recognition mechanisms to match the current situation to patterns on memory [22,27].

Acute care units feature high activity, excessive input, uncertainty, interruptions, and competing responsibilities -- often described as chaotic environments [39,71]. On these units, nurse clinicians strive to provide humanistic, clinically sound, and timely nursing care to their clients. At the system level this translates to evidenced-based practice, error reduction and patient-centered care. Computerized decision support systems provide a viable means to enhance best practice and reduce decisional errors [28,33,46].

Benbenishy et.al. [9] argued that “fallibility, therefore, is an inseparable feature of clinical judgment under uncertainty” (p.195). One means to minimize the degree of uncertainty is to move research findings and expert consensus guidelines into the mainstream of practice. Three issues arise. First, traditional methods (e.g., research publications, continuing education) evidence significant time delays in moving knowledge into practice [24]. Second, methods to encourage evidenced-based practice have been limited in assisting

Organizational goals: enhanced clinical decisions, evidenced-based nursing and error containment
nurses to apply generalizable knowledge to individualized patient problems. Third, nurses tend to resist standardized guidance for clinical decision [55].

The “guideline movement” [80], emerging in recent years, highlights an effort to stimulate evidence-based practice. The NIH Agency for Health Care Policy Research assumed a pivotal role in the development of scientific evidence report guidelines [43]. The intent is to encourage best practice by reducing variability, controlling costs and improving client outcomes. However, research reveals that the mere existence of paper or even web-based guidelines does not necessarily lead to changes in practice (p. 227). Consensus or expert guidelines tend to be lengthy and complex. While this contributes to their overall value, busy clinicians are frustrated if unable to quickly access the section relevant to the presenting client [80].

At the organizational level, there is growing awareness of the knowledge overload facing the clinician. The notion of knowing everything is being replaced by the idea of knowing where to quickly access needed knowledge [28]. Focus has shifted therefore to managing knowledge within healthcare environments by focusing on the structures and algorithms necessary to “acquire, conserve, organize, retrieve, display and distribute what is known” ([11], p. 6). In addition, leaders need to find mechanisms to encourage clinicians to be conscious decision-makers. That requires the ability to structure and clarify clinical decision problems and develop a more critical attitude of examining the possibility that initial decisions might be incorrect [49].

Nurius, ([49], p. 13) described a growing recognition of the demands on the health care clinician. She concludes, "An important determinant of sound reasoning is the ability to recognize the signs of high-risk or problematic scenarios -- both an a priori understanding of what these include and the capacity to step out of routine processing enough to notice and to interpret accurately these warning signs" (p. 13). In addition it is recognized that no clinician can remain continuously vigilant, or reflective while reasoning-in-context (p. 15).

One solution to enhancing evidenced-based practice, error reduction and effective knowledge management in context resides in computer technology. A 1998 survey of the Health Information and Management Systems Society (HIMSS), demonstrates increased organizational interest in point-of-care systems, with 30% indicating spending plans for emerging technologies, particularly wireless [68]. In examining the environment, the author further notes, “lightweight handhelds will be most useful for extremely mobile applications such as trauma, home care, nursing at the bedside, and, for administrative purposes, inventory management” (p. 21). Even sensitive issues of information security are being effectively addressed by wireless manufacturers who have adopted communication security standards, including encryption of send/receive signals [68].

Decision-support systems: types, components, development

Benbenishty et.al. [9] defined a decision support system (DSS) as a “computerized user-interactive system that uses data or models or both to generate information that will support (and not replace) a decision maker” (p. 196). Ideally this occurs at the point of service and in the context of a particular clinical situation [23]. Passive systems (much like a reference) can provide information at clinicians request but these are not patient specific. Active systems “may use rules based upon simple logic or systems based upon probability” [28], p. 23). These provide information and feedback in the context of the presenting client. Active systems may be probability-based using algorithms or fuzzy logic, rule bases drawing on sources of evidence such as clinical guidelines and protocols or built as neural networks, with parallel computations to “train” the computer using case-based data entered into the systems [28,31]. Or they might be designed as a combination of these approaches, optimizing the best features (as developed in this proposal).

An active DSS is a type of expert system, a subcategory of the larger area of artificial intelligence. These systems are comprised of three components: knowledge domain, inference engine, and user interface. Early work in the area of expert systems suggested that decisions via computer would be somewhat superior to expert clinical judgment. Recent efforts have moved from attempting to model expert knowledge to managing, organizing, and relating knowledge in ways that provide support without prescribing the decision [79].

Previous Trials: Lessons learned:

Though the majority of DSS developed in health care have been in medicine, valuable lessons can be extrapolated from these trials. Ozbolt et.al. [56] and Henry [33] provide excellent reviews and descriptions of decision support systems developed to date in nursing. These efforts have primarily been in the area of establishing a nursing diagnosis [31] nursing education [56] or requiring direct internet or server access (Henry, 1995).

Knowledge domain. Reported DSS research tends to highlight the technical development with minimal focus on the content. Ruyle [67] emphasized the critical element of drawing useable knowledge from content experts while Brailer [11] explored the way knowledge is acquired, transformed and applied within modern health care systems. Cullen [15] stressing the importance of the explication of the knowledge content in the development
of a DSS, argued that real computational power does not derive from the design of the algorithm but from a careful choice of attributes based on knowledge of the domain.

In nursing, discussions of computerized DSS draw out concerns about the readiness and standardization of nursing knowledge [33]. In describing evidence-based practice in nursing, Lang [39] contended that it is really a combination of participating in evidenced-based medicine and determining interventions for patient problems that are uniquely nursing, such as pain, incontinence and confusion. She further asserted that there is ample evidence that nursing has amassed an adequate array of research and intervention studies to begin constructing evidence-based practice. Areas of symptom management such as pain, delirium, incontinence and skin breakdown are particularly well developed and present with high frequency in practice (p. 541). O’Neill et.al. [55] support this position noting trends to make scientific nursing knowledge more visible while still preserving the experiential wisdom embedded in practice. Examples of these knowledge sources include the Online Journal of Knowledge Synthesis for Nursing with reference links to Medline as well as AHCPR guidelines www.guideline.gov and best practices network www.best4health.org.

The sheer volume of nursing knowledge is both an asset and detriment to DSS development. Brailer [11] argued that unless efforts to hasten translation of this massive database into practice can be found, it will be of limited use to clinical performance. Approaches to map and synthesize large volumes of knowledge are emerging in the literature [17,43]. Computers provide a new option for tracking and identifying connections while mapping knowledge.

The development and acceptance of standardized nursing taxonomies for nursing diagnoses (NANDA), interventions (NIC), and outcomes (NOC, Omaha) provide accepted language structures. In fact, Nursing Information and Data Set Evaluation Center (NIDSEC) of the American Nurses Association has developed language standards for nursing, particularly in the area of documentation [3].

Finally, knowledge is never static, health care knowledge in particular. A means to integrate new practice and research knowledge is required. Additionally, knowledge exists at varying levels ranging from novice to expert. Benbenishty et.al. [9] described DSS development that attempts to differentiate these levels.

Inference (knowledge) engine.

The challenge from nursing practice influencing the development of the inference software is to provide access to knowledge that is “flexible, patient specific and easy to use” [11]. Hajioff [28] summarized optimal design principles for CDSS systems as acceptability, currency, validity, relevance, transparency, accessibility and blendability. Examples in nursing have primarily focused on arriving at a single decision point – a nursing diagnosis[31]. As described previously, the design decisions attempt to match inference strategies with the type of knowledge base and intended purpose of the expert system. Modified versions of rule-based, case-based, neural networks and fuzzy logic approaches are appearing in the literature[31,64]. Details of the software decisions are described in the method segment.

Knowledge domain: Configuring Nursing Knowledge for a DSS

Currently, there is no standardized method to compile and engineer nursing knowledge to conform to an expert decision support system (DSS). Suggested methods to date include determining expert protocols (directly or with computer assistance), building from a theoretical perspective [56], or relying on standardized nursing language and taxonomies [33]. None of these provide sufficient information to engineer a knowledge base for a decision support system that is useful to practicing nurses. The following method extends a knowledge mapping method [17] and blends this with assumptions underlying structured knowledge representation methods [55] as well as clinical reasoning strategies in nursing [52,53]. The proposed method seeks to uncover state-of-the-art formal and practice knowledge and determine the degree of confidence in that knowledge. The development of the knowledge domain for this expert system depends on understanding the way nurses access knowledge bits for decisions as well as uncovering language variations and linkages within nursing knowledge.

The method applied to this project involves the individual development and testing of each system
component as well as integration activities. A summary of the development and testing follows.

1. Recruit two small groups of future DSS users to serve as focus group/testers.
2. Set up secure web-site for 24/7 asynchronous discussions with selected group of staff nurses throughout development phase.
3. Limit the knowledge domain for initial research by selecting a discreet, contained clinical problem for an acute care population. Alterations in respiratory status has been selected based on:
   - adequate scientific knowledge base developed,
   - there are unique patient population characteristics yet generalizable components to nearly every other acute care population,
   - it easily permits forward and backward inferencing,
   - preliminary data indicates acute care nurses encounter this problem on regular basis and find the decisions difficult.

4. Synthesize formal content into a tentative expert knowledge map using a previously developed strategy for knowledge compilation and synthesis [17]. (Figure 1)
   The nursing researchers and graduate students are collecting and mapping formal knowledge of respiratory status issues across all four areas outlined. The position in each of the four quadrants will suggest degree of scientific confidence. Specific features of each source of knowledge are tracked to begin to link across the four quadrants. A decision support system will need to accommodate this variety of possible connections to effectively assist nurses in reaching a clinical decision. After an initial map is developed revealing possible if-then rules (facts), estimates of probability weights based on best available data care included. This finalizes the content aspect of the knowledge.

5. TEST & REVISE: Validate Knowledge Domain by Application Expert (USERS)
   GROUP A staff nurses will review the knowledge map developed from formal expert systems designers. Expert users typically have difficulty articulating the factors they consider in decision making. Providing a beginning model to critique is an effective way to elicit their input. Each will then respond verbally to the following:
   A. Can you identify any areas related to respiratory status that do not appear on this map? (test for comprehensiveness)
   B. Are there areas on this map that do not relate to the topic of respiratory status? (test for appropriateness)
   C. Are the connections that have been shown on this map appropriate? (test for logic)
   D. Can you identify any areas that do not seem accurate? (test for validity)
   E. Review the probability estimates. Indicate any that seem too low or too high based on your experience and indicate why. (test of comparison of estimations to practice occurrence)
   F. Do you see any areas on this map that you do not consider useful? (test for utility, relevance)
   G. Identify any words that seem unfamiliar or awkward to you. Can you suggest better choices? (test for practice vs. formal language systems)

6. Revise the domain map based on user input. Working with software team, begin to code the knowledge domain to inference system. Track compromises to aid in interpretation of final proof of concept testing.
7. Construct an efficient method to develop nursing knowledge domain in any area, based on process to date.
8. Recruit a new group of staff nurses (GROUP B) with similar representative characteristics for testing.
9. “Proof of concept” testing using both GROUP A and GROUP B. Evaluate results and incorporate into Phase II design.

**INFEERENCE ENGINE DESIGN:** Modifying inference systems & data-base management for real-time nursing decisions

1. Create domain database architecture and system based on following principles & work to date

There are two main methods used in machine reasoning applicable to this problem -- case based and rule based reasoners. Both methods fall into the category of an expert system, differing only in the means used to compute decision aids. Case based reasoning uses past case data to model related new scenarios. Similar prior cases are retrieved from a case-base and modified to fit the current situation. New derived cases are added to the case base thereby increasing the total base of knowledge. Old cases are updated with knowledge indicating whether the old case succeeded or failed in providing support for the solution of the new case (these tend to be domain specific). Rule based reasoning, unlike case based reasoning, stores all facts concerning a situation. These rules can be sequenced and chained to create new complex rules (facts) concerning the base items, for example when people buy hotdogs and mustard they also buy hotdog buns with some probability. These chains, with conditional rules can be used to implement a structure similar to a decision tree. Rules facilitate ease of storage, indexing and lookup, making them attractive alternatives to cases [66].

Case based reasoning requires sets of complete solutions be composed and stored in the case base. These initial cases can be difficult to initially derive and validate. Rule bases on the other hand can grow as new rules (facts) and relationships between items or rules are discovered, making such a system easier to iteratively grow.

Rules are declarative statements that drive activity in a software system through the description of an action or actions to perform, when a specified set of conditions is met. A rule-based system consists of a rule engine and a set of rules. The rule engine is designed to evaluate and execute rules. The rules are encoded as stand alone atomic units, making them easier to develop, maintain and expand [63].

Our implementation will use a Structured Query Language (SQL) lite database engine (Microsofts SQL CE) as the storage and query engine for rule base management running on an augmented Compaq Ipaq handheld computer. The device (Ipaq) is being augmented to include a micro disk drive (added storage above base unit), wireless capabilities and voice recognition capabilities as plug-ins. Rules will be stored in relation tuples (rows) and will be linked (related) through the use of parent/child hierarchies and indices constructed during the knowledge acquisition, representation and insertion phase of system construction (Figure 2). The individual stored rules are then combined into sub-clusters, clusters and cases of rules using a variety of concepts. We wish to examine how technologies such as clustering of association rules[42], distance based outliers, integration of classification and association rules and formation of cases using association rule grouping can aid in development of nursing domain knowledge.

These concepts are postulated for use in detecting and forming weak and strong collections of association rules. These collections can then be used in the formation of nursing care cases, consisting of those which strongly map to existing cases and those with weak correlation’s where outliers may be used to detect additional case knowledge. These outliers may be composed of single rules or collections of rules indicating how far a specific patient’s symptoms lie outside the norms for the patient’s present diagnosis, and may indicate need for additional care (for the outlier rule or set), or may add to nursing long term knowledge.

2. TEST database engine for rule storage, indexing, rule clustering into cases, chaining rules into scenarios, efficiency of access, retrieval, & processing of cases, rules & rule chains.
3. TEST database and inference engine for scalability: load synthetic information into the system (fisheries database) and determine point of saturation.
4. Simultaneously with testing procedures initiate Knowledge Engineering (KE) with nursing.
6. The database will be developed using this format of rules:

   IF antecedent THEN consequence
   WITH certainty_factor

and stored as original base rules, chained rules, case based rule chains, false rule chains which cannot occur in this domain, and rules based on rate change (e.g. temperature rate change per period of time for rule relationship x). Complete case histories will be maintained as indices connecting related rules into the case. Such an ordering will enhance efficient recall for similar cases in the system.

7. The knowledge utilization process concentrates on answering user queries either directly or indirectly through the return of intermediate facts generated by rule firing and final results of chains of rule firings based on user provided data. An important innovation in this system is the ability to use both forward and backward chaining methods to retrieve knowledge from the system. In essence, this technique allows the user to state results and test if the given facts strengthen or weaken this hypothesis (Agrawal, Agrawal, & Prasad, 1999).

8. Validate & refine database & inference engine. The feedback element, illustrated in Figure 2, is used to further refine and augment the existing rule base using newly acquired facts, relationships, constraints or complete cases.

9. Integrate software with hardware components
   • TEST hardware/software integration
   • Performance TEST for functionality, capacity, & scalability


Summary

The development of an innovative clinical nursing decision aid can prove to be an invaluable tool for the critical care clinician. This ongoing research project hopes to prove the viability and benefits of such a tool. This paper outlined the area of this research and the state of knowledge applied to nursing decisions in practice today. The tool under development will use proven concepts applied to other domains. By the time of the conference, we expect to have data from the prototypes initial testing and deployment.

Literature Cited


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