Health Care Informatics

Intelligent Systems Applications in Health Care

Final Report
March 2005

Study Commissioned by:

precarn

Intelligent Systems. Thinking Technology.
Systèmes intelligents. Penser technologie.

Study conducted by:

UNIVERSITY OF CALGARY

CHAPS
CENTRE FOR HEALTH AND POLICY STUDIES

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Health Care Informatics

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Executive Summary

Canada is experiencing unprecedented growth in interest and innovation with respect to information and communications technologies in health care. Central to the evolution of health informatics in Canada is the pan-Canadian electronic health record, which has received substantial investment at federal, provincial, regional, and institutional levels, with additional and recent support from Canada Health Info*way* Inc. The success of this investment will depend, in part, on the health care information technology industry in Canada. This industry has limited markets and substantial competition from other countries. At the same time, there has been limited investment in information technologies in health care, as compared to investment in other industries such as transportation and banking.

Not surprisingly, computer-based applications comprising intelligent systems have thus far had little or no impact in health care, despite the potential social, economic and clinical benefits. Artificial intelligence technologies offer substantial opportunities to present enhanced knowledge to the user. Accordingly, there is a real and apparent opportunity for increased application of intelligent systems to health care.

This Report addresses the current state of decision support systems and various intelligent systems technologies that can be deployed to assist decision makers, whether they be public, patients, physicians, managers or policy makers. Based on extensive literature review, this paper categorizes intelligent systems technologies into multi-agent systems, discrete event simulation, formal reasoning, evolutionary algorithms, planning and scheduling systems, machine learning and data mining, image analysis and natural language understanding. This provides the conceptual and technological background for discussing future trends in health care in relation to the potential for intelligent systems, taking a five to ten year perspective.

In addition to the literature review, expert opinions on the state of the art and future trends in health informatics were solicited through a standardized survey, which took place in November and December 2004 and a workshop, which took place in January 2005.

Drawing from Canadian experience, survey and workshop feedback, this Report reviews potential social, economic and clinical benefits that would come from greater application of intelligent systems. Intelligent systems were perceived to offer great promise with regards to improving efficiency and effectiveness in health care. Using intelligent systems as assistive technology could greatly increase the productivity of health care workers, improve quality of care and allow for more efficient use of resources. Not withstanding this potential, many barriers exist to the adoption of these technologies in health care. In particular, funding and access to patient data were perceived as major challenges. Despite these challenges, it was suggested that Canada was well positioned to take a leadership role in the development and implementation of intelligent systems for health care. The four strengths identified in the Canadian system were the single-payer, publicly funded health care system, the electronic health record, the intelligent systems community and Canadian health informatics vendors.

Substantial feedback was received as to future trends in health informatics and is discussed here in terms of electronic health records, privacy protection, wellness, patient safety, patient access, shifting care location, financial constraints, staff and resources, bio health informatics, and the health informatics sector.

Finally, the document concludes by recommending strategies to encourage more research and development and the commercialization of intelligence systems related to health care and the health informatics sector. These largely revolve around increased communication and collaboration between intelligence systems academic researchers, health informatics companies and health care institutions and organizations.

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1. Introduction to Healthcare Informatics

Health Care Informatics is a unique and challenging field. It represents convergence of the medical and clinical domains with the information technology sector. Even though information technology has played a vital role in other industries, such as the financial and transportation sectors, information technology has yet to make a similar impact in health care. Hence, health information technology and informatics in Canada has to be seen as in its infancy.

When the general public thinks about technology in health care, they have images of advanced diagnostic equipment such as MRI, CT Scanners and Intensive Care Units. When it comes to information technology and for instance, the "patient's medical record", they are surprised to find that it is still mainly paper-based.

Although hospitals and health care clinics have employed many variations of health care information systems in the past, currently the "intelligent aspect" of these systems is extremely limited or altogether non-existent. Often these systems are based primarily on capturing data and redisplaying that data in much the same way as a paper chart; in essence, digitizing the paper record. The intelligent aspect of these systems often equates to little more that changing the color of the lab value when the result is out of range, signaling alerts for potential drug interactions or providing simple rule-based guidelines for treatment. These are useful knowledge tools, yet they represent only the infancy of research, development and implementation of intelligent systems in the health care environment.

The structure of health care information systems as they exist in most hospital environments can be seen as follows (Figure 1):

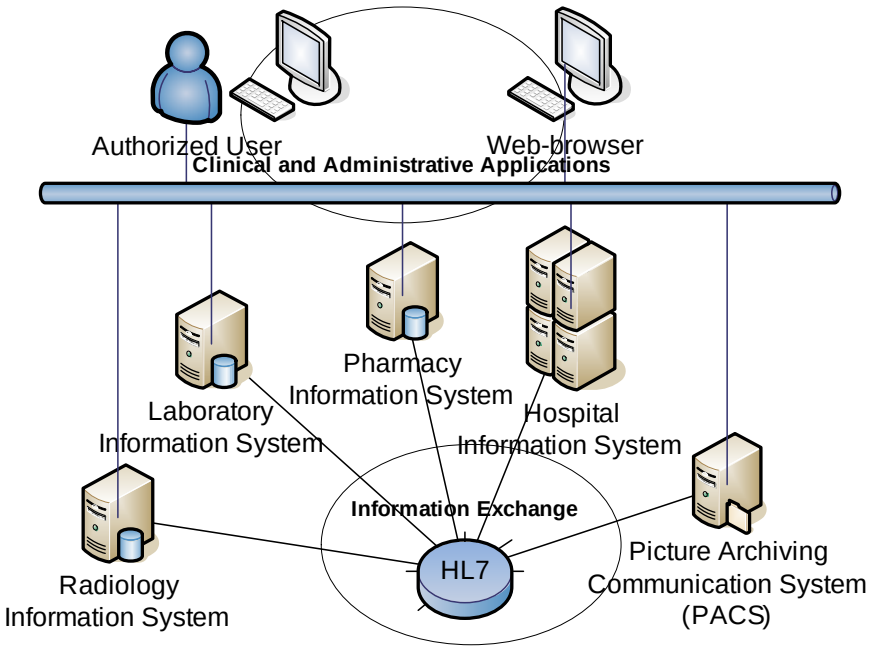

Figure 1 - Hospital Information Systems Topology

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Hospitals typically have several key information systems that relate to various departments or functions. These include the Laboratory Information System, Pharmacy Information System, Patient Placement (Admission Discharge Transfer System), and other systems such as a Radiology Information System, Picture Archival Communication System (PACS), Order Entry System and various clinical specific Information Systems.

The Hospital/Clinical Information Systems form the basis of the Electronic Patient Record as they bring together and collate data from the other systems to represent a comprehensive longitudinal patient record.

Each of these systems transfers information between each other using a protocol called Heath Level 7 (HL7) for text-based information, and a protocol called Digital Imaging and Communications in Medicine (DICOM) for diagnostic imaging information. These protocols are widely used and represent international standards for data transfer in health care. They are critical components of health care informatics, because interoperability (the ability for systems to communicate between each other) is essential and has been a limiting factor for health care information systems in the past and must not be in the future.

Broadly considered, intelligent systems can be best described as computer-based applications that provide decision support. The nature and intent of the decision support is found within an assortment of technologies such as data mining, agent-based models, machine learning, expert systems and simulation modeling. All of these technologies could potentially be applied in health care to present much-enhanced knowledge to the user. Thus, it is reasonable to assume that their increased application in the health care industry can yield significant gains, particularly in relation to quality and safety, and substantially improved tools for managing resources and decision making.

Health care has some track record of applying intelligent systems. One of the earliest expert systems ever developed was used to diagnose and recommend medical treatment for certain blood infections. This system was called Mycin and was developed at Stanford University in the 1970s. However, despite expert prediction that artificial intelligence would be applied in health care and would have a significant impact, the use of intelligent systems in clinical practice remains extremely limited. Some would argue that this has been partially the result of persistent use of paper-based medical records.

It should also be noted that health care informatics has continued to expand beyond an acute care focus, into the community as part of home care, telemedicine and home monitoring, patient education and wellness programs. Moreover, health informatics is being applied to great effect in health care administration, in areas such as capacity planning, staffing and resource allocation. Indeed, many of the ongoing health informatics projects in Canada revolve around applying intelligent systems to manage common administrative problems. These projects include:

- Development of new methodologies and systems to manage waiting lists and times.
- Research and development to improve resource utilization, such as the effective use of hospital beds and streamlining of patient flow.
- Identification of high-risk patient populations in the community and the development of outreach systems to adequately address their issues.

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2. Healthcare Informatics Intelligent Systems Applications

Health informatics often uses the term Decision Support Systems (DSS) to encompass a wide-range of intelligent solutions and systems technologies.

DSS are designed to help decision makers, whether they be patients, physicians, administrators, policy makers or other users, to anticipate the consequences of particular options and point out possible decisions that will lead to a desired outcome. As such, DSS are not the decision makers, they are the tools for the decision maker. These tools are closely related to formal reasoning, evolutionary algorithms, planning and scheduling systems, data mining and machine learning. Specifically, DSS incorporate the aforementioned elements to simulate outcomes, and vary inputs in these systems to elucidate the best options.

Intelligent systems are integrated into healthcare applications in several ways.

- Embedded into medical hardware
- Embedded directly into heath care software applications such as laboratory or pharmacy information systems
- Developed as parallel systems that communicate with other health care software applications, using health care specific messaging standards or other technologies, such as web services.
- Developed as a "Stand-alone system" that has no connectivity with other software applications.

An example of an intelligent system developed to communicate with other health care software applications can be seen below (Figure 2).

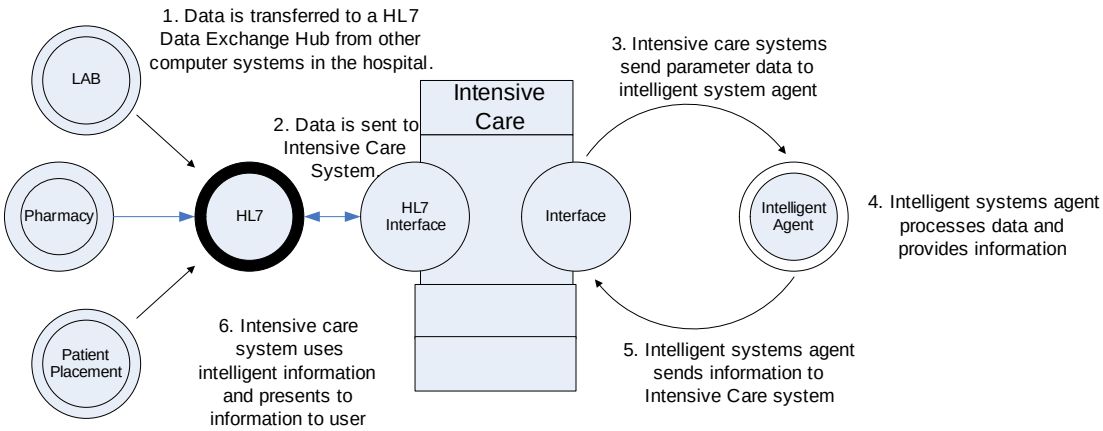

Figure 2 - Intensive Care Intelligent Agent

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This system shows three feeder systems, laboratory, pharmacy and patient placement, channeled into an Intensive Care information system through an HL7 interface.

The Intensive Care system then communicates with an Intelligent Agent system through another interface, for instance a web service. All the relevant data is transferred to the Intelligent Agent system which then performs some action by utilizing the data. This "action" can be anything, from predicting the likelihood of mortality for a specific patient to looking for a pattern/trend in the data provided.

The Intelligent Agent system then passes back the newly derived "information" to the Intensive Care system where the information is used appropriately.

To facilitate the deliberation and dialogue about intelligent systems and examine their present and future applications in health informatics, this paper categorizes the various intelligent systems technologies into several broad categories;

- Multi-Agent Systems
- Discrete Event Simulation
- Formal Reasoning
- Evolutionary Algorithms
- Planning and Scheduling systems
- Machine Learning and Data Mining
- Image Analysis and Understanding
- Nature Language Processing

The following is a description of these individual categories, and their possible application in health care.

2.1 Multi-Agent Systems (MAS)

Multi-Agent systems (MAS) deal with concepts that attempt to achieve cooperation, or at least co-existence between independent intelligent entities. This could be represented as a patient having several software agents, each responsible for a specific function, cooperating with other agents that may represent other hospital functions, such as scheduling. As such, MAS are very well suited to model distributed processes (Godo *et al.*, 2003; Moreno and Garbay, 2003; Richard *et al.*, 2004; Silverman *et al.*, 1998; Vicari *et al.*, 2003).

Usually, agents are assumed to have specific goals, such as watching over a patient's pharmaceutical record or being responsible for a patient's laboratory record. MAS try to establish processes by which most of the agent goals can be fulfilled, by interacting with other agents to ensure that specific tasks are undertaken and achieved. An example of this may be a patient's treatment sequence being guided by standardized clinical practice guidelines with inputs and information from multiple systems or a patient's placement on the waiting list being informed by specific laboratory or diagnostic imaging test results,.

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Realistic and possible applications of Multi-Agent Systems include:

- Pharmacy Drug-Interaction intelligent agents cooperating with intelligent agents representing individual patients, and scrutinizing laboratory test results and the prescriptions of these patients to identify side-effects unfavorable drug-drug interactions and adverse drug reactions.

- Intelligent agents managing hospital resources involving the care of an individual patient, such as scheduling appointments and discharge planning.

2.2 Discrete Event Simulation

Discrete Event Simulation has been used in health care for several decades. However, it has failed to gain widespread adoption, as have many tools drawn from the fields of Operations Research and Industrial Engineering. Discrete Event Simulation is the creation of a computer model that imitates the behavior of a system or situation. The use of simulation to model variables allows the prediction of how the system would work, based on the inputs of the model.

Examples of Discrete Event Simulation applications to health care include models developed to examine and analyze the impact of patient flow in emergency rooms (Anonymous, 2004; Coats and Michalis, 2001; Kilmer *et al.*, 1997; Liu *et al.*, 2003; McGuire, 1997; Miro *et al.*, 2003; Simon *et al.*, 1997), operating theaters (Dexter *et al.*, 1999; Hansen, 1998) and critical care units (McManus *et al.*, 2004). These models often form the basis for implementing new workflow measures, staffing models or even prompt the creation of new facilities and wards.

Realistic and possible applications of Discrete Event Simulation models include:

- The development of models to examine how hospitals could cope with a public health epidemic such as SARS or a pandemic flu.

- The development of systems that reflect how Emergency Rooms function and where improvements could be applied in order to reduce the waiting times of emergency patients and to improve ambulance turn-around times.

- The development of models to simulate and assess waiting lists for hip replacements or MRI scans and the development of new methodologies/approaches such as alternative queuing strategies to shorten waiting times.

2.3 Formal Reasoning

Formal Reasoning Systems are based on mathematically described theories. These define how new knowledge can be inferred out of existing knowledge. Such systems include; theorem provers, that use mathematical descriptions of logic, and so-called calculi suggesting possible deduction steps; Bayesian networks that allow reasoning with probabilities; and, rule-based systems (Andreassen *et al.*, 1999; Antal *et al.*, 2004; Coupe *et al.*, 1999; Delgado *et al.*, 2001; Imberman *et al.*, 2002; Kwok *et al.*, 2003; Lucas *et al.*, 2004; Tsakonas *et al.*, 2004).

The rigorous mathematical background behind Formal Reasoning Systems allows for the establishment of guarantees behind every deduction/recommendation that such a system makes.

Realistic and possible applications of Formal Reasoning Systems include:

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- Triage of incoming patients and rendering projections of future treatments, based on systems developed using learned Bayesian networks.

- A rule-based system related to surveillance of hospital-acquired infections. In this example, the system would constantly be analyzing new data, such as microbiologic cultures, and going through a series of rules to determine if new cases represent an outbreak of a hospital-acquired infection.

2.4 Evolutionary Algorithms (EA)

Evolutionary Algorithms (EA) are a large family of methods for problem-solving and optimization, that are inspired by the biological process of evolution. EA work on sets of potential solutions, producing new solutions by combining successful old solutions, and removing old solutions that are worse than all of the other ones currently under consideration.

Programs using EA have shown that they are capable of achieving results very similar to those that humans attribute to the use of intuition. Consequently, EA are often applied in machine learning and for problem-solving when little information is available.

Realistic and possible applications of EA include:

- Optimizing workflow processes, mining data and detecting safety flaws in procedures. (Marvin *et al.*, 1999; Paetz, 2004; Pena-Reyes and Sipper, 2000; Shun Ngan *et al.*, 1999; Tan *et al.*, 2003).

2.5 Planning and Scheduling Systems

Planning a sequence of decisions or steps that lead to achieving a given goal is the core ability of intelligent systems and the genesis of the discipline Artificial Intelligence (Dexter, et al., 1999; Hashimoto and Bell, 1996; Hulsey, 1999; Spyropoulos, 2000; Wright *et al.*, 1996). The ability to deal with uncertainty in both planning and planned implementation has been at the core of research in this area. Planning has to consider various constraints dealing with temporal, spatial, and other restrictions. While the number of constraints and steps in a plan influence the efficiency of a planning system, state-of-the-art planning and scheduling goes far beyond human capacity.

Obvious application areas of such systems in health care are scheduling of planned examinations for patients, or management and procurement of supplies for a hospital. The latter is becoming increasingly important, given the expansion of e-commerce.

Realistic and possible applications of intelligent Planning and Scheduling systems include:

- Effective scheduling of nursing staff to minimize stress leave and sick time and maximize employee retention.

- Effective scheduling of elective surgery based on urgency and urgency-related maximum acceptable waiting times.

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2.6 Machine Learning and Data Mining

Machine Learning (ML) deals with the development of systems that are able to find and create new knowledge out of examples and/or experiences. This ability can then be used to improve the performance of other systems. Due to the many different kinds of knowledge and different ways to represent knowledge, there is a multitude of ML methods.

Data mining refers to the application of ML to large collections of data. This imposes additional requirements on the efficiency of the learning. Also, a good understanding of database systems is required to meet the performance requirements associated with large amounts of data.

Given the enormity of data collection in health care, there are many possibilities for applying ML and data mining in health informatics (Breault *et al.*, 2002; Cios and William Moore, 2002; Delgado, et al., 2001; Isken and Rajagopalan, 2002; Lavrac, 1999; Marik and Hedman, 2000; Shun Ngan, et al., 1999).

Realistic and possible applications of Machine Learning and Data Mining include:

- Development of new "Expert Systems" for clinical decision making out of existing data sources. This approach is extremely advantageous, as the expert system could be developed from past clinical treatment information. The "machine" has the capacity to learn several ways to diagnose or treat a specific condition.

- Elucidation of unknown patterns, such as identifying high-risk or high-use patient groups from clinical and administrative data.

2.7 Image Analysis and Understanding

Image analysis systems extract knowledge out of visual information. These systems are gaining particular prominence in health care and medical diagnosis. This growth has largely been the result of the adoption of digital radiology systems such as MRI, CT scanning, Ultrasound and the increasing use of digital x-ray machines instead of traditional film-based machines. This has also led to the increased use and implementation of PACS (Picture Archiving & Communication Systems) and industry standards such as DICOM (Digital Imaging and Communications in Medicine).

Image analysis systems face unique challenges in terms of the technology that is applied and also the issues encountered. Identifying objects in images, their relation to each other, the similarity of an object to a prototype object (from any angle of view) and also tracking objects within sequences of images are among the most important research topics in this area.

There are many applications of image analysis and understanding in medicine and health care, because of its potential capacity to work with all kinds of imagery. These include creating models or comprehensible pictures out of various sensor data. There are many ways in which image analysis can be used to detect unusual objects (for example, tumors in x-rays) or unusual behavior of picture elements in image sequences (for example, pointing out an irregular heart beat or unusual brain activity). (Dojat, 2004; Hothorn and Lausen, 2003; Ohlsson, 2004; Richard, et al., 2004; Sorensen *et al.*, 2001).

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2.8 Natural Language Understanding

Natural language understanding deals with extracting knowledge out of information provided in the form of language. The information can be textual, such as a document, but may also be part of a spoken conversation.

Some of the challenges encountered in extracting information form textual or spoken language are the interpretation of ambiguous words and figures of speech. In addition, for spoken information, it is a challenge to identify the spoken words, especially if several people are involved in the conversation. Similarly for written information, identifying the correct meanings of words in the given context is a major challenge. Natural language understanding has made significant progress in this area over the last decade and there are already systems commercially available for medical and health care applications that require only a limited amount of customization when introduced into a new environment.

Realistic and possible applications of Natural Language Understanding include:

- Development of systems that are able to parse clinical free text, such as physician notes, and identify diagnoses and procedures that can be used in the coding of health record information for administrative or billing purposes.

- Development of systems that interpret verbal speech and allow this information to be placed within a clinical information system, where the information is not stored as “free text” but is referenced to the medical chart.

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3. Social, Economic and Clinical Benefits

Application of intelligent systems in health care has been slow to evolve despite examples of significant benefit to other industries. Thus, exploration of the potential benefits and further application of these technologies seems timely.

Survey respondents initially identified many possible social, clinical and economic benefits of the application of intelligent systems for health care. These were explored in substantially more detail at the workshop. Participants formed small groups to discuss the benefits of and potential barriers to further application of intelligent systems from three perspectives: patient/public, clinician/physician and administrator/policy maker.

Common themes identified in both survey responses and the workshop included:

- Enhancing patient safety through “intelligent watchful” systems.
- Improving patient access through better management of waiting lists and times.
- Maximizing the use of scarce resources, such as critical care beds.
- Improving the scheduling and efficiency of available resources, such as operating theaters and emergency rooms.
- Reducing unnecessary costs, such as unneeded or duplicated laboratory testing.

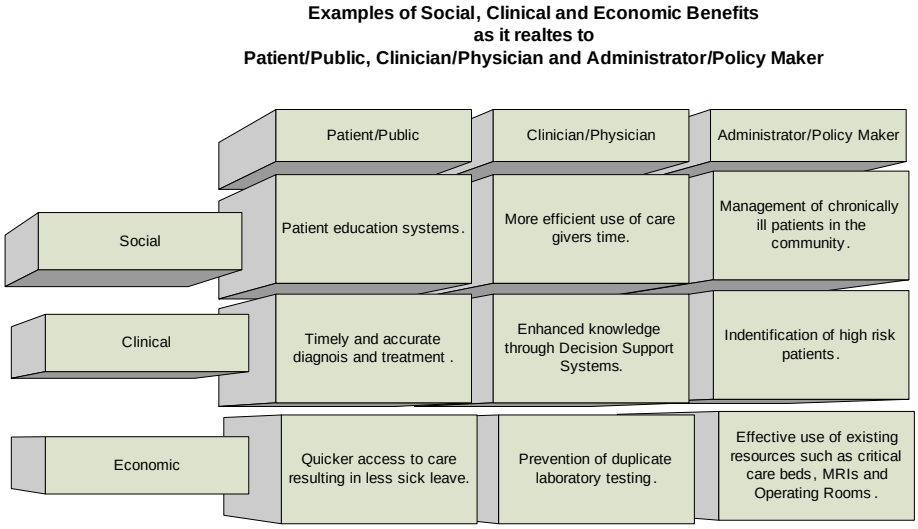

Figure 3 - Examples of potential social, economic and clinical benefits of the application of intelligent systems in health care

In general, the idea of deploying intelligent assistive technology to enhance the capabilities of the humans in the three decision making groups illustrated above was considered as an acceptable role for intelligent systems. In the workshop discussions, it became obvious that the early claims of intelligent systems researchers of “replacing” humans with artificial systems” still lingered in the minds of many health care professionals. A new approach of providing assistive technologies that can supplement, but not replace, care-givers is required.

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3.1 Patient/Public

There are many potential opportunities from the perspective of the patient/public in the application of intelligent systems related to health care needs.

An essential aspect of patient-centered decision making is the changing locus of care. In response to the preferences of patients and financial pressure within the health care system, care has increasingly relocated to ambulatory settings and the community. The application of intelligent systems in this environment would enable home care, self and remote monitoring and education of patients as their own care-givers, through the use of an increasing amount of information via internet.

Patient/public applications also tie into access. Canada is a vast country with unique "geographical challenges". Intelligent systems have the potential to contribute to quicker diagnosis and referral of geographically isolated patients.

A major unmet need, characterized by long waiting times, is access to scheduled or elective services. The management of waiting lists could be vastly improved through the application of intelligent systems. For example, intelligent scheduling systems could assess multiple factors concurrently in the placement of a patient on a specific waiting list. This system could rebalance the "waiting time" and "order of the patient" through intelligent means by trying to assess the clinical benefit of having the scan or procedure versus the social and clinical aspects of delaying care.

Not only is there a role for intelligent systems to aid in the treatment and diagnosis of patients, the population at large could also benefit from technologies designed for the prevention of disease, maintenance of wellness, and management of chronic diseases through, for instance, intelligently monitoring blood glucose levels for diabetic patients. A potential area of focus should be public health surveillance. An example of this is a public health surveillance system with the intelligent ability to recognize emerging patterns or outbreaks of disease, such as SARS or pandemic influenza.

An obvious and important benefit of intelligent systems in health care is the potential to improve patient safety that will come through the use of decision support systems, which would aid clinicians in the timely and correct diagnosis and appropriate treatment of patients.

3.2 Clinician/Physician

Clinicians and physicians process vast amounts of information from many sources in order to make diagnosis and treatment decisions. However, in some cases accurate and real-time information is not at the clinicians fingertips. Such a situation commonly occurs in the emergency room, where patients admitted are unable to provide their medical history to care-givers. Thus, in emergent situations treatment decisions may be delayed or clinically inappropriate, with potentially devastating consequences for patients.

In a clinical setting, intelligent systems present enhanced knowledge to the clinician, as well as providing a decision support element that may be as simple as providing a clinical practice guideline which outlines the recommended practice of care for that patients condition. These systems facilitate better clinical decision making because they provide relevant and timely information, thereby improving the efficiency and potentially the effectiveness of care. Clinician buy-in is essential in order to promote the use of decision support systems and there are varying

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opinions as to the receptiveness of clinicians to change and whether the right incentives to change exist.

However, there is agreement that the new generation of physicians and clinicians are more computer savvy and may embrace these emerging technologies in their clinical practice if they provide a clinical as well as a efficiency benefit.

3.3 Administrator/Policy Maker

Active areas of interest and research in the application of intelligent systems include the management of common administrative problems. Administrators would like to maximize efficiency and minimize cost, as in other industries such as the financial and pharmaceutical sectors, where intelligent systems have been deployed to great effect to improve process efficiency, thereby reducing costs.

In health care, there is a potential for great cost saving through the implementation of these systems, where they could aid in maximizing the use of scarce resources, improving the efficiency of available resources and reducing unnecessary costs. An intelligent system could be used to ensure that there is maximum and optimal use of scarce resources, such as MRIs and operating rooms, for example. This could be accomplished through a variety of intelligent systems technologies, such as scheduling and planning systems or discrete event simulation to optimize throughput.

Health care is facing major human resource challenges. Intelligent scheduling systems offer the ability to help plan the human resource needs for a hospital or ward based upon a combination of predicted patient flow demand, predicted workload and predicted staffing levels.

Intelligent systems naturally have the ability to offer a host of social, clinical and economic benefits by improving the quality and efficiency of care, overall.

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4. Potential Barriers

Despite the myriad benefits that may arise from the application of intelligent systems in health care there are many potential barriers to their implementation. Several key areas were identified by the survey respondents and workshop participants. As expected, funding was near the top of the list.

Other potential barriers included:

- Access to patient data and concerns about how that data will be used, while at the same time preserving privacy.
- Partnerships with health care organizations, including concerns about existing infrastructure, skill sets, and the ability for timely interaction.
- Variation in data standards and interoperability of systems between regions, provinces and internationally.
- Limited expertise in intelligent systems technologies and in the commercialization of health informatics software.
- Ethical concerns.

These potential barriers are discussed below:

4.1 Funding

As compared to other sectors, health care organizations spend relatively little of their annual budgets on information technology. Canadian hospitals spend on average 1.43% of their annual budget on information technology (Irving, 2003). Not surprisingly, funding was identified as a major barrier to research, development and adoption of intelligent systems in health care.

The fact that hospitals and other health care organizations need high-priority systems that must be implemented, but are restrained by existing budgets, presents a major challenge to the development and adoption of intelligent systems. It is a tough sell to propose innovative "unproven" technology in an environment that already has limitations around implementing "proven" systems. The risk that an organization accepts by adopting new technology is compounded not only by the actual development and implementation of the new system, but also by the uncertainty of its effectiveness.

Several health care organizations have adopted innovative strategies in tackling this issue. These include creating strategic partnerships with industry to share the costs and risks, acting as reference sites, and creating private-public partnerships.

It should be noted that the average 1.43% figure (Irving, 2003) presented does not include the influx of funding that has occurred over the past two years from provincial agencies such as

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Alberta Wellnet and Ontario's Smart Systems for Health or the federal government's contribution of 1.1 billion in 2003, through Canada Health Info*way* Inc. (Info*way*, 2004).

4.2 Access to Patient Data

A major barrier to the development of intelligent systems in health care is concern surrounding access to patient data.

Intelligent systems, in general, are data dependent and very data intensive. In short, data is essential to their development. Concerns around patient privacy, confidentiality, and security limit acquisition of data and remain a sensitive policy issue in health care. These concerns include consideration of the purpose and nature of the data, who will access it and for what purposes. For example, there will be substantially different considerations for an academic institution accessing waiting list data for approved research programs, versus a commercial enterprise wanting to data mine health records for laboratory and pharmaceutical information.

Options associated with improving access to patient data include anonymizing existing data sources through simulation or enhanced encryption methods. However, it is often extremely difficult to simulate new data due to the complexity of patient care. Simulated data may not perform as expected if it is not adequately validated against actual patient experiences.

Anonymizing data presents other issues. It is not simply a matter of providing an encryption algorithm on the patient identification number or last name. For instance, a unique set of symptoms or conditions may be traced back to an individual based on demographic data such as age, sex, admission date or even geographical region.

Data variability presents an additional challenge to information access and information exchange. Having said this, data access will improve when it is in electronic format. Clinicians and physicians will have easier access to patient information in emergent circumstances. In addition, more than one care-giver may view the patient's information at the same time and it will appear in different contexts depending on which care-giver is accessing it. For example, a physiotherapist and a respiratory therapist require different information upon reviewing a patient's chart.

The strength of Canada's pursuit of the Electronic Health Record has enabled information and data to be collected from a wide range of sources, in a wide range of clinical settings, from acute care to the community.

4.3 Partnerships

The establishment of supportive partnerships comprising academic researchers, commercial companies and health care organizations is seen as another potential barrier. Partnership is inextricably linked to funding. Even when there is clear support from administration and clinical personnel to partner with an academic or commercial company around the development and implementation of an intelligent system, the health care organization itself may be facing competing priorities or lack the infrastructure to support an innovative solution. Examples of this may be a hospital that lacks the information technology resources to dedicate to a joint project such as the creation of a system that requires an HL7 interface (a protocol for exchange of medical data) to feed the data to the new system. Other obstacles may arise because the hospital lacks the IT resources and/or skill sets to extract data from existing systems or even provide anonymization of the data needed for research and development of that new intelligent system.

In addition to the resource limitations around the health care organization's infrastructure, there may be limited long-term resources to actually adopt and support these technologies. Acquisition

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of new clients (other health care organizations) may also be impossible without first partnering with a health care organization and then validating that the technology is effective in that environment.

An additional issue identified in relation to the creation of partnerships was the long lead-time for the establishment of contracts in the publicly funded Canadian health care system. The sales cycle was typically viewed as long, often several years, which presents a challenge for implementing intelligent systems solution in a timely manner. The time it takes from when a new concept or opportunity is identified to when a partnership arrangement is put in place and the new technology is tested in a clinical setting, may leave some companies in Canada with a distinct disadvantage, as compared to similar entrepreneurs in the United States with shorter contract cycles.

Overall, it is believed that a strong partnership relationship with health care organizations is critical to the research and development of innovative systems.

4.4 Data Standards and Interoperability

The relative absence of data standards in health care was seen by survey respondents and workshop participants as a potential barrier to the creation and development of intelligent systems.

Despite standards like HL7, DiCOM and diagnosis coding systems that are accepted at an international level, implementation varies between provinces, regions and health care facilities. Other data standards such as patient identifiers, clinical terminology and normal values may also vary. In the case of clinical terminology there are competing standards, which add ever more complexity in this environment.

Data standards have a fundamental impact on companies that develop systems based on local-area standards. Each additional client may have to alter or recreate their software applications. The difficulty here relates to market size. Depending on the specific application, there may be relatively limited commercial opportunities and a ceiling for widespread adoption.

An area being addressed that should be highlighted, is the increased focus on the adoption of national and international standards by health care institutions. This permits an innovative technology developed in one region of the country to be re-deployed in another region of the country without having to re-develop significant components to make it compatible in that new environment.

Interoperability of systems is a related issue. This occurs when disparate systems are able to exchange data and information without difficulty. An example of this is the transfer of laboratory information from a laboratory information system to a critical care information system. Beyond interoperability is the use of open systems, which not only share data but may share program functionality as well. A Web Service is an example of an open system that can be shared through the internet.

From a computer science perspective, the problem of data standards is often coupled with the problem of open systems (Hewitt, 1985). While data standards are a must-have in open systems, open systems require more than just the existence of and compliance with data standards. The ability to make use of the functionality offered by other systems, the ability to easily offer their own functionality (which requires the ability to describe this functionality to others), and the ability to adapt to various environments are at the core of the requirements proposed by advocates of open systems.

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While there is not one all-encompassing solution to the problems of open systems in computer science, decision makers in health care and health informatics have limited knowledge of the work done in informatics with regard to open systems. This promises to be a substantial future barrier that could constrain the application of intelligent systems in health care, if it is not understood and addressed in a timely manner.

4.5 Expertise

Even though Canada enjoys a growing community of interest in intelligent systems, health care has really been a niche market in research and commercialization. Expertise in intelligent systems for health care will need to be built, encouraged and supported throughout Canada. This will include the future interaction of computer science and electrical engineering departments with health care organizations, and the increasing exposure of academics and industry to the issues and opportunities that health care faces.

Shortage in expertise refers not only to technical skill sets but also to entrepreneurial skill sets. Canada has been described as having a “cottage” health informatics industry, in terms of the development and commercialization of health informatics applications. There are shining examples of Canadian health informatics commercial successes, however, these are the exception rather than the rule, and survey respondents commented several times that there are many failed health care technology companies and products in the Canadian landscape. This creates an additional risk factor in terms of creating partnerships with health care organizations, as they are aware of this perspective and are traditionally risk averse and therefore even more unlikely to support innovative technology and projects.

Canada, however, does enjoy a strong health informatics consulting sector that is well versed in the implementation of technology, change management strategies and the overall Canadian health care marketplace. This consulting sector provides a valuable resource for opportunities in the development and implementation of intelligent systems in health care.

4.6 Ethical Concerns

There are many ethical concerns regarding the application of intelligent systems to health care which must be addressed before their adoption can become a reality.

An example that illustrates the ethical concerns around the use of information technology in patient care is in the case of acuity scoring with predictive survival algorithms for critical care patients. If a patient is admitted to the Intensive Care Unit with a computed 90% chance of not surviving their ICU stay, does this or should this affect how that patient will be treated?

Another concern expressed by survey respondents and workshop participants, is the issue of responsibility and culpability of care providers, who follow suboptimal or incorrect decisions based on the intelligent systems output. Who is responsible, the care provider, the systems inventor or both?

The issue of trust was also raised by survey respondents and workshop participants. Will patients have problems trusting a computer program to help make decisions about their care? Will and do patients trust the health care system and health care professionals to make appropriate use of their data? Will clinicians trust the suggestions provided by the intelligent decision support systems available to them. Most if not all of these issues could be addressed through further research into the application of intelligent systems in health care that demonstrate their safety and efficacy. Proving the benefits rather than merely talking about these new technologies would

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assuage much of the fear and address many of the ethical concerns regarding their widespread implementation in health care.

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5. Canadian Strengths and Opportunities

Canada has several key strengths and associated opportunities in health informatics that position it well for the future. Many of these strengths are unique to Canada and are the result of our single-payer, publicly funded health care system. A major advantage is the investment that has been made over the past two years by both the federal and provincial governments in an effort to expedite the development of a pan-Canadian electronic health record.

The key strengths can be summarized as follows:

- Canadian health care system
- Electronic health record
- Intelligent Systems community
- Healthcare informatics vendors and industry

These topics are explained more in depth below.

5.1 Canadian Health Care System

Canada's single-payer, publicly funded health care system is evolving to integrate the entire health care spectrum from acute care to public health and the community environment. This presents a unique opportunity and challenge for health information systems that are able to support a patient through multiple stages in the delivery process, whether it be location-specific (i.e. hospital, home care, long-term care, community) or care-related (i.e. preventative, acute, chronic).

As one survey applicant responded:

> "*If you view health care as being divided into three major phases -- preventive, acute, and chronic -- significant opportunities seem to lie at both the interfaces of these phases*"

Canada is ahead of other countries in this regard, as health care organizations in the United States are focusing on integrated organizational or business solutions, with less incentive to share personal health information across organizations.

Other countries share similarities with Canada and represent the potential for greater intellectual exchange as well as market opportunities, most noticeably Australia, New Zealand and the United Kingdom.

5.2 Electronic Health Records

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The pan-Canadian Electronic Health Record (EHR) that is being developed in the Provinces and Territories and partially supported by Canada Health Info*way* Inc. is an incredible opportunity for commercial health informatics companies and researchers. The EHR provides an opportunity for further research, using clinical and administrative data from a more accessible system. This creates a need for several types of intelligent systems to be researched and developed as the EHR will span clinical environments, as well as spanning various decision makers, including physicians, nursing staff, other healthcare professionals, managers, policy makers and patients.

The pan-Canadian EHR offers the additional benefit of supporting Canada's health informatics industry, as well as being a stimulant to the "creation of up to 2,000 healthcare IT jobs and reinforce Canada's international reputation as a global technology leader" (Info*way*, 2004).

However, it should be noted that Canada Health Info*way* Inc. has no mandate for economic development within Canada. This presents a challenge for small Canada companies competing for EHR contracts, as many of the vendors in this area are larger non-Canadian based companies.

5.3 Intelligent Systems Community

Canada enjoys a developing and strengthening intelligent systems academic community that includes several research groups who are internationally prominent in their respective fields of research.

These include:

- Machine learning, with strengths at the University of Alberta and the University of Waterloo.
- Probabilistic reasoning, with strengths at the University of Toronto and the University of Guelph.
- Multi-agent systems, with strengths at the University of Toronto, University of Waterloo, University of Calgary and University of New Brunswick
- Artificial Intelligence and games, with strengths at the University of Alberta and Simon Fraser University
- Search algorithms with strengths at the University of Alberta, University of Waterloo and University of British Columbia

Even though there is excellent research occurring at these centres, the application of this research to health care remains limited and sporadic. Any application that does occur is primarily the result of the individual researcher's relationships with the health care community. In addition, the application of this research to health care appears to be mainly "theoretical" in nature.

5.4 Healthcare Informatics Vendor Community

Canada has been described as having a "cottage" or "boutique" industry when it comes to product offerings and health informatics software development. These health informatics companies are usually smaller, focused on a niche market and have a geographical presence in one region of the country.

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There also appears to be a difference between the opportunities available in the acute care sector compared to the community care sector. The acute care sector is difficult to enter for health informatics vendors and is more resistant to change compared to the community care sector. This appears to be the result of a combination of factors. Firstly, the systems required in acute care hospitals are usually larger and therefore more expensive. In order to develop these larger systems such as Hospital Information Systems, Laboratory Information Systems and Pharmacy Information Systems a major investment in software development is required and the Canadian market may be too small for these large systems to originate, develop and be commercialized.

Second, it appears that acute care facilities are more risk adverse when it comes to dealing with small companies. This puts Canada's "cottage" industry at a disadvantage when introducing new products, because hospitals and health care regions may be looking for a larger company to provide more stability and ensure the longevity of their investment. This said, there are examples of several Canadian companies focused on the acute care sector that continue to innovate and development leading-edge solutions and because of their successes, many of these companies have become industry leaders in their product and services offerings. However, during the past few years, several of these Canadian-based companies have become acquisition targets for larger US-based companies. These include:

- A.L.I. Technologies (Diagnostic Imaging) acquired by McKesson Corporation in 2002.
- BDM Information Systems Ltd (Pharmacy) acquired by GE Medical Systems in 2002.
- Triple G Systems (Laboratory) acquired by GE Medical Systems in 2003.

In addition to the innovative product companies, survey respondents and workshop participants widely felt that Canada had a strong health care informatics consulting sector that provided many of the hospitals and health care regions with technical expertise and local solutions.

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6. Future Trends – Five to Ten Years

Comments were collated from survey responses, phone interviews and the workshop into ten broad categories representing perspectives on the 5-10 year trends in health care and health care informatics.

The ten categories are as follows:

- Electronic health records
- Patient privacy
- Wellness and aging demographics
- Patient safety
- Patient access
- Continued shift of care from acute care to community-based locations
- Financial constraints
- Staffing resources
- Bio health informatics
- Health Informatics sector

They are explained in detail below.

6.1 Electronic Health Records

Implementing the Electronic Health Record (EHR) is viewed as a fundamentally important trend in the next five to ten years. The EHR goes beyond an electronic version of the paper-based chart and provides the opportunity for accessing patient information in all care environments, from community-care to acute-care.

One of the main reasons for optimism around the EHR is Canada Health Info*way's* support for interoperable pan-Canadian EHR solutions. Canada Health Info*way* Inc. has increased its capitalization from $500 million to $1.1 billion in 2003 (Info*way*, 2004). This is allowing health informatics infrastructure projects and investment in other building blocks of the EHR.

Essential to the EHR is the requirement of interoperability and data standards, which will allow information exchange between the various systems that make up the EHR. The ability to access data in real-time also presents the opportunity to build parallel systems that provide intelligence based upon the data flowing from one clinical system to another.

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Intelligent systems that could be developed to interact with the EHR include real-time decision support using a variety of technologies, as well as alert-based systems that can scan for patterns in real-time.

With the development and deployment of the EHR, it is envisioned that there will be massive clinical and administrative data repositories. These information resources are of major interest to researchers and medical professionals, as well as managers and policy-makers. Such databases will allow the study of population trends in health, for instance rising obesity rates, and will provide accurate administrative data and track resource utilization.

6.2 Patient Privacy Issues

The capacity and need to collect, use, and disclose personal health information forces central consideration of patient privacy. Information exchange and access has to be accompanied by sound rules for privacy protection, confidentiality, and security.

As the EHR is implemented, more and more data on individual patients will be collected and stored in an electronic format. Issues around data stewardship, access and usage will become significant concerns and must be effectively managed. It should be noted that intelligent systems themselves can greatly contribute to solving these issues since they can be used in upholding established privacy policies, in very much the same as they are used in financial institutions to prevent unauthorized use of credit cards.

6.3 Wellness

The concept of healthy aging and wellness was identified as a major theme for the next five to ten years. This is based upon growing knowledge of the trends from a population health, health promotion and disease prevention perspective. Such a trend will demand better information for patients and the public.

An aging population presents its own challenges. With it, it is expected that additional funding will be needed to maintain the health care system. People will be living longer and incurring increased health care costs, thereby putting a greater strain on the health care system. Chronic disease management systems become ever more important and an essential component of the health care system for managing this growing segment of our population.

The opportunities that exist for the creation and deployment of intelligent systems are vast in this area, including often-overlooked solutions of knowledge-based educational systems, which focus on providing information to the patient about wellness, aging and chronic disease management.

6.4 Patient Safety

Patient safety is an essential theme and trend that will continue to be at the forefront for all health care organizations for the next 5 to 10 years.

“To Err is Human” (Linda T. Kohn, 2000) has propelled this issue into the limelight and emphasized the importance of addressing it.

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From the survey, the most commonly cited focus around safety was on drug interactions, and the adoption of systems that could prevent drug errors. An example of how an intelligent system could be applied in the prevention of drug interactions is one that monitors what drugs a patient is already taking and compares a profile of those drugs against new pharmaceutical prescriptions, at the time of prescribing, to identify potential adverse reactions and drug-drug interactions.

Projects such as the Alberta Wellnet Pharmaceutical Information Network (PIN) provide an example of how drug monitoring for interactions is being approached with physician office systems and pharmacies.

Other survey responses referenced the EHR and how the use of these applications combined with intelligent systems technology, such as multi-agent systems, could provide a watchful eye over care and treatment of the patient, in fact allowing for what are commonly known as patient centered care models.

To emphasize the impact of patient safety and how the use of an EHR could help in the treatment of patients, one survey participant recounted a recent experience:

> *"The mother of a friend was recently admitted to a hospital and had her case managed by multiple providers over a period of a number of days. Failure to communicate/coordinate appears to have led to a failure to realize that excess fluids were being ordered and administered relative to fluid loss. Fluid retention triggered other serious complications. A system based on EHRs and intelligent devices (e.g., infusion pumps and catheters that report flow rates and volumes automatically to the EHR, beds that report patient weight, video systems that can interpret patient appearance and track caregiver activities, and diagnostic/prognostic software) carries the potential of preventing this kind of problem."*

6.5 Patient Access

Access to publicly funded health care continues to be a significant health policy issue. The most noteworthy example of unmet need in Canadian healthcare is access to scheduled services.

Long waiting times have become the norm in Canada, with examples being cited of patients waiting months to years in order to receive diagnostic imaging examinations (i.e. MRI) or surgical procedures (hip replacements).

Patient access to the emergency room is also a major issue. Patients commonly wait several hours to be seen by a physician. Once admitted to acute care, challenges ensue with respect to patient flow. Often, patients are blocking beds in the hospital because they are waiting to access community resources such as long-term care or home care. Accordingly, expensive in-patient beds are being used less than optimally.

An additional element of Patient Access is the use of the Internet for patients in researching and managing their care. The use of the Internet has enabled patients to research their specific condition, and become aware of new information that may have otherwise not been available to them through their traditional sources of information. The Internet also has the promise to change the nature in which diseases are treated in the future, particularly through the use of home care-based chronic disease management systems.

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6.6 Continued Shift of Care from Acute Care to Community-Based Locations

A major trend that will continue, if not intensify, is the shift from caring for patients in acute care environments such as hospitals, to community-based care, such as home care programs.

Patients are discharged earlier, thereby reducing in-hospital length of stay and returning them to the community. In-hospital beds are used with greater efficiency but patients are requiring more post-discharge care in the community. The application of telehealth systems has enabled some patients to be monitored and remain in the community.

Furthermore, the extension from acute care into the community is not only a Canadian experience but is paralleled in other publicly funded health care systems such as the United Kingdom, Australia and New Zealand. In addition, the United States is also starting to focus on moving care into the community with the advent of the Regional Health Information Organizations (RHIO).

6.7 Financial Constraints

Survey respondents felt that financing health care in the next 5 to 10 years would be a major issue.

An aging population, new and more costly procedures and technologies, combined with new pharmaceuticals, are all expected to place additional strain upon the finite resources allocated to health care.

The opportunity is great for intelligent systems to assist with the financial pressures being experienced in health care. Intelligent systems are often applied in other industries to enhance efficiencies and reduce waste from inadequate systems or processes. Examples of this may include decision support software based upon either rule-based systems, practice guidelines or some type of machine learning algorithm, used specifically for identifying and reducing inappropriate or duplicate laboratory tests.

6.8 Staffing Resources

An anticipated trend in the next 5 to 10 years is the progressive shortage of skilled health care professionals, most noticeably nurses. A significant proportion of nurses are nearing retirement and there is concern that not enough are being trained to replace them.

Several survey respondents discussed the creation of intelligent systems designed to offset some of the factors associated with staffing resources. An example is the development of an advanced scheduling system designed to identify staff most likely to experience sick time and to provide interventions to lessen this occurrence. The first step is knowledge of what risk factors are associated with staffing problems. The second step is the development of systems that use this knowledge to better schedule staffing resources, lessen sick-time and burn out and improve retention.

6.9 Bio Health Informatics

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An increasing trend will be the convergence of bio informatics and health informatics, as it relates to the clinical treatment of the individual patient.

With the success of the Human Genome Project exciting research and development in relation to how a patient's genetic information can be applied to the diagnosis and treatment of disease is occurring. An example of this is pre-symptomatic or confirmatory genetic testing for diseases such as Huntington's Disease. In addition, genetic-epidemiological studies have identified a host of genes whose carriers are at increased risk of certain diseases. For instance, women with copies of the BRA genes have an increased risk of breast cancer. The clinical significance of this genetic information is vast and has the potential to be applied to preventive as well as diagnostic efforts.

The application of intelligent systems in this case could be the deployment of expert systems that use the genetic make-up of individuals to better guide care plans or specific drug or genetic interventions.

6.10 Health Informatics sector

A growing health informatics sector was viewed as a trend in the next five to ten years. This was mainly the result of an overwhelming view that the health care system would require better information systems to improve the system overall and make it safer and more efficient.

It was strongly felt that spending would continue to increase around health information technology and that it would be increasing in every sub-sector of health care, from acute care facilities to long-term care and home care. The influx of financial resources around the EHR was a major emphasis in this growth.

It was also strongly felt that the health care information technology systems needed to become more "intelligent" and provide decision support capabilities for a variety of clinical specialties, as well as assist in gathering clinical information for administrative purposes.

Canada was seen as a place where research and development could lead to the successful commercialization of innovative products and solutions and provide growth in the health informatics sector.

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7. Recommended Directions

In it is widely believed that intelligent systems have a lot to offer health care. However, to date, the potential of intelligent systems in health care has not been realized. There is no single reason that we have identified for why there is not more research and development of health informatics intelligent systems occurring in Canada. Undoubtedly, this is multi-factorial. A major contributor may be the limited investment in information technology in the health care sector. Since it is relatively low compared to other sectors, this may have a compounding effect in that the supporting systems and infrastructure required to support intelligent systems is simply not in place.

Additionally, communication and cooperation is limited between the health care sector and the people and institutions involved in intelligent systems research. The activities and projects that do exist seem to be based on one-off personal relationships.

The following is a list of eight recommended directions to encourage more research and development in intelligence systems related to the health informatics sector:

- Provide additional education about intelligent systems to health care institutions and organizations including the potential benefits and potential for use in a variety of clinical and administrative environments.

- Enhance training and education in academic institutes on intelligent systems technology and its application to health care.

- Increase support from health care institutions and organizations for joint partnerships and projects in the field of intelligent systems, with both commercial companies and academic researchers.

- Provide Federal and Provincial incentives and funding for health informatics intelligent systems projects including the commercialization of these initiatives.

- Promote communication and collaboration between intelligent systems researchers, commercial health informatics companies and health care institutions and organizations.

- Encourage health care institutions and organizations to partner and support Canadian-based health informatics companies developing intelligent health informatics systems.

- Continue to support national and international health informatics standards development and usage and encourage the development of open systems that allow for increased interoperability and task sharing between systems.

- Develop simulated data sets based upon national and international health informatics standards that can be used for the research and development of intelligent health informatics systems in Canada.

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Appendix A – Recommended Reading

Survey on the use of smart and adaptive engineering systems in medicine
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Knowledge management in healthcare: towards 'knowledge-driven' decision-support services
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