Integration of a Stand-alone Expert System with a Hospital Information System

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ABSTRACT

A stand-alone PC expert system for evaluating the appropriateness of inpatient admissions has been integrated with an existing hospital information system. The expert system supports preadmission screening for appropriateness of inpatient admissions. The HIS provides extensive clinical data in a coded electronic form, permitting high-level decision support. The integrated system was developed for a 20 week randomized clinical trial to evaluate the effects of preadmission screening on inappropriate inpatient admissions. Three factors of the integration are considered: programmatic integration of the expert system, seamless presentation of mixed platform applications, and integration of coded data from the stand-alone application into the HIS data structure.

INTRODUCTION

A number of researchers have pointed to unnecessary utilization of healthcare resources as a contributing factor to the rising cost of healthcare.[1,2] Simply stated, overutilization results from administering unnecessary tests or procedures. In the inpatient setting, overutilization is the result of unnecessary hospitalization or providing services that can be more efficiently provided in the outpatient setting. Patients not in need of the full services of a tertiary care facility are said to be inappropriately admitted. Rates of inappropriate admissions ranging from 10% to more than 20% have been documented in the literature.[3,4,5]

Management of hospital resources is the role of Utilization Management (UM) personnel. Hospital utilization managers review inpatient cases for appropriateness of admission and necessity of services provided after admission. Utilization review consists of manual review of a patient's chart. Standardized criteria are used to evaluate the appropriateness of treatments, procedures, and services provided.[6] State Peer Review Organizations (PRO) provide guidelines for admission appropriateness that are used both by the PROs and hospitals to evaluate admissions. In many cases the reviews are retrospective (following discharge of the patient) and are primarily for reimbursement justification. However, retrospective review is too late for hospitals to take any corrective action.

One approach to the utilization problem is to screen patients for appropriateness before they enter the healthcare system. Preadmission screening of inpatients permits real-time intervention in the care process that may have positive impact on utilization. Effective screening directs patients to the most cost effective point of healthcare delivery.

At LDS Hospital in Salt Lake City, UT, we implemented a computerized preadmission screening process as part of the existing hospital information system (HIS). The computerized preadmission system was part of a randomized clinical trial designed to assess the impact of screening on the rate of inappropriate inpatient admissions. Briefly, the system identified and tracked inpatient admissions (scheduled and unscheduled) and automated the review process. This paper describes aspects of the implementation of the preadmission screening system which involved the integration of a personal computer expert system and a mainframe HIS.

DESIGN

The preadmission screening system consisted of two separate computer systems: the existing mainframe HIS at LDS Hospital (known as **HELP**) and a personal computer-based expert system program for evaluating admission appropriateness.

HELP

The **HELP** (Health Evaluation through Logical Processing) system is the result of more than 25 years of research and is currently in use at LDS Hospital in Salt Lake City, UT.[7,8] The **HELP** system provides computer access to clinical as well as administrative and financial data. **HELP** runs on 12 networked Tandem (Cupertino, CA) processors and provides over 3 gigabytes of disk storage. Patient data are gathered from laboratory instruments, bedside monitoring equipment, and bedside nurse entry. The types of data collected include: demographic information, vital signs, medications, laboratory results, full-text interpretations of radiological films, and nursing care plans. More than 1000 PC-based terminals are located at the bedside throughout the 520 bed facility,

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as well as at nursing stations and in ancillary departments. The PC terminals provide a sophisticated windowed environment. While the use of PCs as terminals can also support local processing, thus off-loading processing from the mainframe, as well as support specialized applications, these capabilities are not in general use. The preadmission system reported here is one of the first attempts to take advantage of local processing and was implemented on only two PC terminals.

Data in the **HELP** system are coded representations of medical terms and concepts. A data dictionary maps the coded elements to a hierarchical semantic structure called PTXT (for Pointer to TeXT). The **HELP** system is interfaced to a number of stand-alone information systems: laboratory, blood bank, radiology transcription, medical record coding and billing. To support advanced decision support, such as order critiquing,[9] alerting[10] and protocol-driven therapy,[11] clinical data are passed from these external systems and centrally stored in the **HELP** database.

HELP provides a standardized programmatic interface for external systems. The interface is designed to support real-time, two-way exchange of data between **HELP** and large stand-alone departmental information systems, such as a billing system, a laboratory system or a radiology system. As noted above, clinical information is maintained centrally in **HELP** to permit decision support from a single database. In addition to clinical results that must be reported to **HELP**, many stand-alone information systems also allow updates or changes to demographic information that must also be reported to **HELP**. The block diagram in Figure 1 shows the processes connecting external systems to **HELP**.

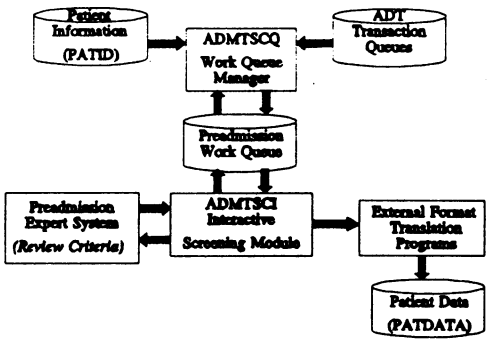

Figure 1 Block diagram of showing interface programs (ADMTSCQ and ADMTSCI) between preadmission screening expert system (*Review Criteria*) and HELP.

The programmatic interface is comprised of a system of circular queues and input/output processes. Most interactions originated in **HELP** are driven by an admit/discharge/transfer (ADT) event, such as an admission to the hospital or a change in demographic information. Transaction records containing minimal patient identification information are queued for the appropriate output process based on the type of ADT events of significance to the external system. A separate output process (**HELP** program) specific to each external system processes the queued transaction records. Based on internal logic for the particular transaction code and using the patient identification information, the output process can query the **HELP** database for additional information to be transmission to the external system.

For each external system, an input process translates the incoming data from that system to a form understood by the **HELP** system and 1) queues a transaction record in an input queue for storage of the data into the **HELP** database, or 2) queues a transaction record in an output queue to other different external systems or 3) does both. The I/O processes use standard protocols where they exist in the external system both for physical communication (e.g., X.25) and in the encoding of the data (e.g., X.409 and X.410). This approach to external systems using queued interfaces allows **HELP** to support connections to a wide variety of external systems and to replace or an external system without significant reprogramming.

Review Criteria

Review Criteria (Code 3/HSI, Murray, UT) is a personal computer (PC) application program for the evaluation of inpatient admission appropriateness under state-specific guidelines. *Review Criteria* is a frame-based expert system. In stand-alone operation, the user of *Review Criteria* enters demographic and clinical information in text form. The expert system uses menus to narrow the textual descriptions to a set of coded descriptions of the patient diagnosis and treatment. Based on the treatment plan, *Review Criteria* makes a recommendation about the appropriateness of inpatient admission and returns codes representing the specific criteria met or unmet that led to the decision. In addition to the recommendation, the expert system gives the ICD-9-CM codes for the diagnosis and procedures selected, as well as a prospective DRG classification. Previous to implementation as part of the computerized preadmission screening system, *Review Criteria* was not used at LDS Hospital.

A commercial expert system was selected because it was believed to offer a more complete knowledge base than could be constructed internally and the hospital would not be required to keep the system current with the frequent updates to Medicare reimbursement guidelines. *Review Criteria* was available in both mainframe (though not Tandem) and PC versions; the PC version was perceived as more easily interfaced with the existing

mainframe as well as easily integrated into the PC terminal environment.

HELP and *Review Criteria* worked together in the following manner. **HELP** detected admission events (scheduling of an admission or a direct admission) and managed a queue process of outstanding reviews. A utilization review nurse began a preadmission review by selecting a patient from the **HELP** patient census list. A **HELP** program gathered information to be passed to *Review Criteria* and invoked the expert system. The review nurse interacted with *Review Criteria* and on completion of the review, *Review Criteria* passed the results back to **HELP**.

IMPLEMENTATION

Three aspects of the implementation are considered here: 1) real-time, programmatic interaction between the PC application as an external system; 2) seamless integration of the PC application into the mainframe HIS application at the user level; and 3) integration of the PC application output into the mainframe data structure.

System Interface

A primary consideration in the integration was sharing of data between systems to reduce redundant entry of information. Because the expert system was a stand alone system, it was designed to request demographic and diagnostic information from the user that might already exist in **HELP**. The exchange of input information from **HELP** and results from *Review Criteria* to **HELP** was accomplished using an adaptation of the existing external system interface using a PC-to-mainframe gateway.

The existing interface model was modified to support real-time interaction from the external process. The "external system" was actually a **HELP** program tightly coupled with the expert system. Unlike an external computer system, the UM nurse who conducted the preadmission reviews was not available 24 hours a day, waiting for an event to appear in the preadmission review queue. Instead, a **HELP** program module processed the ADT generated transaction events, maintained its own database of outstanding transactions and managed the interactive exchange of data with the expert system. The nurse initiated a program that processed the output queue and called the PC expert system as an external system and managed the input queue at the same time.

The preadmission screening system ran on PCs connected to an existing local area network (LAN) running NetWare v2.15 (Novell, Inc., Provo, UT). Tandem Computers' (Cupertino CA) MULTILAN gateway was used to provide terminal emulation to **HELP** and file exchange via the network. It was necessary to engineer minor modifications to the gateway to support full file exchange between MULTILAN and NetWare.

Review Criteria provides an input/output file interface. With file exchange between the LAN and the mainframe established we were then able to interface the mainframe to *Review Criteria* without modification of *Review Criteria*. The **HELP** front-end process created a temporary input file on the Tandem which was read over the gateway by the expert system. The expert system created an output file that was read over the gateway by **HELP**. This same mechanism for file exchange had previously been prototyped by one of the authors (JWH) for the integration of a commercial word processing package for radiology results transcription as part of the **HELP** system. The solution was not sophisticated, but solved the redundant entry problem. The intermediate data files were variable length, ASCII text files containing coded data phrases. The data phrases included input data for the review process, as well as command instructions for the PC expert system or the phrases contained the results of the review as output from the expert system.

Application Integration

An additional consideration was making the transition between the **HELP** frontend and the PC application transparent to the user. Recall that the review nurse begins a review by selecting a patient from the **HELP** census list. Even though we were able to pass information to the PC application directly, the programmatic interface did not eliminate the need for interaction with the expert system.

The next step was to make the PC application appear to be part of the **HELP** system. This integration allowed us to use standard routines for identifying patients from the census on the HIS and integrate the review results in realtime into the HIS database. The emulator supported command strings passed via the MULTILAN gateway from the mainframe to suspend the emulator and invoke a local (PC) process. Following selection of the patient to be reviewed, the **HELP** frontend module prepared the input data file and then issued a command string to the emulator which invoked *Review Criteria*. After the review had been completed, the termination of *Review Criteria* returned control to the emulator and the **HELP** frontend program.

The **HELP** frontend module also acted as the input processor for data coming from *Review Criteria*. The data returned by the expert system included the coded diagnosis and procedure information and an error condition code. The frontend processor dealt with the abnormal return codes and the absence of the input file. The **HELP** module also prepared the review results for input into the **HELP** database, including the translation of the coded data items into PTXT codes.

Data Integration

Review Criteria makes an appropriateness recommendation based on established criteria used by PROs. The criteria for admission appropriateness in Utah are the Appropriateness Evaluation Protocol (AEP) admission guidelines. A portion of these guidelines is shown in Figure 2. The output of *Review Criteria* provided an additional level of detail to the AEP as shown by the examples in Figure 3.

A. Severity of Illness Criteria
   1. Sudden onset of unconsciousness or disorientation (coma or unresponsiveness)
   2. Pulse rate: < 50 per minute or > 140 per minute and not presently on beta-blockers
   3. Blood pressure: systolic < 90 or > 200 mm Hg, or diastolic < 60 or > 120 mm Hg

   etc...

B. Intensity of Service Criteria
   1. Intravenous medications and/or fluid replacement (does not include tube feedings or TKO IVs)
   2. Inpatient-approved surgery or procedure scheduled within 24 hours of admission:

   etc...

Figure 2 A portion of the AEP Adult Admission Guidelines as modified for use by UPRO. (See Gertman[4] for a complete list.)

A1 Sudden onset of unconsciousness
7026 unconsciousness (sudden onset)
7027 disorientation (sudden onset)
7053 hemoglobin below 9 gm
7055 hematocrit below 21%
7158 disorientation to time or place
etc...

A2 Pulse rate abnormality not explained by current drug therapy
7001 pulse below 50/minute and not presently on beta-blockers
7002 pulse above 140/minute and not presently on beta-blockers
etc...

Figure 3 Example of *Review Criteria* findings represented as children of higher level AEP findings with their *Review Criteria* code numbers.

Along with the AEP, these 341 more detailed findings were coded according to an internal scheme in *Review Criteria*. The finer resolution findings of *Review Criteria* were easily integrated into the hierarchical structure of the PTXT data dictionary. As children of the parent concept at the AEP level, findings could be referenced in searches by their more specific *Review Criteria* code or by their parent AEP concept. Even though the more specific *Review Criteria* findings represent greater detail than the AEP criteria, they did not map unambiguously to the AEP criteria. The conceptual hierarchy used by the developers of *Review Criteria* to map their new finding codes to the AEP was not available. Based on experience with the AEP, the principal preadmission nurse assigned the 341 *Review Criteria* findings to AEP categories. The assignments were reviewed by a physician. Despite some uncertainty, only 5 of the 341 findings (1.5%) were mapped to a "catchall" category. In all, approximately 400 new terms representing the AEP admission guidelines and *Review Criteria* detailed AEP findings were added to PTXT. The complete ICD-9-CM and DRG classifications already existed in PTXT.

Alternate Cross References

A new feature of PTXT, known as alternate cross references, was used to facilitate the storing of ICD-9-CM, DRG and *Review Criteria* codes in the patient database. PTXT is fundamentally a numerical assignment to a medical term or concept. In some instances, the term or concept is already represented in a coded scheme external to PTXT. ICD-9-CM, DRG, and SNOMED codes are all examples.

PTXT supports mappings to these external code schemes by way of an alternate cross reference. Each PTXT code may have one or more alternate cross reference codes assigned to it. Relational tables for each scheme supported by alternate cross referencing contain inverted index pointers to PTXT elements. The alternate cross reference facility supports one-to-one, one-to-many, and many-to-one mappings. As a result, one or more PTXT codes can be used to represent a concept described by a single code in an external coding scheme. A library of **HELP** routines support translation between PTXT and supported external code schemas. Previously, numerical translation algorithms were used to move between ICD-9-CM or DRG codes and their PTXT equivalent codes.

The alternate cross reference feature was used to map from the returned ICD-9-CM, DRG and *Review Criteria* codes to PTXT for storage of preadmission review results into the **HELP** database.

Evaluation

Evaluation of the preadmission screening system was conducted in a two-phase clinical trial whose primary goal was to assess the usefulness of preadmission screening. The second phase, a concurrent randomized trial, did not show a significant reduction in the rate of inappropriate inpatient admissions as a result of preadmission screening and led us to conclude the preadmission screening system was not effective at our institution. Followup studies identified a number of contributing factors which, along with the experimental results, are discussed in detail elsewhere.[12] None of these factors was related to the success of the implementation as described here.

The implementation was not formally evaluated except through qualitative checks on completeness of data exchange. In phase one of the clinical trial, 631 admissions and scheduled admissions were tracked. Subsequent review of the manual (paper) records of admissions showed 19 patients were not detected nor processed due to program errors. The screening program was modified to correct these errors. In phase two of the clinical trials, from April 12, 1991 to August 31, 1991, 2511 admission events were detected. A sample of 421 patients were reviewed by manual process. Only one case was missing representing an error rate of less than 0.25%. Data files were missing for four of the 2300 patients reviewed.

The most significant problem encountered by users of the preadmission system was incompleteness of the expert system's knowledge base. Other comments noted included the fact that transition between the PC and mainframe application was smooth, with no excessive delays, however, the integration was detectable due to screen color changes. Perhaps the greatest measure of the success of the implementation was the daily use of the screening program for the 20 week period of the randomized trial. Success of implementation was also evidenced by interest in linking *Review Criteria*'s coding engine to **HELP** for use in other areas of the hospital to do interactive ICD-9-CM coding from text for insertion into the **HELP** patient record before the final discharge abstract coding.

CONCLUSIONS

Increasingly hospital information systems rely on integration of existing or specialized information systems with basic centralized functions to meet the breadth of the needs of a hospital. A variety of integration techniques have been employed by other researchers.[13] This paper documents two features of **HELP** that facilitated the integration of external systems that have previously been undocumented in the literature: a standardized interface to external systems and internal support for external code schemes. Additionally, new functionality in the form of LAN-to-mainframe data communication was demonstrated. Integration of knowledge-bases and expert systems with existing clinical data represent an important step toward a fully automated patient record with advanced decision support.

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