

Clinical Reminder System: A Relational Database Application for Evidence-Based Medicine Practice

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Abstract

Evidence-based medicine is the distillation of a large volume of medical research and standards into treatment protocols for diseases and preventive care procedures that represent the most accurate knowledge available. In this project, we implement evidence-based medicine principles via a decision support system that provides suggested actions for physicians based on individual patient characteristics and established treatment protocols. Such a reminder system may enable physicians to make better-quality decisions, and may enable patients more consistently follow medical recommendations.

We present a prototype DSS, called Clinical Reminder System, that combines a relational database, a knowledge base consisting of algorithms that implement disease treatment protocols, integration with hospital legacy systems and a web-based interface allowing for physician management of patient data and suggested medical responses. This application has been in use within a clinical setting since 2001. Formal evaluation and assessment of patient outcomes associated with use of this system is currently being performed by Carnegie Mellon University and The Western Pennsylvania Hospital.

Keywords: Decision support systems, medical informatics, evidence-based medicine

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I. Introduction

Information technology (IT) is playing an increasingly significant role in health care service delivery: value-based purchasing, cost cutting, and integrated electronic patient records management (The Jewish Health Care Foundation 1999). Development of medical IT applications has traditionally consumed just 2 percent of capital budgets, but this share is sure to rise as hospital mergers and pressures from government bodies and insurers combine to make systems integration and IT innovation mandatory.

Doctors are increasingly having to transition from a “1-to-1” view of medical practice in which the “fee for service” model has dominated, to a “1-to-n”, population-based view, and are required to be familiar with business practices and health care economics in a managed-care environment that may at times run counter to this population-based view. Bodenheimer (1999) notes that recent trends towards disease management may place greater emphasis on a smaller, sicker population than on the larger population with chronic illnesses at lower immediate health risk. Greenlick (1992) outlines a population-based clinical practice model that addresses allocation of appropriate medical resources to all populations, serious study of epidemiology as it relates to clinical practice and the need to perform outreach to populations not usually served by clinical practices. Greenlick (1995) further argues that special education in population-based medicine will be necessary for the many physicians who will work in large organizations. The Council on Graduate Medical Education (1997) has produced resources for medical education that specifically address population-based medical practice in a managed care environment, in many broad areas identified by Greenlick.

Health maintenance organizations, medical researchers and health practitioners realize that in an environment that rewards short-term cost savings and emphasizes management of current diseases, increased use of patient reminders can significantly improve delivery of preventive care services and treatment for chronic illnesses and can lead to long-term beneficial outcomes as well. UnitedHealth Group, a large health-maintenance organization, has found that use of billing information to design patient reminder treatment strategies for patients with diabetes, heart-attack survivors and women at risk for breast cancer has increased the rate of

utilization of simple interventions in all of these areas (Burton 1999). Solberg, et al. (1998) has studied organized processes to provide preventive care services in primary care clinics and finds that most clinics did not have use a complete suite of preventive care processes. Leninger, et al. (1996) presents a methodology for designing office information systems to improve delivery of preventive care services that span written practice policies, through implementing a computer-based information system and monitoring progress.

The three trends listed above: the increased importance of information technology throughout the medical enterprise, the practice of population-based medicine practiced in larger organizations, and the use of office-based information systems to prompt physicians and patients to execute steps associated with prevention of diseases or treatment of chronic illnesses, reach a synthesis in a parallel stream of medical research that is over twenty-five years old. This research domain comprises the design of computer-based reminder systems to assist preventive care and disease management through generation of specific recommendations using *evidence-based medicine*, or the use of best available external clinical evidence, combined with individual clinical expertise, to make decisions about the care of individual patients (Sackett, *et al.* 1996). Such patient/physician reminder systems have been shown to improve physician compliance with clinical guidelines for many diseases and preventive care categories (Shea, DuMouchel and Bahamonde 1996, Nilasena and Lincoln 1995) and to improve patient outcomes (Hunt et al. 1998).

This paper focuses on the development of a Clinical Reminder System (CRS), a computer-based decision support system intended for use in a primary care clinic setting, that uses evidence-based medicine, in particular, protocols for application of preventive care and chronic disease treatment strategies, and information systems technology to allow physicians to better monitor the treatment of patients. This research is motivated not just by the research findings listed above that make a strong case for computer-assisted population-based medical practice in the clinical setting, but by the limited number of commercially-available systems that generate customized reminders on a just-in-time basis for primary care.

Over the past four years, students in the H. John Heinz, III School of Public Policy and Management at Carnegie Mellon University have worked with Heinz School faculty advisors and staff from the Western Pennsylvania Hospital to develop (Berger, et al. 2000; Diamond, Johnson and Padman 2000), refine (Carlen et al. 2000) and evaluate (Zheng, *et al.* 2004) the Clinical Reminder System, a decision support system deployed in the Medical Ambulatory Care Clinic (MACC) at West Penn for treatment of four chronic illnesses and four preventive care categories. The latest release of Clinical Reminder System (CRS) is an intelligent decision support application with a web-enabled user interface. The core of the application is developed in C# and Web Services using Microsoft's .Net Technology. CRS also implements a universal data access layer to communicate to major database and Electronic Medical Records (EMR) vendors.

We believe that the Clinical Reminder System represents a contribution to the literature on decision support systems for three reasons. First, CRS incorporates an innovative knowledge engineering component to the design of physician/patient reminders. Second, the database and user interface design of CRS allows extension of the system to more chronic illnesses and preventive care categories in a straightforward way. Third, the web-based user interface of CRS enables various user classes - physicians, clinic staff, program administrators and system administrators - to interact with CRS in an intuitive and productive manner no matter where they are located. Finally, the modulated architecture allows easy transition to integrate to other medical information systems and to deliver the reminders to other platforms, such as handheld devices.

The Clinical Reminder System began as a prototype system and has grown into a fully-integrated software tool used daily at MACC. The feedback received from the West Penn client has been positive. The evaluation of CRS along a number of dimensions, including ease of use, improvement in clinic productivity, improvement in physician performance, cost impacts and improvement in patient outcomes is continually being assessed by Carnegie Mellon University and West Pennsylvania Hospital.

This paper is structured as follows: Section II reviews the various strands of research literature related to this project. Section III presents the functional requirements for CRS, featuring the medical decision trees that are at the heart of CRS. Section IV outlines the system design portion of CRS development, including encoding physician reminders, database design and user interface design. Section V presents preliminary steps taken towards implementation of CRS. Section VI concludes and lists a number of next steps for CRS development.

II. Literature Review

Clinical Reminder System is an application that relies heavily on research in a number of fields: evidence-based medicine, medical informatics, decision support systems, clinical reminder systems and information systems development methodology. In this section we briefly survey the academic literature in these fields and indicate research that is particularly relevant to CRS.

Sackett *et al.* (1996) summarize the history of evidence-based medicine, address objections to its practice and emphasize the large amounts of data necessary for its proper use. The authors note that evidence-based medicine relies on data from a number of practice areas, generated using a number of research designs and must be combined with individual clinical expertise. Examples of data sources for evidence-based medicine practice include: U.S. Preventive Services Task Force (1989), Task Force on Osteoporosis Guidelines (1996), Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (1993) and many others. As a result, “knowledge engineering” is an important component of CRS, and a challenge of developing and extending CRS will be the extent to which embedded treatment algorithms may be modified to reflect changes in current best practices.

Medical informatics is a well-developed research field that applies information technology principles to specific problems health care. Van Bommel and Musen (1997) make clear that clinical decision support systems, of which CRS is an example, are numerous at the prototype stage but much less so at the level of daily use in a professional setting. CRS may be classified, using the terminology of these authors, as using decision trees for knowledge

representation, providing solicited suggestions for physician review and intended for clinical practice. Further, CRS ought to be closely integrated with the broader information technology infrastructure of the medical institution and should embody the best practices of modeling research-based medical information from a wide range of sources. The report *Bringing Health Care Online* (U.S. Congress, Office of Technology Assessment 1995) provides a panorama of existing and potential medical informatics applications and policies, and emphasizes the connections between patients, health care providers, suppliers and government bodies via local area networks, wide area networks, the Internet and telecommunications networks, and through use of the electronic patient records.

Decision support systems (DSS) represent a domain that overlaps medical informatics but which focuses more closely on systems architecture, implementation issues and the decision making process. Carter, et al. (1992) distinguish between *decision aids*, which enhance the performance of a decision maker by clarifying the problem, and a *decision support system*, which they define as a “computerized decision aid.” Thus, evidence-based medicine, by itself, constitutes a decision aid, while the encoding of evidence-based medicine guidelines in a computer system constitutes a decision support system. The authors also present typical DSS components, which we examine in more detail in Section IV. Since DSSs use databases to support multiple, simultaneous users, issues of system architecture feature prominently. Simon (1995) surveys client-server database technology and provides alternative development strategies to implement client-server computing. There have been many applications of decision support systems to medical decision making; Hunt, *et al.* (1998) identify positive physician performance and patient outcomes associated with clinical use of DSSs, while Lobach and Underwood (1998) describe an Internet-based clinical DSS for application of clinical practice guidelines. (In contrast to Clinical Reminder System, the DSS developed by Lobach and Underwood, called SIGFREID, does not use individual patient data and is not designed to follow protocol-based treatment regimens over time.)

Reminder, or cueing, software systems are a particular kind of decision support system intended to provide suggestions regarding treatment plans to physicians who without computer assistance might not make appropriate or timely treatment decisions. The insight by McDonald

(1976) that the volume of medical information may simply be too high for any physician to consistently follow treatment protocols, in particular, underlies much of the academic work in this area since that date. From among the many articles describing or evaluating computer-generated reminder applications to chronic illnesses or preventive care, a number stand out as relevant to this paper. Beneficial outcomes along a number of dimensions, including compliance with treatment standards, reduced treatment costs, improved population health outcomes, have been reported by Evans, *et al.* (1998) (antibiotic and antiinfective drug treatments), Curtin, *et al.* (1998) (asthma), Nilasena and Lincoln (1995) (diabetes), McDonald, *et al.* (1984) (multiple preventive care categories) and Tierney, *et al.* (1986) (multiple preventive care categories). Two extensive literature reviews have confirmed the efficacy of computer-based reminder systems (Shea, DuMouchel and Bahamonde [1996]) and clinical decision support systems (Hunt, *et al.* [1998]) with respect to physician performance and patient outcomes.

Finally, the literature on systems design and the systems development life cycle is relevant to this paper because of the complexity of clinical DSSs, in terms of knowledge acquisition, business process modeling, user interface design, implementation and management of the development process. Without a solid knowledge of this area, a promising concept for a clinical DSS may never be realized, or, if developed, never used outside of an experimental setting. The development of Clinical Reminder System has relied on business process design as presented by Shelly, Cashman and Rosenblatt (1998), the software development life cycle as presented by Whitten and Bentley (1998) and project management techniques contained in McLeod and Smith (1996).

III. System Functional Requirements

Clinical Reminder System is based on accepted treatment protocols for chronic diseases and preventive care categories, as modified by practitioners at the Western Pennsylvania Hospital. The key functional requirement for CRS is that, given medical and demographic information about a patient and a detailed description of alternative treatment paths based on a treatment protocol, it generates specific reminders to a physician that assist in treatment of the patient. The physician may choose from a number of responses to each recommendation

generated by CRS; for evaluation purpose all that is important is that the responses be recorded in a “repository” for later analysis. In this section we examine the mechanisms by which treatment protocols are represented graphically, and by which specific cues are generated. We also identify other key functional requirements for CRS: that the system monitors usage by end-users and enforce data confidentiality and that the system generate summary reports for four types of users: physicians, clinic staff, administrators and analysts, and patients.

Treatment Protocols and Physician Reminders

Clinical Reminder System has initially been designed to provide treatment assistance for three chronic diseases—hyperlipidemia, diabetes and lower-back pain - and five preventive care categories - cervical cancer, breast cancer, pneumonia, influenza and steroid-induced osteoporosis. For each disease and preventive care category, we use standard treatment protocols as a basis for intensive discussions regarding the timing, data inputs, acceptable alternatives and wording of cues associated with particular decision points. The standard treatment protocols for each chronic illness/preventive care category are:

- Hyperlipidemia: Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (1993);
- Diabetes: American Diabetes Association (1999);
- Lower-Back Pain: Bendix et al. (1996);
- Cervical Cancer: “Screening for Cervical Cancer,” in U.S. Preventive Services Task Force (1989);
- Breast Cancer: “Screening for Breast Cancer,” in U.S. Preventive Services Task Force (1989);
- Pneumococcal Vaccine: “Adult Immunizations—Including Chemoprophylaxis against Influenza A,” in U.S. Preventive Services Task Force (1989);
- Pneumonia: “Adult Immunizations—Including Chemoprophylaxis against Influenza A,” in U.S. Preventive Services Task Force (1989);
- Steroid-Induced Osteoporosis: Task Force on Osteoporosis Guidelines (1996);

These discussions have culminated in a *decision tree* describing the sequence of *events* (observed patient conditions, test results, patient reactions to physician reminders) and *physician reminders* themselves to be generated specifically in response to the combination of one or more events.

By identifying the data required to generate physician reminders, we began identifying the outlines of a *database* to store data related to patients, office visits, tests, medical procedures and physician reminders. For data readily available in other hospital information systems, we assessed the feasibility of establishing live links or selective data feeding. In addition, by spelling out the sequence of events associated with treatment protocols, we began defining pseudocode that formed the basis of *procedures* that would be implemented in computer code. Finally, since events and physician reminders occur in a business context, we developed requirements for a *user interface* that would enable users to maintain the data used for treatment protocols, respond to reminders and to view reports that summarize system inputs and outputs.

In developing functional requirements for Clinical Reminder System, we have identified a distinction between physician reminders that parallels the distinction between chronic illnesses and preventive care categories. We define a *visit-driven cue* as a physician reminder that is generated during a physician's interaction with CRS and the patient, based on patient responses to physician questions (or previous system-generated reminders) or database queries. An example of a visit-driven cue is a physician's recommendation that a patient previously diagnosed with diabetes commence a smoking cessation program, if the patient smokes. A *time-driven cue*, on the other hand, is a physician reminder that is generated independently of a visit, based on elapsed time and database queries. An example of a time-driven cue is a reminder to a patient to visit the clinic to receive an influenza vaccine, based on the time of the year and the patient's age, among other criteria.

We examine the treatment protocol for prevention of influenza in detail. This protocol uses detailed patient information (history of previous flu shot, age, presence of chronic diseases) and external environment information (current date) to determine whether a flu shot should be recommended or not. Figure 1 contains the decision tree for prevention of influenza. Figure 2 contains a sample questions and reminders associated with a hypothetical patient who meets the

criteria for flu vaccine based on the decision tree in Figure 1, as provided by the current version of CRS.

[Figure 1: Decision Tree for Influenza Vaccine]

[Figure 2: Sample Questions and Reminders from CRS]

A fully functional database design has been derived and is documented in section five of this document. It is useful to denote entities, attributes and queries have been combined with data elements associated with other treatment protocols in the formal entity-relationship. Figure 3 indicates the data elements associated with this prevention of influenza protocol.

[Figure 3: Data Elements Associated with Influenza Vaccine]

Security and Confidentiality

Discussions with the client have revealed confidentiality of data and system security to be major concerns, as is the case in the medical community overall. Four main tasks related to security and confidentiality have been identified as: create username and passwords, create user categories and grant system privileges, management of passwords and generation of audit trails describing system login attempts and user access to specific screens and data elements.

A framework assigning users to three categories associated with security and confidentiality is contained in Figure 4. This framework is used to define specific tasks, contained in Section IV, “System Implementation.”

[Figure 4: Proposed User Roles and Privileges for Confidentiality and Security]

End-User Reports

The greatest value of Clinical Reminder System, beyond a user-friendly interface that enables physicians and clinic staff to use the software without undue decreases in productivity, is contained in printed reports that summarize data contained in CRS and enable users to interact

with the system without the benefit of a computer. Four main categories of reports that CRS generates are:

- Physician-directed reports:
 - Pre-visit reports for physicians who cannot or choose not to use Clinical Reminder System, and which allow physicians to respond to system-generated reminders for each patient by hand;
 - Post-visit reports containing summaries of patient data, including reminder responses, that are intended to be attached to patient charts;
- Staff-directed reports:
 - Periodic summaries of patient characteristics, such as current diagnoses;
 - Daily list of patients scheduled for clinic visits;
- Patient-directed reports:
 - Letters that remind patients to make clinic appointments for various services;
 - Summaries of individual patient compliance with treatment protocols;
- Administrator-directed reports:
 - Audits of user access to CRS and specific screens, reports and data elements;
 - Summaries of outcomes associated with CRS, including patient compliance with treatment recommendations, physician reactions to CRS reminders and population health outcomes.

IV. System Design

In this section we present the system design portion of Clinical Reminder System, concentrating on four areas: high-level application design, relational database design, reminders design and interface design.

High-Level Application Design

Clinical Reminder System is intended to follow the design principles of a decision support system (Carter, *et al.* 1992), i.e. software that assists, but does not necessarily prescribe, decisions made by human experts. Figure 5, below, shows that CRS is composed of five main components: a *database*, storing all information related to patients, physicians, visits and so

forth; a *model base* storing all information related to the algorithms that generate physician reminders; a *user interface* comprising all code associated with screens that process user inputs and display system outputs; *reminders and reports*, formatted system outputs intended for permanent paper storage, and a *dialogue management system*, comprising code that allows all of the system components listed previously to share data and which translates requirements of one component, e.g. reports, into elements that another component, e.g. database, can understand.

[Figure 5: Conceptual System Architecture]

CRS utilizes database-driven web technology and is able to support activities of multiple end-users simultaneously, each of whom communicates with a central repository consisting of business rules and database components executed via user interface code and functions stored on a common web server. Multiple physicians and clinic staff members have the ability to use CRS simultaneously in the MACC. CRS is available to multiple clinics and small physician practices via the World Wide Web.

Relational Database Design

After completing the design of all decision trees associated with chronic illness and preventive care treatment protocols, we have consolidated all candidate entities and attributes defined explicitly (i.e. updated at a decision point) or implicitly (i.e. used in queries whose responses are used as inputs to decision points). Typical common entities included “PATIENT”, “LABTEST”, “MEDICATION”, “DIAGNOSIS”, “STAFF” and so on. Discussions with the West Penn regarding the business rules that govern current operations of the MACC have allowed us to identify a subset of sound, consistent business rules that govern the interaction of key entities. Such business rules include: “Each patient can visit the MACC on many different occasions,” “Each patient’s visit can result in treatment for multiple diseases,” and so on.

Finally, we have made a number of fundamental design decisions related to storage of treatment-specific base data and of reminder inputs and outputs. First, we believe that for purposes of database extensibility, it is best to define treatment-specific base data in terms of test and procedure results, e.g. “URINALYSIS” as a type of “BATTERYTEST” and “FOOT

EXAM” as a type of “NONLABTEST”, both used in the Diabetes treatment protocol, rather than disease-specific entities, e.g. “Diabetes”, and all treatments, tests, etc. associated with it. This is because tests and procedures could be common across multiple illness and preventive care categories. Second, we believe that for purposes of outcomes analysis, it is essential to store physician responses to system-generated reminders.

Details of the entity-relationship model at the heart of Clinical Reminder System are contained in Figure 6. Note that there is an entity called “SCHEDULE” not previously described in the system functional requirements. This entity is included because of client concerns that daily schedule information be stored in CRS as well as in paper form - though CRS is not intended to have the full functionality of a patient scheduling system.

[Figure 6: Entity-Relationship Model]

This design makes clear that extension of CRS to additional chronic illness and preventive care categories, or to additional reminder categories, or to additional staff categories, is a straightforward task.

Reminders Design

Design of a system to implement reminders relies on translation of the questions and decisions implicit in the decision trees presented in the previous section to procedural pseudocode that can be implemented in software. We have designed and developed object-oriented C# classes for each treatment protocol that incorporates the exact wording of each reminder and executes. Such object-oriented technology makes the treatment protocols reusable and provides the ability for treatment objects to be implemented in any relational database system on any platform. See Berger, et al. (2000) for examples of pseudocode for a number of chronic illness and preventive care categories.

We have also identified two types of cues as essential for enforcing the connection between the database, the interface and the model base: *external reminders* and *turn-around reminders*. External reminders are those that leave the system, typically in the form of reports, to

prompt action on the part of physicians or clinic staff. Most of these reminders are time-driven, such as reminder letters to patients to schedule an appointment with the clinic or to have a test performed. Turn-around reminders are those that are displayed in the user interface and which re-enter the database as an input. For example, a reminder that a patient's test result be examined to determine if a treatment be modified would be output from Clinical Reminder System for physician response (e.g. "Medicine dosage to be increased") would result in the addition of a new record to a reminder repository and a new record to the appropriate test/treatment results table, the latter of which would be input for another reminder at a later time, consistent with the treatment protocol.

Interface Design

As is true for most decision support systems, the user interface is the most visible and most important component, at least from the perspective of end-user acceptance and day-to-day use. Therefore, we have identified key interface design principles and codified existing and proposed clinic business practices. Some design principles used in development of CRS include:

- Integration with work flow;
- Ease of use;
- Consistency;
- Appropriately worded messages and labels;
- Clearly distinguishing between read-only data elements and those that may be modified by the end-user.

We have captured a number of business rules that are associated with user interaction with the application interface adapting the standard language of *data flow diagrams* (DFDs) (Shelley, Cashman and Rosenblatt [1998]). Such diagrams allow us to identify end users and data stores associated with specific processes, many of which would be performed by CRS, but some of which would not. These latter processes, however, are essential to integrating CRS into daily clinic operations, and may use data stored in CRS. An example of a high-level diagram is contained in Figure 7.

[Figure 7: High-Level Data Flow Diagram for Reminder Generation Process]

This figure contains a number of general processes familiar to client staffers and developers, such as patient registration and patient-physician contact, and are indicative of the functionality that would have to be provided by the user interface to duplicate these processes.

Based on the data flow diagram and knowledge of an existing management information system used by the client for management of patient-related data at the enterprise level, we have identified a set of processes that addressed the needs of different user groups and ensured, to the extent possible, a modular design for the user interface. The collection of these processes is presented in Figure 8 as an interface hierarchy.

[Figure 8: Interface Hierarchy]

This figure indicates that all users access CRS via a login screen and a form that allows the choice of various functions tailored to specific user groups. Consistent with the security functionality requirements, it is the security-based user *roles* (see Figure 4) rather than the organization-based user categories (e.g., physician, staff, managers) that determine which portion of the application is accessible to whom. In addition, it indicates that some functions, e.g. patient search and reports, are common to both physician and staff users. Finally the interface hierarchy encodes the business rules that processing of visit-driven reminders is primarily the province of physicians, while processing of time-driven reminders is primarily the province of clinic staff (though this division of labor is not unchangeable).

V. System Implementation

The system implementation phase of Clinical Reminder System development has entailed a number of difficult decisions regarding both development platforms and deployment platforms. The system was initially developed as a client-server application for use primarily in a single site, the West Penn MACC, but available to remote users via local area network, wide area network and modem dial-up. CRS has been converted to a web-based system utilizing

Microsoft's .Net technology to enable it to be used a large number of physically-dispersed offices. ASP.Net with C# classes has been developed to provide object reusability within any clinical decision support system.

There are, potentially, a large number of end-users, chronic illness and preventive care treatment protocols, patients and patient-related clinical data to be managed by the Clinical Reminder System; therefore, a robust relational database management system is essential for the smooth functioning of CRS. For this reason, we chose Oracle as our internal database development platform. By establishing a universal data access layer to communicate to other information systems, the dynamic data link or off-line data downloading, CRS can also consume information from any other data sources. We also recognized the requirement of the user interface to be flexible, intuitive to novice users and highly responsive. Although there are a variety of interface development platforms available, we have chosen Microsoft's .Net technology because of its true object-oriented capabilities which promote object reuse across multiple applications and its flexibility in user interface design. Figure 9 provides details of the actual system architecture of CRS

[Figure 9: Actual System Architecture]

Clinical Reminder System is integrated with information systems at West Penn in a number of ways. First, CRS receives transfers of patient demographic and test/procedure-related data elements into the Oracle database from a central data repository using the HL7 protocol. Second, CRS has a built in scheduling module that works with the registration system of the West Penn Hospital. Third, CRS receives data on individual patient characteristics such as diagnoses, tests, procedures and visits via the user interface. Finally, CRS generates output data in the form of reports to be stored in patient charts, reminder letters to be sent to patients or summary reports to clinic staff and administrators for evaluation and resource allocation decisions.

Database Implementation

The database at the heart of the Clinical Reminder System has been implemented using Oracle and is based on the entity-relationship diagram shown in Figure 6, above. Data formats have been designed using CPT-4 and ICD-9 standards used at West Penn, and where attributes could not be matched with these standards, HL7 standards have been used. We have devised sequence numbers to maintain uniqueness of table records where necessary. Data integrity is maintained at the database level using check constraints.

Reminders Implementation

Reminders are generated from treatment protocols that have been coded using Microsoft's C# language and .Net technology, transitioned from data flow diagrams such as the one shown in Figure 1, above. Based on a patient's condition, symptoms, medication and diagnosis, reminders are generated from treatment protocols in the form of C# objects. These objects, or classes, generate time-driven reminders and visit-driven reminders.

Interface Implementation

As indicated above, the user interface to Clinical Reminder System has been developed using Microsoft .Net technology including ASP.NET, ADO.NET and C# classes. This interface relies on a number of principles identified in discussions with West Penn physicians and staff: first, that CRS should have an appearance similar to the current hospital information system, and second, that CRS should minimize data entry and guide, but not require users to make certain choices.

As a result the CRS user interface has a number of features to maximize flexibility and ease of use:

- Physicians are able to select from among patients scheduled for visits - patients for whom treatment will be provided using CRS;
- Detailed information on a selected patient is displayed in such a way that static demographic data and the chief complaint are at the top of the form, and categories of treatment data (visits, tests/procedures, diagnoses and orders) are available at the

bottom of the form accessible through expandable and collapsible tree structure controls within the form and along the left margin of the screen.

- Physicians should be encouraged, but not required, to respond to current reminders for a given patient via a pop-up reminder response form and a variety of reminder response options, including free-form comments.

A portion of the physician-directed portion of the CRS user interface is shown in Figure 10.

[Figure 10: Physician-Directed Interface]

Finally, CRS contains a summary report, called a “check-out form” (Figure 11) that lists the diagnoses made, tests and procedures recorded, and reminders generated and responded to during the patient encounter. This summary report is intended to replace multiple pages of possibly difficult-to-read entries in the patient’s physical chart, and, in a paperless office, to summarize a portion of the patient’s electronic medical record.

[Figure 11: Patient Check-Out Report]

VI. Conclusion

The Clinical Reminder System is an example of a decision support system for clinical medical practice that is consistent with a number of trends in the medical field: increased emphasis on information technology to provide services, business trends emphasizing population-based medicine and increased use of reminders in preventive care and treatment of chronic illnesses. In this paper we have shown that CRS incorporates key principles of evidence-based medicine, is the result of a well-accepted systems development methodology and embodies development choices that maximize system attributes such as scalability, generalizability, interoperability, usability and response time.

CRS is well-positioned to enable organizations such as the Western Pennsylvania Hospital achieve benefits in a number of categories: increased compliance with medical guideline recommendations, decreased inappropriate variation in clinical care, decreased cost of

care, increased clinic productivity, and beneficial population-based health outcomes. CRS, initially developed and used as a client-server application, has been extended to use over the Internet, greatly increasing the potential user base and scale of desirable outcomes.

Clinical Reminder System is currently installed at the West Penn MACC and is being used on a daily basis. Future development plans include fuller integration of CRS with West Penn information systems and modification of CRS, where necessary, to more fully account for clinic business practices. Data stored in CRS regarding physician responses to reminders and patient compliance with these reminders will be combined with data regarding development, implementation and ongoing maintenance costs of CRS and baseline data on patient treatment to develop the five outcome measures referred to above.

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Project External Review Board:

Phil Campbell, PhD (Institute for Complex Engineered Systems, Carnegie Mellon University), Adam Landman (Master of Science in Healthcare Policy and Management, Carnegie Mellon University), Victor Weedn, MD, JD (Mellon College of Sciences, the Carnegie Institute of

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References

American Diabetes Association. 1999. Clinical Practice Recommendations. *Diabetes Care* **22 Suppl 1**: 51 – 114.

Bendix, A.F., Bendix, T., Baegter, K., Lund, C., Frolund, L. and L. Holm. 1996. Multidisciplinary Intensive Treatment for Chronic Low Back Pain: A Randomized, Prospective Study. *Cleveland Clinic Journal of Medicine* **63**(1): 62 – 69.

Berger, D., Bortey, I., Brown, M., Carter, C., Chandrasekar, K., Desai, R., Groce, R., Johnson, T., Lee, E. and B. Rodriguez. 2000. *Physician Reminder System for the Practice of Evidence-Based Medicine at Western Pennsylvania Hospital*. Systems Synthesis Final Report. Unpublished draft. Pittsburgh: H. John Heinz III School of Public Policy and Management, Carnegie Mellon University.

Bodenheimer, T. 1999. Disease Management – Promises and Pitfalls. *The New England Journal of Medicine* **340**(15): 1202 – 1205.

Burton, T.M. “UnitedHealth Gets Physicians to Improve Medical Care,” The Wall Street Journal, Thursday, August 19, 1999, p. B4.

Carlen, C., Lau, H.-H., Shen, Q., Son, I.-S., Wu, X. and H. Xia. 2000. *Physician Reminder System for the Practice of Evidence-Based Medicine at Western Pennsylvania Hospital-Summer 2000 Extensions*. Information Systems Project Final Report. Unpublished draft. Pittsburgh: H. John Heinz III School of Public Policy and Management, Carnegie Mellon University.

Carter, G.M., Murray, M.P., Walker, R.G. and W.E. Walker. 1992. “Organizational Decision Support Systems,” in *Building Organizational Decision Support Systems*. Boston: Academic Press, Inc.

- Council on Graduate Medical Education. 1997. *Preparing Learners for Practice in a Managed Care Environment*. Washington, DC: U.S. Department of Health and Human Services, Public Health Service, Health Resources and Services Administration, Bureau of Health Professions.
- Curtin, K., Hayes, B.D., Holland, C.L. and L.A. Katz. 1998. Computer-Generated Intervention for Asthma Population Care Management. *Effective Clinical Practice* **1**(1): 43 – 46.
- Diamond, H.S., Johnson, M.P. and R. Padman. 2000. “Design and Implementation of a Physician Reminder Information System using Evidence-Based Medicine.” Presented at INFORMS National Conference, Salt Lake City, UT, May 8, 2000.
- Evans, R.S., Pestotnik, S.L., Classen, D.C., Clemmer, T.P., Weaver, L.K., Orme, J.F., Lloyd, J.F. and J.P. Burke. 1998. A Computer-Assisted Management Program for Antibiotics and Other Antiinfective Agents. *The New England Journal of Medicine* **338**(4): 232 – 238.
- Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults. 1993. Summary of the Second Report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel II). *Journal of the American Medical Association* **269**(23): 3015 – 3023.
- Greenlick, M.R. 1992. Educating Physicians for Population-Based Clinical Practice. *Journal of the American Medical Association* **267**(12): 1645 - 1648.
- . 1995. Educating Physicians for the Twenty-First Century. *Academic Medicine* **70**(3): 179 – 185.
- Hunt, D.L., Haynes, R.B., Hanna, S.E. and K. Smith. 1998. Effects of Computer-Based Clinical Decision Support Systems on Physician Performance and Patient Outcomes. *Journal of the American Medical Association* **280**(15): 1339 – 1346.
- Leininger, L.S., Finn, L., Dickey, L., Dietrich, A.J., Foxhall, L., Garr, D., Stewart, B. and R. Wender. 1996. An Office System for Organizing Preventive Services. *Archives of Family Medicine* **5**: 108 – 115.
- Lobach, D.F. and H.R. Underwood. 1998. Computer-Based Decision Support Systems for Implementing Clinical Practice Guidelines. *Drug Benefit Trends* **10**(10): 48-53.
- McDonald, C.J. 1976. Protocol-Based Computer Reminders, The Quality of Care and the Non-Perfectibility of Man. *The New England Journal of Medicine* **295**(24): 1351 – 1355.
- McDonald, C.J., Hui, S.L., Smith, D.M., Tierney, W.M., Cohen, S.J., Weinberger, L. and G.P. McCabe. Reminders to Physicians from an Introspective Computer Medical Record. *Annals of Internal Medicine* **100**: 130 – 138.

- McLeod, G. and D. Smith. 1996. *Managing Information Technology Projects*. Cambridge, MA: Course Technology.
- Nilasena, D.S. and M.J. Lincoln. 1995. "A Computer-Generated Reminder System Improves Physician Compliance with Diabetes Preventive Care Guidelines", in *Proceedings of the Annual Symposium of Computing Applications to Medical Care*, pp. 640 – 645.
- Sackett, D.L., Rosenberg, M.C., Muir Gray, J.A., Haynes, R.B. and W.S. Richardson. 1996. Evidence based medicine: What It Is and What It Isn't. *British Medical Journal* **312**: 71 – 72.
- Shea, S., DuMouchel, W. and L. Bahamonde. 1996. A Meta-Analysis of 16 Randomized Controlled Trials to Evaluate Computer-Based Clinical Reminder Systems for Preventive Care in the Ambulatory Setting. *Journal of the American Medical Informatics Association* **3**(6): 399 – 409.
- Shelly, G.B., Cashman, T.J. and H.J. Rosenblatt. 1998. *Systems Analysis and Design, 3rd Ed.* Cambridge, MA: Course Technology.
- Simon, A.R. 1995. *Strategic Database Technology: Management for the Year 2000*. San Francisco: Morgan Kaufman Publishers.
- Solberg, L.I., Kottke, T.E., Brekke, M.L., Conn, S.A., Magnan, S. and G. Amundson. 1998. The Case of the Missing Clinical Preventive Services Systems. *Effective Clinical Practice* **1**(1): 33 – 38.
- Task Force on Osteoporosis Guidelines. 1996. Recommendations for the Prevention and Treatment of Glucocorticoid-Induced Osteoporosis. *Arthritis and Rheumatism* **39**:1791 – 1801.
- The Jewish Healthcare Foundation of Pittsburgh. 1999. "The Information Transformation." *Branches*, May 1999.
- Tierney, W.M., Hui, S.L. and C.J. McDonald. 1986. Delayed Feedback of Physician Performance Versus Immediate Reminders to Perform Preventive Care: Effects on Physician Compliance. *Medical Care* **24**(8): 659 – 666.
- U.S. Congress, Office of Technology Assessment. 1995. *Bringing Health Care Online: The Role of Information Technologies*. OTC-ITC-624. Washington, DC: U.S. Government Printing Office.
- U.S. Preventive Services Task Force. 1989. *Guide to Clinical Preventive Services, 2nd Ed.* Baltimore: Williams and Wilkins.
- Whitten, J.L. and L.D. Bentley. 1998. *Systems Analysis and Design Methods, 4th Ed.* Boston: Irwin McGraw-Hill.

Van Bommel, J.H. and M.A. Musen (Eds.) 1997. *Handbook of Medical Informatics*. Bohn, Germany: Houten/Diegem.

Virtual Naval Hospital. 2000. *Hyperlipidemia*. World Wide Web:
<http://www.vnh.org/GMO/ClinicalSection/50Hyperlipidemia.html> (accessed May 3, 2000)

Zheng, K., Padman, R., Johnson, M.P., Engberg, J. and H.M. Diamond. 2004. "User Acceptance and Adoption of a Clinical Reminder System in Ambulatory Care: A Developmental Trajectory Approach." Under review at *Journal of the American Medical Informatics Association*.

Tables and Figures

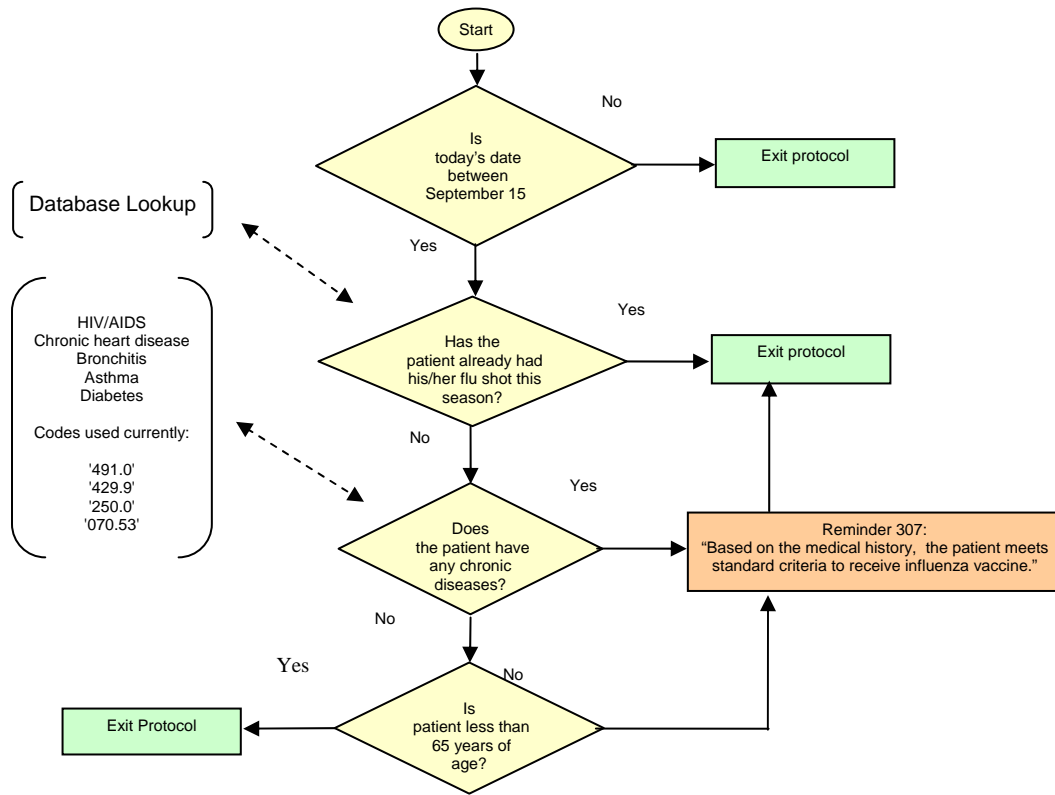


Figure 1: Decision Tree for Influenza Vaccine

Figure 2 Sample Questions and Reminders from CRS

Sample patient data:

Patient characteristics: Male, Age 50, Height 5'10'', Weight 230 lbs, BP 140/90, Smoker.

Diagnosis: Diabetes.

Lab Tests: Urinalysis in last 12 months (value: -5), HBA1C in last 6 months (value: 7.5),

Lipid test in last 3 months (LDL value =180).

Sample “on the fly” questions:

Has the patient received steroid treatments for more than three months? (Reason: to determine if patient meets criterion for prevention of Steroid-Induced Osteoporosis protocol.)

Sample reminders (reminder #, protocol, statement, rationale):

[309 - Pneumococcal Vaccine] Based on the medical history, the patient meets standard criteria to receive pneumococcal vaccine. (Reason: patient has chronic diseases and no history of the vaccine).

[109 - Diabetes] The patient's body mass index is above the desired level. Do you wish to discuss weight maintenance with the patient? (Reason: diabetic patient, BMI over 30.)

[105 - Diabetes] The patient's HBA1C level is above the recommended target level. Do you wish to consider adjustments in treatment and/or additional patient education? (Reason: diabetic patient, latest HBA1C test within 6 months and result value over target level.)

Figure 2: Sample Questions and Reminders from CRS

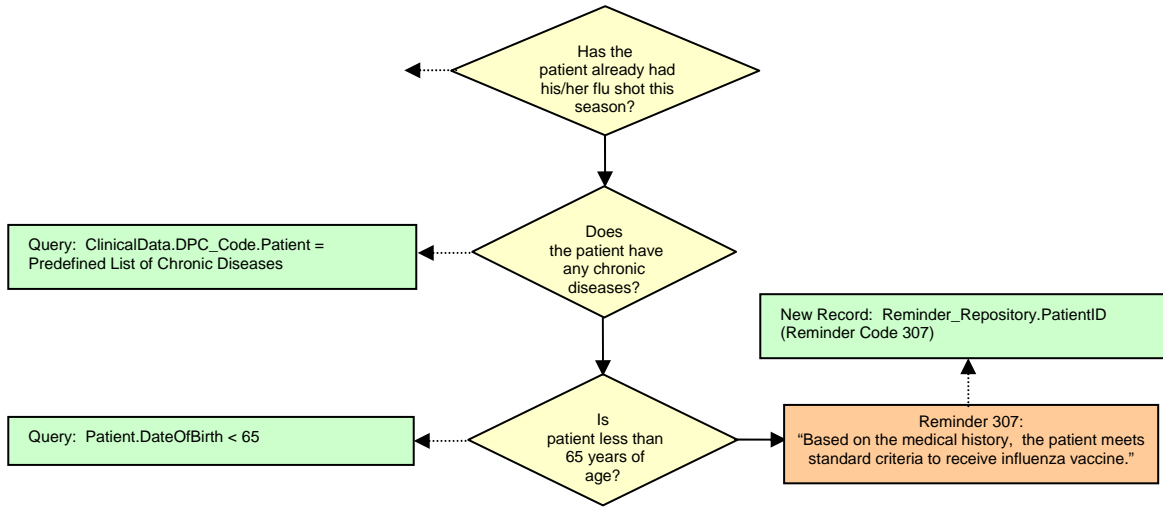


Figure 3: Data Elements Associated with Influenza Vaccine

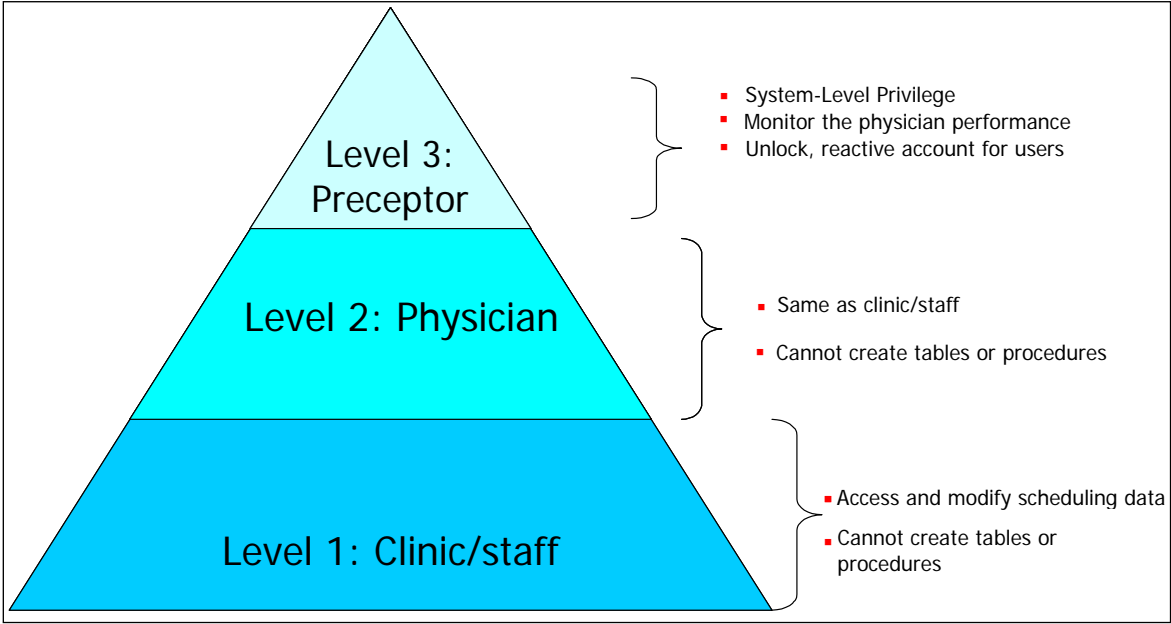


Figure 4: Proposed User Roles and Privileges for Confidentiality and Security

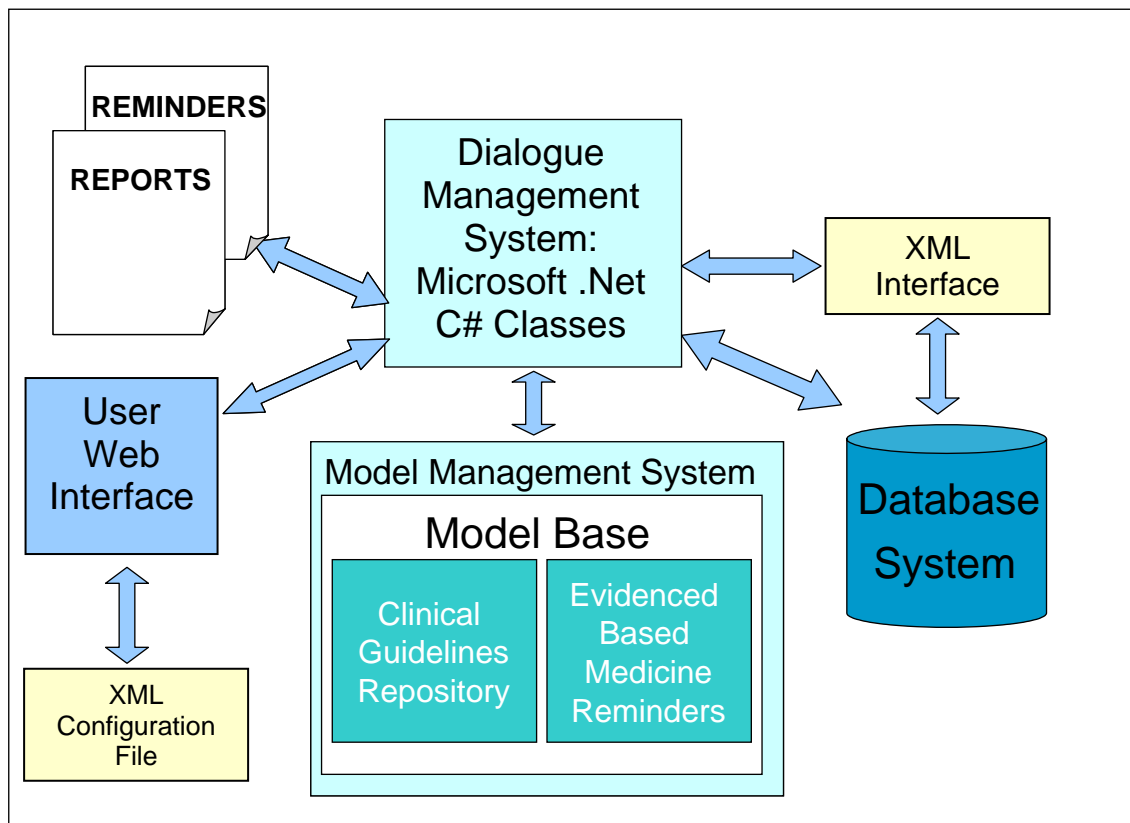


Figure 5: Conceptual System Architecture

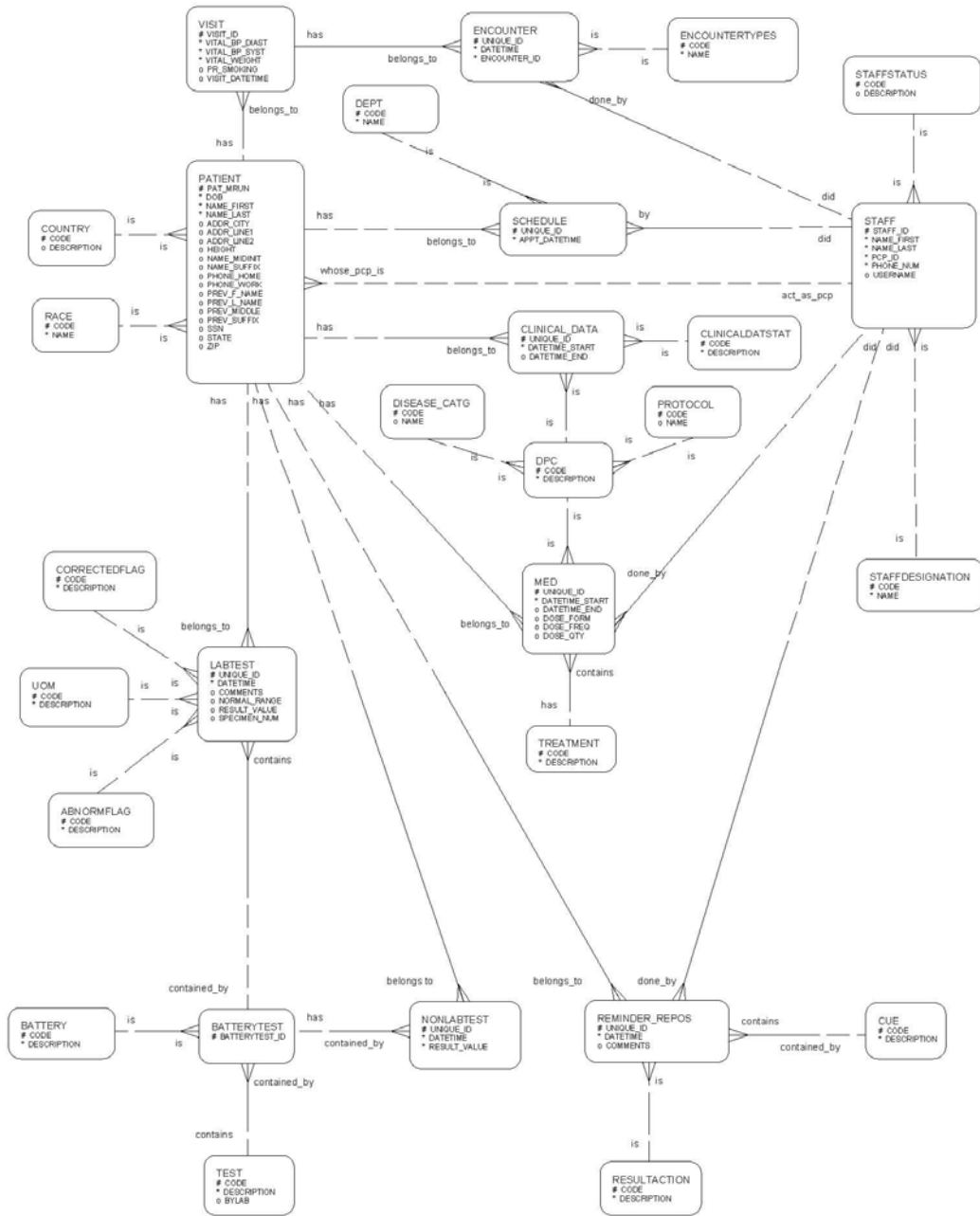


Figure 6: Entity-Relationship Model

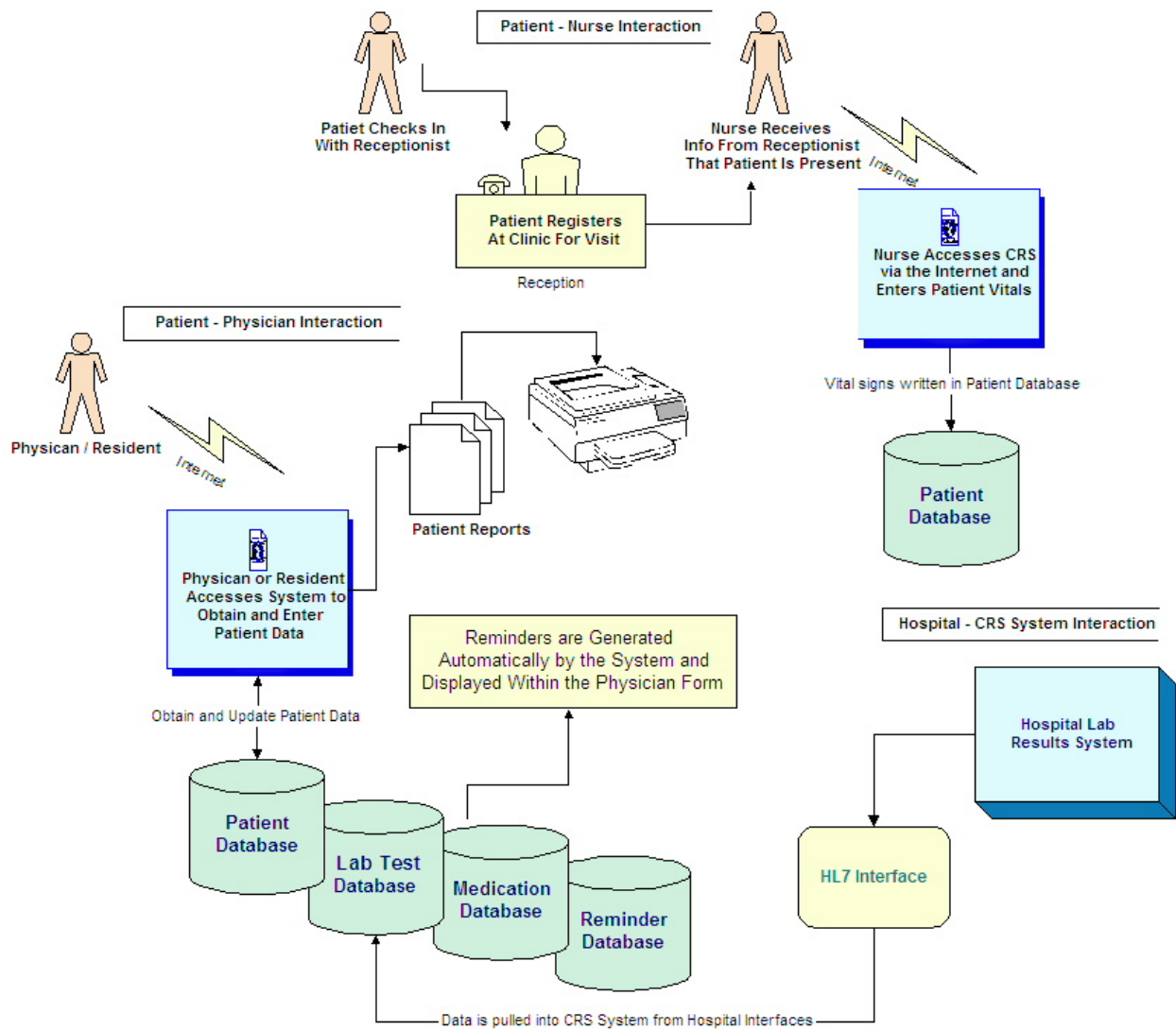


Figure 7: High-Level Data Flow Diagram for Reminder Generation Process

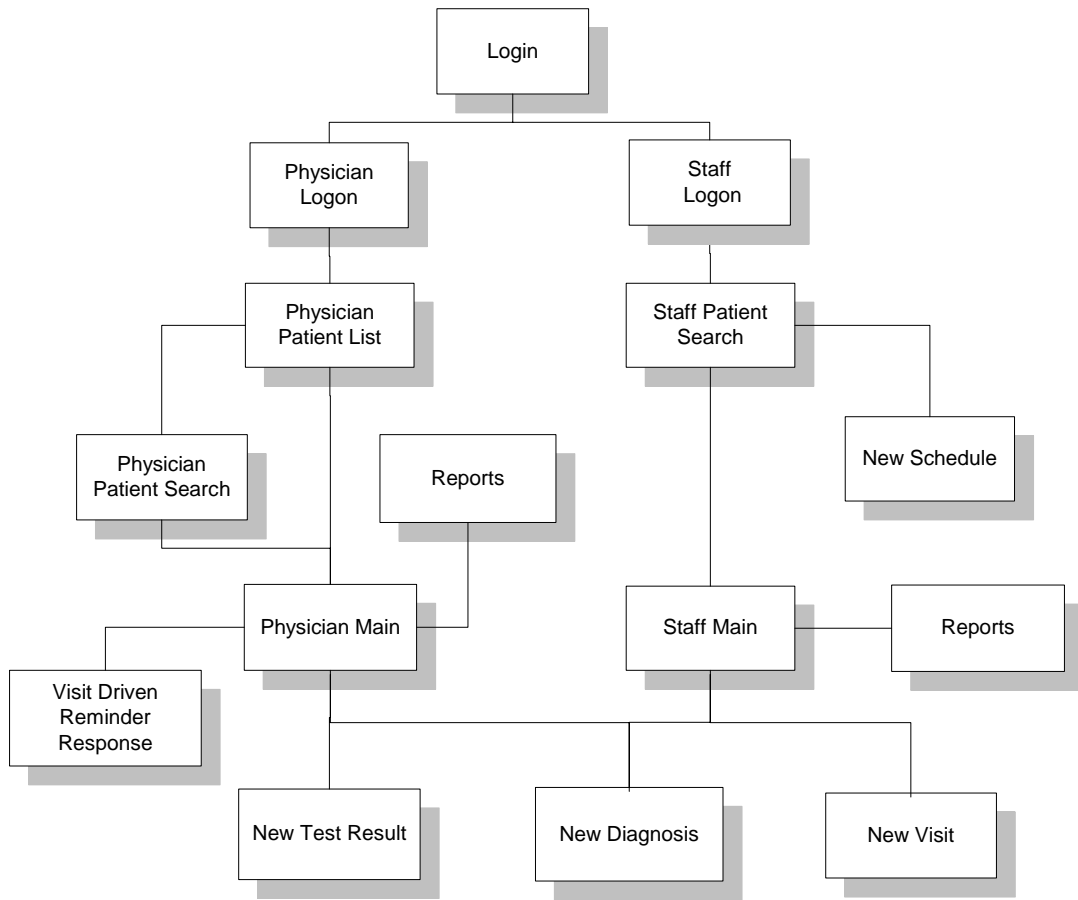


Figure 8: Interface Hierarchy

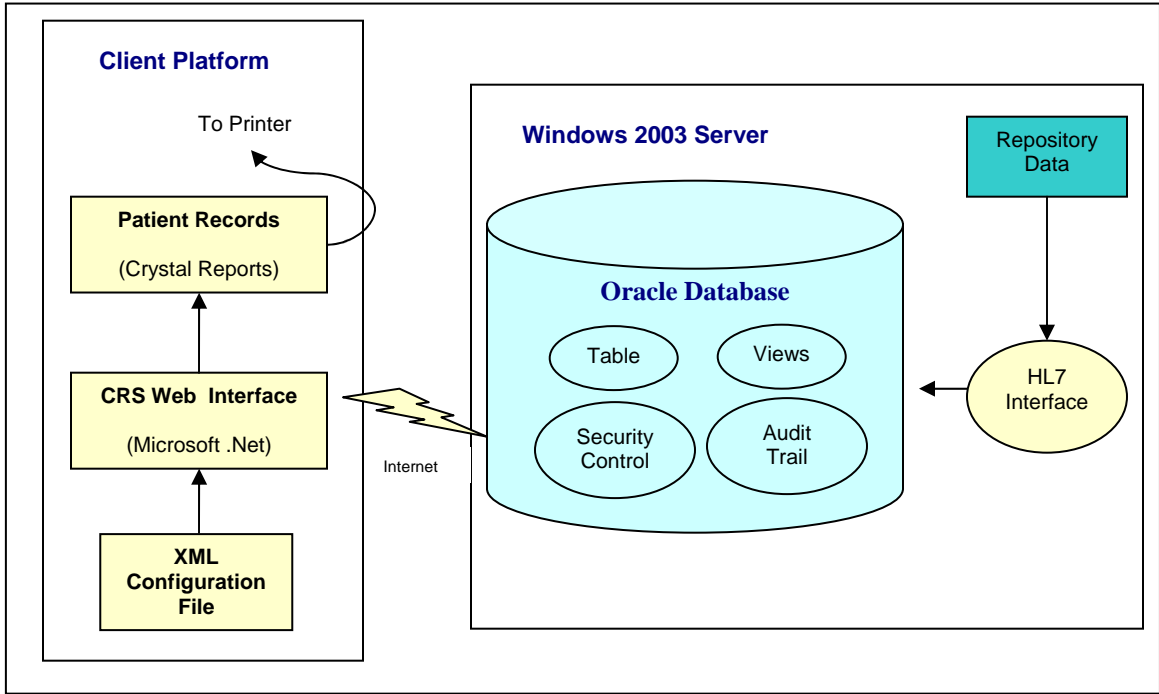


Figure 9: Actual System Architecture

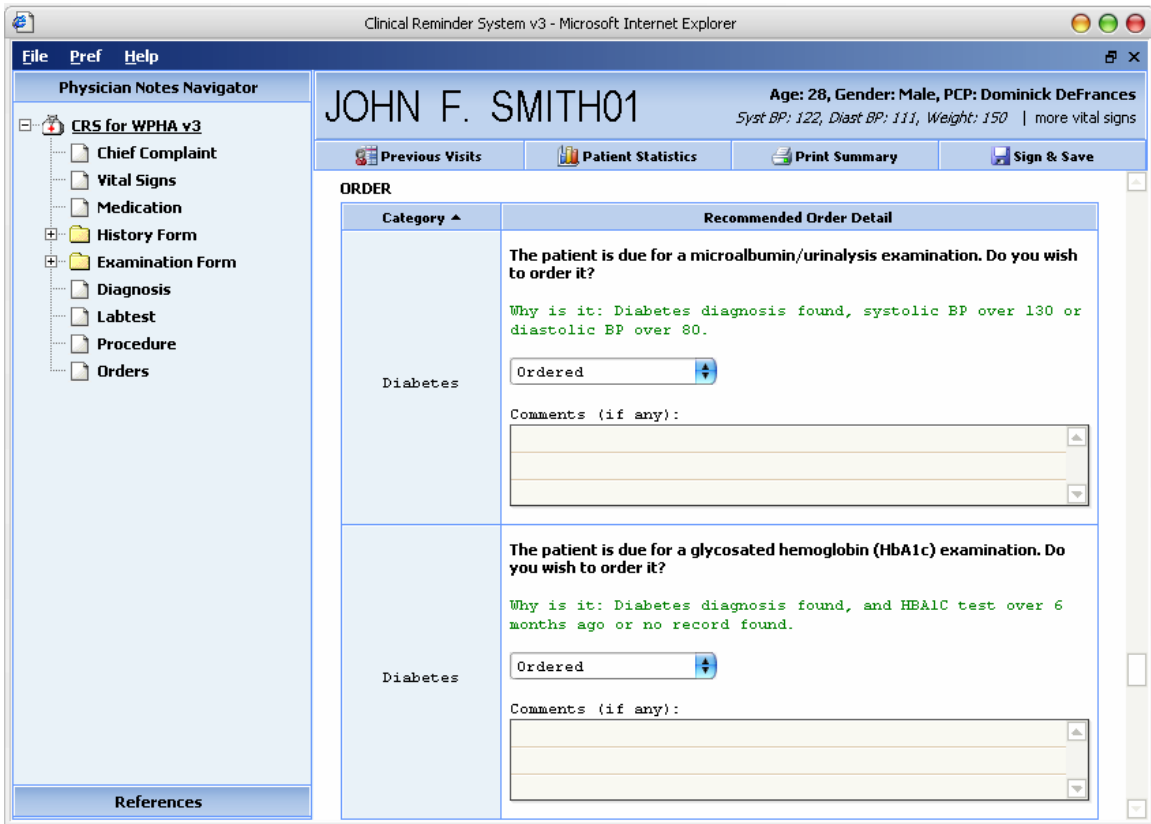
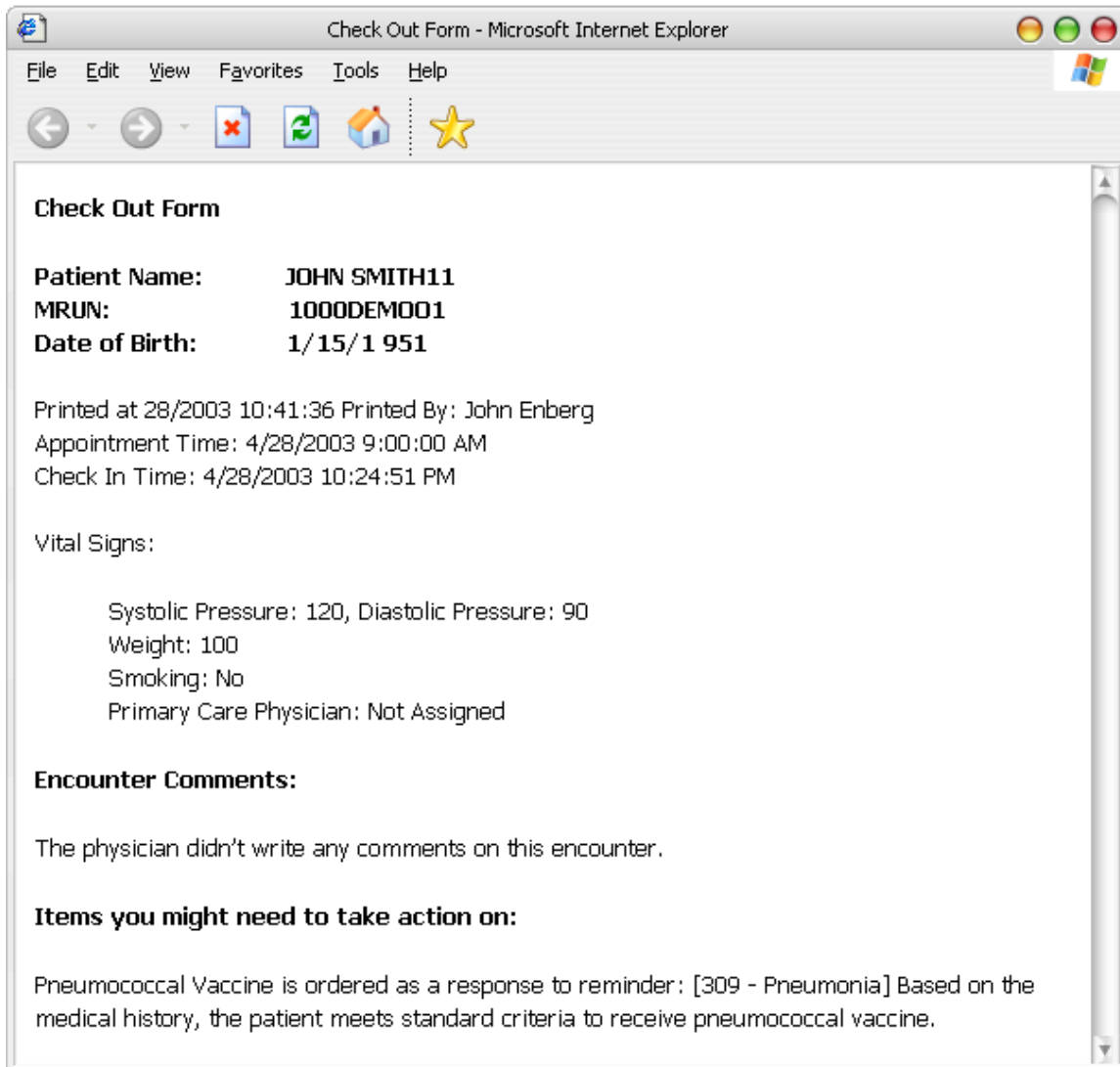


Figure 10: Physician-Directed Interface



[Figure 11: Patient Check-Out Report]