Tracking the Physical and Information Product Flows in Mobile Patient Service Supply Chain: A Real-Vision Lab Approach[1]

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Abstract: In this research we have presented the concept of a Virtual Business Environment (VBE) that supports dynamic decision-making and examined the implications for data quality in such environments. We have motivated the need for such environments using the operations and patient flows in a hospital. We have further described the critical need for high quality information and the need to track and measure quality in such environments where real-time data is collected and used. An important issue here is the need to seamlessly integrate real-time data and data collected by other traditional means. We have proposed an architecture that addresses this requirement. Visualization is a technique that plays an important role in managing information quality. We have proposed the notion of information product maps (IPMAPs) as a modeling method for representing the creation, processing, and consumption of information products in these environments. Quality dimensions incorporated into the IPMAP permit the information manager to examine the quality of the product under different scenarios. This examination can be visually performed using a VBE for managing information quality.

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1. Introduction

Information technology (IT) experts have been pointing out that technology exists to bring the practice of healthcare into a better digital shape for the 21st century. They envision patients all over the country accessing secure medical records and setting up appointments, shopping for the best hospitals, looking up lab results, tracking claims, or consulting with a specialist electronically. From the provider's perspective, patients could be electronically monitored, and medical information shared with other care givers, public health threats identified before they spread, and medication errors reduced by automating order processing and data entry. While many individual components in health care systems are now computerized, techniques for aggregating and storing this data in a system, methods for guaranteeing the quality of the data, and systems permitting effective transmission of information to the right people and the right time lag far behind.

There are several reasons for the lag. With many hospitals struggling to make ends meet under managed care and insurance reimbursements for many treatments being cut in recent years, investing in new data and computing systems is often a low priority [14]. Secondly, complex legal, cultural, and social barriers impact the implementation of such systems. Finally, health organizations are facing difficulties in managing and controlling the quality of large volumes of medical data that is required to support their complex decision-making tasks. This is because data is captured by many different sources, stored in a variety of different systems, and transmitted over networks that transcend organizational and system boundaries. This is further complicated by the advances in wireless technology that now permits capture of real-time data. The data captured by such technologies as the 802.11B networks, radio frequency tags, and infra-red sensors provide richer content in that they can capture the location of the source (in the context of the network) and can potentially monitor the source on a 24x7 basis.

Advances in technology have helped to solve some of the traditional problems of information quality by obviating the need for data entry and by automating the transcription of information. These also decrease the time interval between capturing information and making it available for consumption. On the other hand, the very same technologies also pose some challenges. Clearly, the volume of data that can be captured will be considerably higher – some of this is critical and some not useful at all. What are the useful data elements that can be captured by these technologies? How do we know if we are capturing the "right" data? What new data quality standards are required to ensure high quality data? Understanding the implications of these and other such questions provide some interesting challenges to researchers. Addressing these issues is important because it is believed that the availability of real-time data and its seamless integration with data captured using traditional technologies may significantly impact decision-making in complex environments.

In our research we propose the use of a Virtual Business Environment (VBE) [1] to support dynamic decision-making in complex environments. Conceptually, a Virtual Business Environment can be defined as a suite of integrated applications (processes) and tool sets which support specific, major business capabilities or needs. The VBE provides decision-makers with integrated and seamless access to all the business capabilities required for analyzing and executing business decisions. It includes the required technology infrastructure for capturing and managing the data needs for decision-making. An important component of the VBE is visualization of real-time data. Visualizing data is increasingly becoming an accepted technique for assisting complex decision making processes. Visualization has gained acceptance because it provides a way for senior decision makers to understand and view the results from a complex decision model (e.g. simulations) in a more intuitive fashion. Complex models and results from these have had to be interpreted by model builders and knowledgeable users for it to make sense. The data being visualized is often real-time data that is streamed in from production databases or directly from the source(s).

To successfully implement a VBE for decision-making using real-time data, three important issues need to be addressed. First, a clear determination must be made about the data to be captured and the technology used to capture it. In the case of remote data collection, we must decide on the kinds of sensors (802.11b, infra red, etc.) to be used and their deployment. Second, we must understand how to seamlessly integrate real-time data from wireless networks with data that is captured using traditional mechanisms and technology. This data must be managed in such a way that it can support the wide variety of decision models that are employed in these environments. Third, we need to examine the implications for information quality for dynamic decision-making in such complex environments. The data/information captured, processed, and managed must be of superior quality because it is used in dynamic decision environments with techniques like data visualization. An important objective in such environments is that decisions can be made with a better understanding of the complex decision model and that decisions can be made sooner. If the data streamed in does not conform to high quality standards it is bound to have a negative impact on the critical decisions made.

Our objectives in this paper are two-fold. First we propose a conceptual architecture that permits the collection, storage, and utilization of data in a complex decision environment. We describe an instance of this architecture for the hospital environment. We use this architecture to identify the implications for information quality in such environments. This is described by treating the information as a product, a methodology that has gained considerable acceptance in the recent past [5, 7, 10, 22]. Specifically, we develop an information product map for a sample of the information used here and to help us identify quality implications and measures to ensure high information quality. Second, we describe the VBE in the context of the Real-Vision Lab (RVL), a facility that would support data visualization and the creation of VBEs.

The rest of this paper is organized as follows. We present an overview of the information product map (IPMAP) and its implications for information quality in section 2. In section 3 we outline the mobile patient project. A brief description of the patient service chain and the information flow is in section 4 along with IPMAP representations of two sample products. The Real Vision Lab is presented in section 5. A information technology architecture for creating a VBE in this lab is also described along with the implications for information quality management. We conclude the paper in section 6 and suggest directions for further research.

2. Overview of Relevant Research

The concept of managing information as a product as a method for improving information quality in decision-making environments has received considerable attention in the recent past. Several research papers that deal with various aspects of this concept have been presented. Significant among these are the definition of quality measures for information products [5, 7, 10], principles for managing information as a product [22], specifying practices for continuously improving the processes involved [9], and identifying benchmarks for information quality [13]. A fundamental notion that underlies all of the research in this area is that the final information product is a document/artifact that is sent to the consumer and examples of information products used include birth certificate, eyeglass prescription, student transcript, hospital bill, or bank statement. Analyzing information as product raises some interesting questions. For example, what if the information product is produced and consumed at the same time? What if the information product is used in performing “what if” analysis that is typical in a decision-making environment? In such cases, as the product is being “consumed”, the consumer may decide to modify some inputs/processes to re-create the product with perhaps a different “flavor”? While we assume here that the consumer has some control over the manufacture of the product (not uncommon in such environments), we also need to understand that we are dealing with a dynamic environment in which the product is being created and more importantly, consumed simultaneously.

A method for representing the manufacture of the information product, the IP-MAP, has been described in [20]. It provides a systematic method for representing the processes involved in manufacturing (or creating) the IP by extending the information manufacturing system model proposed by Ballou et al. [5] to develop a formal modeling method for creating an IP-MAP. This representation offers several advantages. First, using this representation, the IP manager will be able to visualize the most important phases in the manufacture of an IP and identify the critical phases that affect its quality. Second, the conceptual representation would allow IP managers to pinpoint bottlenecks in the information manufacturing system and estimate the time to deliver the IP. Third, based on the principles of continuous improvement for the processes involved, the IP-MAP representation would not only help identify ownership of the processes at each of these phases but would also help in implementing quality-at-source. Fourth, the representation would permit IP managers to understand the organizational (business units) as well as information system boundaries spanned by the different processes used in the manufacture of the IP. Finally, it permits the measurement of the quality of the IP at the various stages of the manufacturing process using appropriate quality dimensions.

The information product that we described above will be produced and managed by an environment that we call a Virtual Business Environment (VBE). There are several reasons why it is important to understand the implications of information quality in such environments as the VBE: (1) the decision environment is complex and dynamic where critical decisions need to be made quickly (such as dynamic routing/scheduling in hospitals). (2) Real time data is streamed in and typically there is no time to examine and correct data errors and (3) data is collected and integrated from multiple sources that span organizational and system boundaries necessitating the need for tracking and identifying all data elements and the business units/organizations responsible for capturing / processing / storing each. The IPMAP representation is useful for understanding the information quality implications and controls needed in such environments. Using the IPMAP we can represent the sources, sequentially identify the processes that transform data from these sources into “components” that are assembled to create the final product, the storage mechanisms where the source data and/or components reside during the manufacture, and for each of the above identify the business unit(s) and information systems associated. This would help us “visualize” the creation of the information product, identify the critical points in the manufacture where quality measures/checks need to be performed, and define (subjectively) the quality standards required at each stage of the manufacture. This would ensure that the final product satisfies the specified quality standards defined for each product.

3. Mobile Patient Information Project

The overall objective of the mobile patient information project (MPIP) is to understand the technology, examine its implications on information quality, and gain useful insights that will enable us to answer some or all of the questions listed earlier. Specifically, we will explore how a wireless, sensory network can track patient location and movement within a hospital, and how this information can be integrated with existing patient information to help improve hospital operations, achieve optimal utilization of resources, and ultimately provide superior patient care.

One motivating factor for this undertaking is the widespread use of wireless networks and technologies. We have briefly discussed this in section 1 and will take this issue up again in section 4. The other motivation stems from the complex and yet unsolved problems that hospitals and public health departments are facing today. Services provided by hospitals in the United States have come to be viewed as commodities. In an effort to keep costs down, many jobs and services deemed peripheral have been cut, often at the cost of quality care. Realizing the need to compete on a basis other than cost, and in the face of real or potential financial loss, hospitals are now starting to examine the potential of operational models for improving efficiencies in patient flow.

For example, one of the greatest sources of lost revenue in hospitals is the improper utilization of resources such as operating rooms and intensive care units (ICUs). This problem persists, even as waiting times rise and perceived quality of service drops. Currently, bottlenecks often result as semi-autonomous departments focus on optimizing local throughput without considering how their actions affect the performance of other departments [16]. Even the most efficient operations are subject to the woes of variability. A hospital environment is not only subject to the variability of patient types, arrivals and behavior, but also to a great degree of variability in the processes it uses to provide care. Poor management of resources can serve to intensify systematic variability, further straining the system during peak periods. These "artificial" sources of variability, however, can be eliminated through the use of effective cross-departmental scheduling [15]. With this, the focus can shift to resolving bottlenecks dynamically during those peak periods caused by systematic variability.

Perfect information has the potential of adding enormous value to a complex system such as that in a hospital. Complex decision-making models have been developed to manage the allocation of limited resources in the hospital environment. The accuracy of these models currently depends upon the quality of simulated data. It has been impossible up until now to obtain a comprehensive record of patient movement and location within a hospital, therefore the results of these decision-making models have been based upon an incomplete picture. Access to the total stream of patient movement allows us to explore in more detail the intricacies of the system and may reveal bottlenecks of which we were previously unaware. This information can then be used to coordinate the use of shared resources and ultimately to transform operations, not only in the predictive sense, but also in real time.

Real time data that is directly captured off the network (wireless or otherwise) has two inherent advantages. First, as manual processes are not part of the data capture or data entry and hence the data is more "clean" than in cases where manual transcription or data entry is required. Second, the data is available for use virtually immediately with no delays. This has an important implication for hospital administrators attempting to understand the causes for "traffic jams" in operating rooms, overcrowding of ICUs, and diversion of ambulances from ER due to the operating at maximum capacity. They can use the real-time data captured to replay scenarios and over time identify "events" using which they can predict when such a situation is going to occur and take precautionary measures to resolve it or to avoid it altogether. Visualization can play a vital role here by allowing the administrators to view a "map" of the hospital layout, examine events as they occur by tracking the movement of patients on the map, and visualize the circumstances that triggered overcrowding and poor utilization.

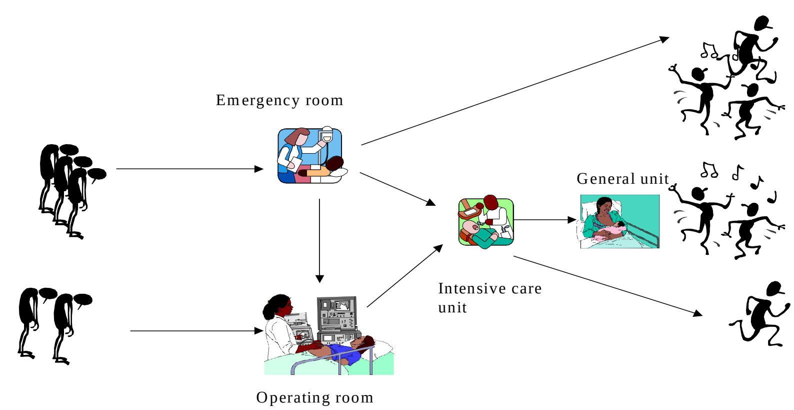

Figure 4.1: Patient flow

Wireless technology can be used to “tag” the patient possibly at the time the patient check-in or registers into the hospital. For very critical patients brought into the ER this may not happen until after the initial examination or emergency treatments. The “tag” identifies the patient uniquely and may be worn on the patient’s person, for example, on his/her wrist similar to what is in practice today. The other data about the patient such as the patient history (prior admissions/treatment records) can be linked with this identifier tag. As the patient is examined by doctors/interns, the data diagnostic information, procedures to be scheduled, and treatment recommendations can be captured and linked with the patient identifier. These data (history, treatment, etc.) are currently being captured in electronic systems using manual data entry (nurses or by physicians themselves). The proliferation of wireless palm tops and PDAs may very soon have this data capture performed wirelessly at the patient’s bedside. Monitoring devices that track patient’s vital signs can also be linked to the patient identifier resulting in all of the patient’s information being tracked with the patient seamlessly.

This collection of information has several advantages to hospital administrators and physicians alike. Accurate information about patient flow through multiple departments in the hospital environment could allow for more precise analyses of demand, and therefore more effective scheduling of shared resources. It could also allow for immediate action in a dynamic scheduling environment. If the system reveals that there is a queue of patients waiting for x-rays, but no wait for MRI, patients who need both may be diverted to the unused resource to balance utilization across departments. From the physician’s perspective, the benefits of having an integrated collection of “clean and accurate” information ranging from patient history all the way to current conditions are easily recognizable and needs no further explanation.

4. Patient Services and Information Flows

A mobile patient service chain is the set of activities that are performed to serve a patient. To understand the information and architecture needs (positions for sensors, meta-data definitions, etc), we must understand the physical and informational flows in patient services. A generic physical flow is shown in Figure 4.1. An emergency patient arrives directly at the admissions area of the emergency room for an unscheduled visit. An ER physician determines if further care is needed or if the patient can return home. If the patient needs further attention, the process is similar to a scheduled patient arrival that is described next. The scheduled patient arrives for a planned procedure and might pass through five stages: scheduling and registration, preoperative care, the procedure followed by recovery in the ICU, and then a few days of recovery in the general floor.

To understand the informational view of the same patient, consider for example the operational status report and/or the patient care status report generated for hospital management once every half-hour. Based on these reports the management may dynamically schedule patient flow or change resource allocation to achieve better management of hospital resources and better patient care. The IPMAP representation for both these products are shown in figures 4.2, 4.3, and 4.4. Figure 4.2 shows the capture, processing, and storage of patient admission information. The registration office obtains personal information about the patient as well as information needed for emergency contacts and billing (Data Source DS_1). Medical records for that patient may be obtained from other sources such as personal physician's office or other health care agencies (DS_2). The patient is then examined and the initial patient conditions are also captured (DS_3). The patient is then allocated a bed (in the ER/ICU/floor) that is also captured in the system (DS_4). The latter two may be done using a palm top/PDA in a wireless network. All of this goes into the patient medical record storage (STO_1). In the figure, raw data from sources is indicated by RD and processed data by CD, each with a suffix assigned in sequential order for identification. Data, during processing may move across multiple systems, some paper-based and some electronic. System Boundary (SB) blocks are used to explicitly capture this. Processing (P) blocks are used to represent data processing and quality blocks (QB) represent checks performed for validating the data. Business boundary blocks (BB) are used to represent the flow of data across organizational or business units and in cases where transfer from one business unit to another also implies transfer between two different systems a combined business and system boundary block (BSB) is used to represent it.

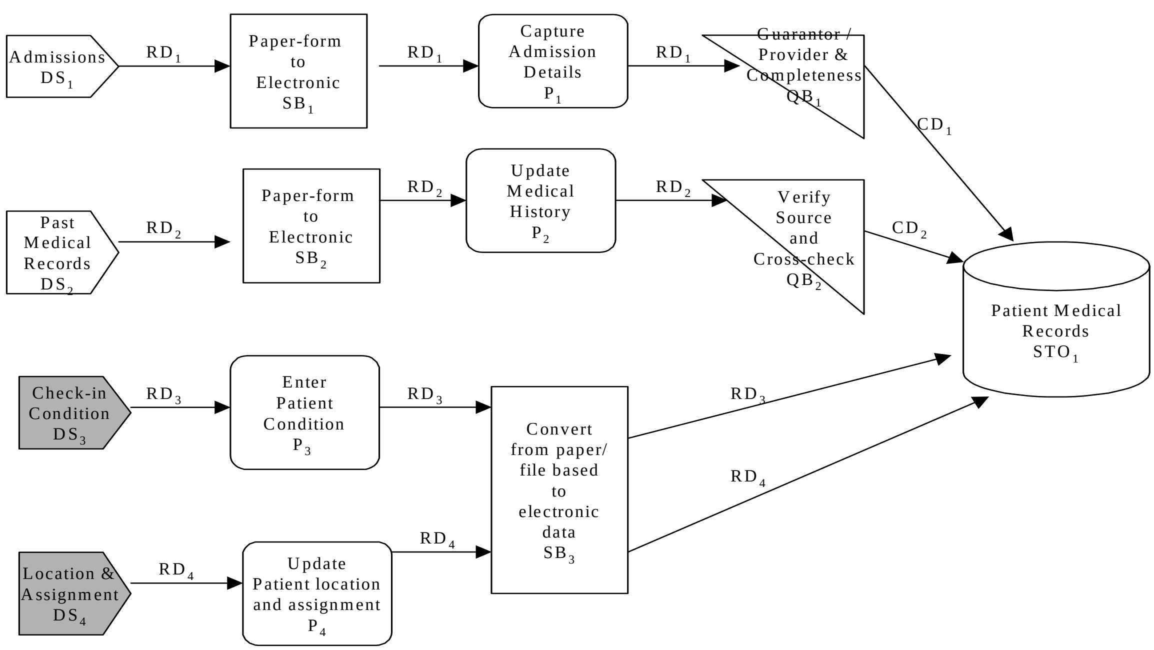

Figure 4.2: Capture, Processing, and Storage of Patient Admissions Information

Figure 4.3 describes the capture, processing and storage of patient treatment and care information. Lab/Radiology records and results (DS_5) and information on surgical procedures performed (DS_6) are captured into systems in corresponding departments and transferred into the patient treatment database. Further, recommendations from specialists (DS_7), progress reports from attending interns (DS_8), and vital signs continuously monitored by wireless devices (DS_9) would also become part of the treatment database after necessary processing.

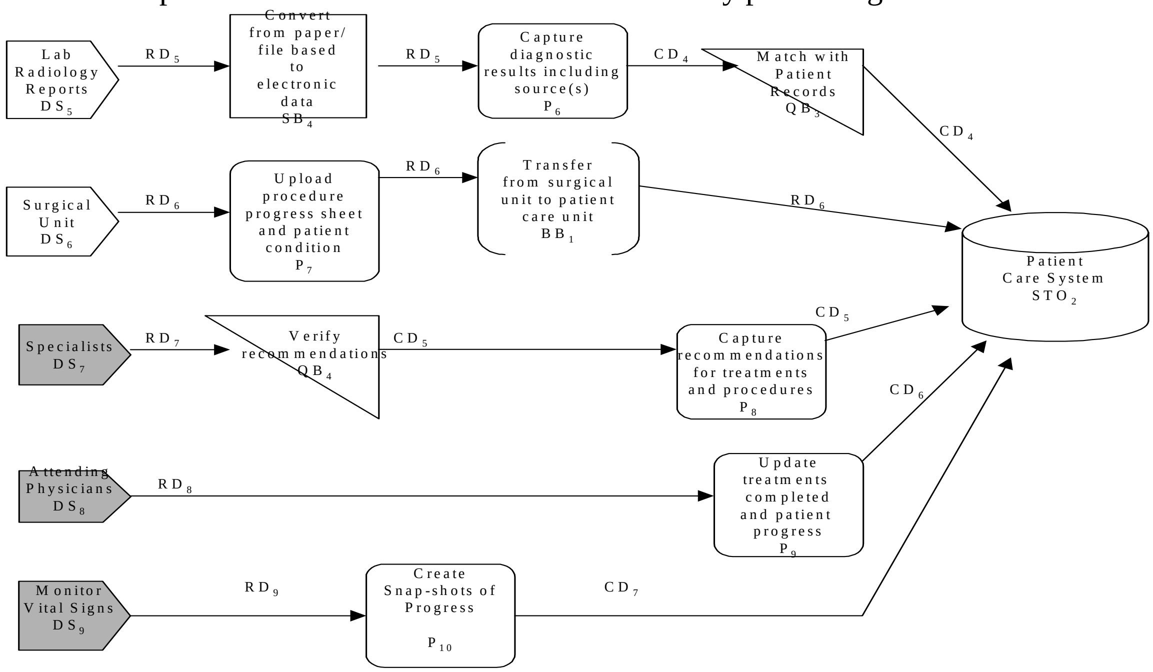

Figure 4.3: Capture, Processing, and Storage of Patient Treatment/Care Information

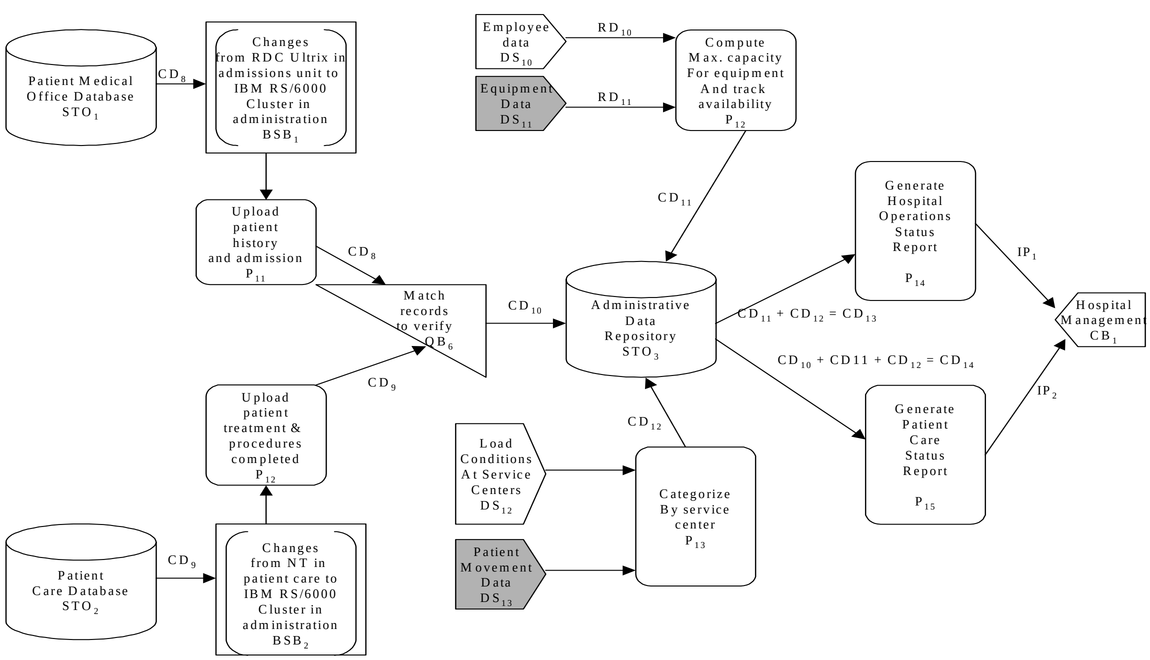

Figure 4.4: The creation of IP_1 and IP_2 for dynamic scheduling and patient flow monitoring

Combining this with data about employees (DS_{10}) and equipments (DS_{11}), data on load conditions at the various service centers (DS_{12}) such as the MRI /CAT/X-Ray, as well as the data on patient and equipment movements (DS_{13}) in the administrative data repository (STO_3), the system creates the two information products. The first product (IP_1) is the status report on the hospital's operational processes which can be used for dynamically allocating or re-allocating resources as well as identifying utilization of the different critical care centers. The second product (IP_2), the status report on patient care will inform the administrators about the location /movement of the patient. Together with patient treatment and medical records, the administrators can determine how the patient should be cared for next keeping in mind the utilization of the different service centers. The data source blocks that are shaded in gray represent information that is captured by wireless or similar networks using infra red or radio frequency tags that may be attached to patients/equipments as described earlier.

Name/Type	***Department/Role***	***Location***	***Business Process***	***Base System***
Admissions /DS_1	Admissions Office/ Patient	Admissions , OB/GYN, Emergency	Standard Form (#1101P)	Paper-based - Patient File
Past Medical Records / DS_2	Admissions Office / Admissions clerk	Admissions Bldg., Records Room	Contact source and request with patient authorization.	Paper-based - patient file

Table 1: Sample metadata for IP-MAP in figure 1

The informational view is captured as meta-data. To complete the representation, we need to capture the information about each of the blocks and the data elements included in each flow in the model(s) above. This is akin to the data dictionary for a data flow diagram and we refer to this as the metadata associated with the model. The metadata repository resides within the data layer of the system architecture described next. For brevity only a sample of the metadata is shown in table 1. Besides metadata, each block in the IPMAP can include a set of quality dimensions such as completeness, accuracy, reliability, and timeliness. The information manager can assign (subjectively, with the help of users if necessary) weights to each of these dimensions. Using methods similar to the one described by Ballou et al [5], the overall quality of the information product(s) can be computed and visualized using appropriate metaphors.

5. Managing Information Quality in the Real Vision Laboratory

As a proof-of-concept, we are developing a VBE to support decision-making within the healthcare context. This environment will house the large quantities of data that will be collected by the sensory layer. The metadata about the quality of information and the databases will also be stored within the environment. Finally, the environment will also provide the visualization support for decision-making. Currently, we are in the process of developing the RealVision Labaratory (RVL) based on the architecture described. This lab will primarily use off-the-shelf (COTS) technology, and software and would serve as a platform to support and build multiple VBEs. Each environment will have a conceptual structure shown in Figure 5.1 below.

Domain Resources Manager is a subsystem that is responsible for managing the multiple resources such as expertise (knowledge), models, and data. Knowledge is captured here in the form of documents, discussion threads, and other subtly structured data that cannot be managed with traditional data management techniques.

Dialog Manager is responsible for converting the answers to the queries as determined by the Engines into outputs for the user. The outputs can be of various forms as determined by the metaphors and can be rendered in different ways as determined by the visualization technology used.

Business Context Engines and the Engine Manager: In addition to Environments, the Process Domain typically contains a number of major software components called Business Context Engines. An Engine is defined as an analysis object that represents and implements a complex business capability requiring the integration of a variety of knowledge resources. Engines are shareable or reusable in disparate business specific applications or contexts. An Engine implements a particular, generic, business algorithm for the processing of a specific class of business Data. An Engine becomes useful by working on the Data that is relevant to the Environment(s) to which the Engine is "subservient". In this way, an Engine is able to provide diverse Environments (and consequently diverse business processes) with a standardized set of computational capabilities and/or evaluation functions. The Engines of this Architecture can be thought of as large blocks of reusable application code which instantiate complex business functions useful to one or more Environments. Engines typically integrates disparate data, synchronize processes to support get relevant information, normalize data to make fair comparisons, allocate resources dynamically, maintain business rules etc.

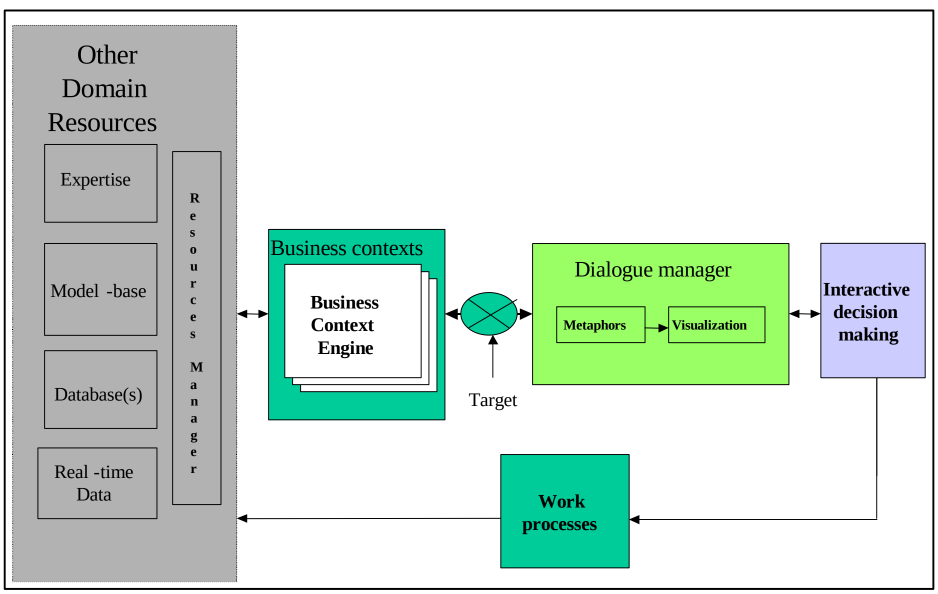

Figure 5.1: Conceptual Representation of a VBE

Information Technology Architecture

As the enterprise continues to grow in size and complexity, several factors impede the ability of the enterprise to solve the problems that it faces. A point is rapidly reached at which there are too many factors that come into play in conducting the business of the enterprise. When dealing with such systems, designers have typically dealt with their complexity by breaking the problem into a set of smaller problems that are themselves less complex [8, 11, 23]. An architecture is a systems design that specifies the way the overall functionalities of the design are to be decomposed into individual functional components and the way in which the individual functional components are to interact to provide the overall functionalities of the system design. *The decomposition of the enterprise into manageable parts, the definition of what those parts are, and the orchestration of the interplay among those parts are called the Enterprise Architecture.* The orchestration of the interplay is governed by a set of *design rules/Principles* or the organization's knowledge architecture [4, 19].

Data quality researchers have identified three stakeholders who participate the management of an information product: data collector, data custodian, and the data consumer [22]. This architecture integrates the interests of all three stakeholders and divides the world into three domains: decision network layer, data network layer and the sensory network layer. This collection of technology networks, data repository, and decision-making environments need to come together for us to benefit from tracking this real-time information. The architecture proposed next addresses this.

The sensory network layer has all the probes that collect information from the environment. For example, it could contain the RF network within a hospital room that collects information on patient movement or the GPS systems that help locate the ambulance and other assets that a hospital owns.

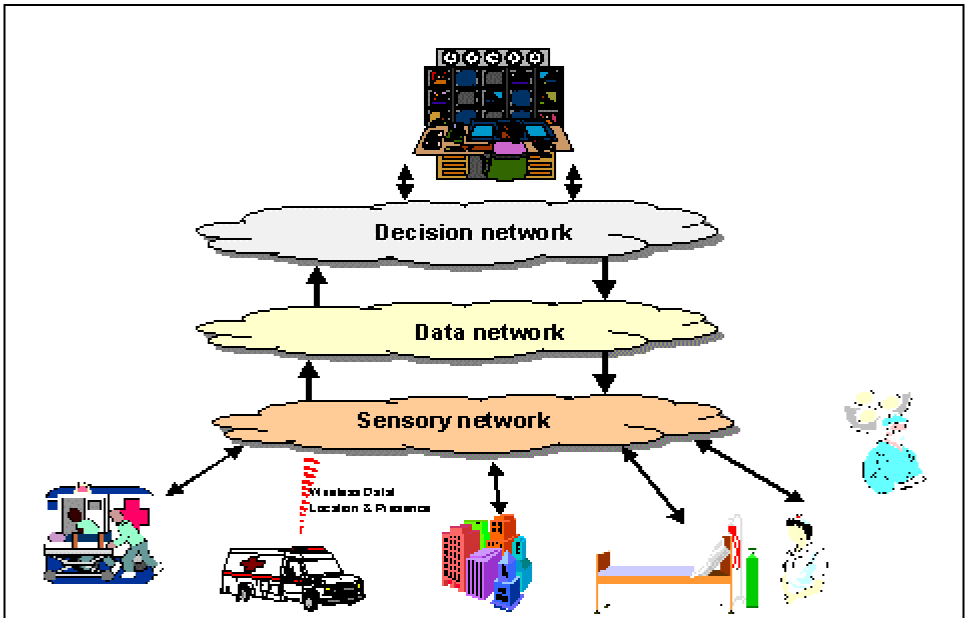

Figure 5.2: Information Technology Architecture

The data network layer has the schema information about the data that is stored in the enterprise. We use the term data broadly to include models as well. The meta information about models will be stored in this layer as described in [2]. Another example of information that may be stored in this layer is the metadata for the IP-MAP described in section 4.

The top layer is the decision network layer. This layer will contain all the processes, procedures, business tools, and rules to support decision-making within an organization. It includes applications needed for evaluating process design alternatives and their implications for cost and quality or models that can help determine staffing levels.

The three C's in an information product management	***The three network layers in the Real Vision Laboratory***
• Data Collector (data creator, data collector, data entry)	• Sensory network (802.11b, RF devices, etc)
• Data Custodian (store, manipulate, and retrieve)	• Data Network (IP-MAP, database schema, etc.)
• Data Consumer (use information products for task at hand)	• Decision Network (metaphors and visualization)

The above architecture and the VBE that is implemented using it will also support information quality management. Information that is aggregated, analyzed, and used in decision-making can be treated as a distinct information product and represented as an IPMAP. This offers several advantages to the information manager. The IPMAP associated with the different products are all captured in the data layer along with the metadata associated. Using visualization techniques, not only can we visualize the data in the information product but also the IPMAP for the product itself. By examining the IPMAP, the information manager can identify the sources of information, the organizational unit responsible for it, the individual(s) responsible for it, and more importantly, the organizational and system boundaries spanned by the manufacturing process, all of which are important when using real-time data. By subjectively assigning weights to quality dimensions (e.g. accuracy, timeliness, reliability, completeness etc.) at each of these blocks, the quality of the information processed at each block in the manufacture can be computed and visualized. A separate set of engines may be used to manage the IPMAP and its visualization. This engine will be part of the library of engines described earlier. Further more, by changing the weights of the quality dimensions on the IPMAP, information managers can visually examine the impacts of these changes on the final product. For example, hospital administrators may be visualizing the patient care status report and/or the hospital operations to determine the necessary re-routing or re-scheduling of resources with an eye on increasing efficiency and/or utilization. The information manager may simultaneously visualize the manufacture of these products (on a different screen(s)), and provide the administrators with the details on how good/reliable the information is and how it might impact decisions made using it including the best and worst cases.

6. Conclusions

In this research we have presented the concept of a Virtual Business Environment that supports dynamic decision-making and examined the implications for data quality in such environments. We have motivated the need for such environments using the operations and patient flows in a hospital. We have further described the critical need for high quality information and the need to track and measure quality in such environments where real-time data is collected and used. An important issue here is the need to seamlessly integrate real-time data and data collected by other traditional means. We have proposed an architecture that addresses this requirement.

Visualization is a technique that plays an important role in managing information quality. We have proposed the notion of information product maps (IPMAPs) as a modeling method for representing the creation, processing, and consumption of information products in these environments. Quality dimensions incorporated into the IPMAP permit the information manager to examine the quality of the product under different scenarios. This examination can be visually performed in a VBE for information quality management.

Currently, we are partnering with a technology vendor and a hospital to identify the requirements for a real-time environment to support decision-making within a hospital setting. We will apply the IP-MAP methodology to identify data quality requirement and implement processes to support it.

This study will help identify the specifications for the architecture described in section 5. For example, what types of sensors are needed in the sensory layer? What is the appropriate technology for the network (RF, 802.11b, barcode, etc.)? Metadata requirements for the data network layer. Finally, at the decision network layer, what tools and support technology are needed for rendering the complex business and real-time data to geographically dispersed users?

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