

DEMAND FOR INFORMATION INTEGRITY IN HEALTHCARE MANAGEMENT

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Abstract

Information Integrity is the dependability and trustworthiness of information. Its determinants are accuracy, consistency and reliability of information. The paper researches the demand for Information Integrity in healthcare management and suggests a systems approach to reduction of errors in medical systems. The paper begins by observing the enormity of medical errors and requirement for informational view of healthcare process for their reduction. For this healthcare system and its components can be modeled as open systems. This sets the basis for developing an *IS* view of a healthcare system and presents it as a network of healthcare information variables. This leads to a closed loop information and control system model of which healthcare process is an integral part and results in a generic business process *IS* view of the healthcare process. Effective patient care calls for efficient and economic information processing under this business *IS* view. This *IS* is a multiple stage decision process comprising stages from initial healthcare problem recognition (goal setting) to delivery of customized healthcare service (information) decision for control implementation. This emphasizes the information gathering (i.e. originating) and processing nature of the *IS*. Of yet greater implication is the reality that at each decision stage these information originating and processing activities are impacted by the system environmental factors of 5“C”s, namely, complexity, change, communication, conversion, and corruption. While on one hand, this results in uncertainty at all *IS* levels leading to errors in information processed from stage to stage and, thereby, to loss of Information Integrity, on the other hand, it makes the business *IS* view - here the healthcare *IS* view - a continuous information originating and processing situation characterized by information errors. In other words, problem transforms from that of dealing with medical errors to that of (dealing with) information errors in medical settings. For effective patient care (that is for effective business) this presents the Information Integrity as a fundamental requirement for competitive business advantage.

1.Introduction

Medical literature search makes it clear the error is common in medical systems. In 1991, the Harvard Medical Practice study report suggested that nearly 4% of patients hospitalized in the State of New York in 1984 suffered an adverse event (AE), defined as an unintended injury caused by treatment that resulted in prolongation of hospital stay or measurable disability at the time of discharge. For the state of New York, this amounted to 98,600 injuries. Assuming similar rates in other states, around that time, then, more than 1.3 million people were getting injured annually in the United States by treatments intended to help them [Brennan et al., 1991; Leape et al., 1991; Leape, 1994]. The scope of medical errors became even further heightened when the 1999 report of the Institute of Medicine of the National Academy of

Sciences entitled “To Err is Human” estimated that as many as 98,000 hospital patients die every year as a result of preventable errors, including medication mistakes. And, now, the recent findings of the second annual medication-errors report from MedMARx, an anonymous program that keeps track of this kind of mistake, observe there were about 111 error reports per hospital in 1999 and about 224 error reports per hospital in year 2000 [DeNoon, 2002]; suggesting doubling of errors in an year.

Given the unanimity in medical literature in concluding that there is substantial underreporting of therapeutic misadventures [Perper, 1994], in the light of above, even after making room for errors that statistics can make and even after admitting that one is clearly looking at a non-linear system, thus, what we have before us is the enormity of growing errors in medical systems. From the patient point of view many of them result in permanent disability and mortality, and it is clearly desirable to reduce their occurrence and impact.

The problem of error reduction can be approached in different ways. One approach can assume that if people are more careful, pay more attention, and in general take more trouble over what they are doing, then errors can be reduced and their effects mitigated. That is to say, the error problem is seen as of that moment having no significance beyond itself [Dörner, 1996]. This approach, ad-hoc in nature, puts whole attention after a particular error. In real world, the error, however, does not occur again in the same form and in a same situation in a linearly predicted manner. Also, although they are arguably among the most careful people in our society, doctors, nurses, and pharmacists make mistakes [Leape, 1994]. As a result, this approach, easier to pursue, gives a false sense of having taken steps for error removal. It never minimizes the error occurrence, though, and is invariably found less effective in the long run.

The other approach - a systems approach - may see design of objects, activities, rules and procedures, norms, commands, and patterns of behavior as being the source of errors. Clearly, systems approach is holistic, more in tune with the setting in which the real world operates. It does not see the error as, say, a “medical” problem, but as that of (or more correctly as that of loss of) integrity, that is trustworthiness and dependability (here say in a “medical” setting), of: each of the system components as also the complete system; of each of system development & implementation phases of design, development, testing, implementation, and maintenance as also the total lifecycle model. This emphasis on integrity of component (or phase) as also of complete system (or total lifecycle) is important in that it also suggests requirement of integrity in respect of relations and interactions between the components and between the phases. Only when this entirety of integrity requirement is ensured will the error be minimized.

Systems thinking - and systems analysis and design tools - have been around for a long time, but healthcare delivery is usually not thought to be as a system [Van Cott, 1994]. This has normally led to addressing the healthcare error reduction problem by recourse to the former approach. Indeed, in resistance to development of systemic mechanisms, traditionally error reporting in medical practice is discouraged, suppressed as undesirable “whistle blowing” [Moray, 1994]; whereas, for systems approach to become applicable, requirement is for error reports to be generated and taken as information to improve upon design of objects, activities, rules and procedures, norms, commands, and patterns of behavior, much in the manner of control theory that sees errors as signals for a needed change in practice. This understandably calls for an informational view of healthcare processes. It is within this framework, then, in what follows, the paper presents the systems approach to reduction of medical errors based on the theme of demand for Information Integrity (I*I) in healthcare management.

2. Healthcare – An Open System View

Healthcare comprises an enormous number of diverse and semiautonomous elements: ambulance services, emergency care, diagnostic and treatment systems, outpatient clinics, medical devices, health care instruments, patient-monitoring equipment, testing laboratories, and many others.

A healthcare system as this has unique features. Firstly, it is a socio-technical system. Each of its many component subsystems – hospitals, emergency care, pharmacies, clinics, laboratories, and others – represents a distinct environment with its own unique goals, norms, and practices. Secondly, in contrast to centralized systems characterized by authority of a hierarchical, vertical management structure, healthcare system, almost in the manner of customer-supplier model, has horizontal spread across several subsystems in which decision making requirements are distributed across many people and units. For example, the management of a healthcare system includes human components, such as doctors, nurses, and managers; hardware components such as computers and telephones that transmit and store information, paper and magnetic records, drugs, operating theaters, scalpels, and beds; the management policies that are adopted; and the financial mechanisms in place to govern the economic control of the system. And, thirdly as a result, a healthcare system has all its components and elements loosely coupled in an intricate network of equipments, devices, procedures, regulations, individuals and teams of people, and communications that function in a variable and uncertain environment with diffused, decentralized management control [Van Cott, 1994].

This indeed is a statement of open system that a healthcare system and its loosely coupled components and elements are, as it is an open system which has goal or purpose, which is characterized by permeable boundary, and which — information that it processes within and between the open systems — is impacted by and impacts its environment. A good example of an open system is a cell within the human body. The cell membrane quite clearly defines the boundaries of the cell, but it also enables nutrients and information (electrical impulses from the nervous system) to enter and waste and information (electrical impulses to nervous system) to exit. Open systems at microlevel (cells) can be enveloped in a more macro system (human body) that is an open system (exchanging material, energy, information with its environment). And macro systems (humans) can be enveloped still further in an organization (say a business organization or a healthcare system), which also is an open system (exchanging, material, energy, information, money with its environment). Interconnected open systems also give rise to an open system [Beniger, 1986; Kelly and Allison, 1998, Mandke and Nayar, 2001].

Conversely, a closed system neither imports nor exports material, energy, money, or information. For example, an aseptic hospital environment is expected to act as a closed environment for admitted patients. However, it may so work out that a burn victim (susceptible to infection and therefore an open system itself) kept in a totally aseptic hospital environment may suffer from nosocomical infection that may be traced to bacteria present in the unremoved stalk remnants of vegetables served to the patient; the unremoved stalk remnants of vegetables served, together, rendering, for *that* patient, the hospital environment septic (that is an open system that the healthcare is) [Perper, 1994].

What went wrong? While one can find fault with the process of food preparation or with the skill or degree of accountability demonstrated by those preparing it, all such are after the event observations. What in reality went wrong is that while serving food the information in respect of the vegetables is assumed correct as validated earlier and the information processing operative in the context here is not geared to anticipate information errors, i.e., loss of Information Integrity. What is important to recognize is this is not a special situation, as *IS* research literature observes tendencies in the manner of closed system on the part of planners and decision makers at all levels (strategic, management and operational) to process only that information that matches already validated information and to adapt “ballistic” behavior and reports difficulty in recognizing what starts small and comes with delay [Dörner, 1996; Madke and Nayar, 2001].

If this error of incorrect assumption on information validation is not done and if the information processing involved anticipates information errors, then the information processing will necessarily call for continuous information validation through recourse to additional information integrity technology, so

as to continually analyze information errors and the extent of loss of integrity and to find out without prejudice what exactly is the cause behind it (and, in all probability, it would be very different from that normally expected), so as to take necessary integrity control action to minimize the error occurrence. This in fact suggests Information Integrity as a bottleneck and, hence, as a resource to achieve effective patient care, i. e., effective business outcome, i. e., competitive business advantage.

The discussion here is certainly pregnant with powerful concepts that will be developed in the course of this paper. However, at this stage of investigation what comes out unequivocally and is of use to recognize is all open systems — and the healthcare system made up of relatively autonomous components and elements, themselves open systems, that can act for different and even conflicting goals, is an open system — whatever else they do, they necessarily process information within and between them. For effective system (business) performance (here patient care) this creates need for their coordination and control through efficient and economic information processing; thus setting the basis for developing an *IS* view of healthcare system [Beniger, 1986; Tallberg, 1999; Mandke and Nayar, 1999].

3. *IS* View of Healthcare System

To develop an informational view, a healthcare system can be analyzed in its different forms; namely, most common that is iatric procedures/tasks; complex and highly technical medical care; complex, dynamic, high risk, acute patient care; situated environments; healthcare of elderly patients; and the activity of patient's exposure to a small amount of radioactivity for diagnostic and therapeutic needs. Together these areas constitute a major share of healthcare operations and, hence, their analysis offers a good enough basis for the modeling query at hand.

3.1 Iatric procedures: *IS* View

Iatric procedures in healthcare cover activities of medical diagnostic, treatment comprising decision and execution (administration), prevention, communication, equipment usage, etc [Perper, 1994]. One of the major steps in iatric procedures is to decide that an actual or theoretical medical benefit justifies a specific therapeutic approach. Seen from systems' angle, this is a step in goal formation and identifying its information requirements. Apart from identifying the concrete and specific (medical) goal that is desired to be met, this step also requires that implicit goals (that is side effects) and their information requirements, that would start small and occur with time delay, be also identified. This characterizes iatric procedure by requirement to generate (originate) and process information.

Hospitalization of patients is one of the important features of the healthcare system. And implementation of iatric procedures/tasks is an integral part of daily hospitalization routines. Amongst the hospitalized patients, in all probability, there will be those who are particularly susceptible to infections from environment; and an institutional medical care environment is more likely to contain injurious agents for such patients. The stage is thus set for such patients - open systems that they are - for being infected by the injurious agents, for being impacted by the environment; in turn setting the tone for informational view of iatric tasks.

As indicated, iatric procedures comprise of therapeutic procedures, tasks of administration of medication, equipment operation, etc. These call for diagnostic or therapeutic manipulation, use of standard medical procedure, administration of required drug dosage, appropriate use of a standard medical equipment, etc. Once again, whatever else implementation of these procedures involves, they necessarily process information.

3.2 Complex, highly technical medical care: *IS* View

Coming to the highly technical medical care, for example, surgical specialties of vascular surgery, cardiac surgery, and neurosurgery, all of them involve many interventions during hospital care involving patients and nurses, doctors, pharmacists, technicians, and others [Leape, 1994]. In the line of the model building that is sought here, it is easy to see each intervention is an occasion for generating, storing, processing and distributing data and information for use in the immediate and long term medical tasks at hand; thereby presenting complex and highly technical medical care in its informational view.

3.3 Complex, dynamic, high risk, acute patient care: *IS* View

Anesthesiology dealing with specialties of surgical anesthesia, pain management, and critical medicine is an example of complex, dynamic, high risk, acute patient care. Literature reports, in spite of all the planning, 18% of cases will involve an unanticipated problem that could harm the patient and that requires intervention by the anesthetist [Cooper et al., 1987; Cooper, Newbower, and Kitz, 1984]. The problems could arise due to external and internal factors such as patient information incomplete in respect of underlying diseases, equipments suffering from design and manufacturing defects and maintenance failures, surgeon and anesthetist having work pressure, fatigue, etc. The dominant features of the anesthetist's problem solving environment, thus, include a combination of extreme dynamism, intense time pressure, high complexity, frequent uncertainty, and palpable risk. For the purpose of the research query at hand, what is important to note is, this is a complex and dynamic decision making requirement in the presence of uncertainty; thereby once again the concerned healthcare area emerging in its *IS* view.

3.4 Situated environments: *IS* View

As regards to the situated environments under the healthcare system, their best examples are the operating room (OR) and the intensive care unit (ICU). Both the OR and ICU environments are complex, with many diverse activities; both are dynamic, with constant change and time stress. A wide variety of high-technology equipment is used in both environments. Such equipment, which may be viewed as aiding the operator, can create additional demands in the full context of the user's environment. As mentioned above, anesthesiologist has to take the brunt of demands of situational factors in her work environment. [Bogner, 1994]. But there are further issues, too. The point is these situated environments are team activities in which doctors, surgeons, anesthesiologist, nurses, technicians, supporting staff, etc. work together; thereby further increasing the complexity and, hence, information processing demands and implications for a cooperative action while components and elements have their separate goals (even conflicting real goals). This again is a statement of complex *IS* in the presence of a changing and uncertain environment.

3.5 Healthcare of elderly patients: *IS* View

Healthcare of elderly patients has still higher dimension of information processing. Specifically, patients cannot be effectively treated for *any* ailment unless they are cognitively competent. They must be able to understand their treatment and cooperate in its implementation. Both tasks require adequate cognitive functioning [Vroman, Cohen, and Volkman, 1994]. In other words, in the model building exercise for a healthcare system for elderly, it is necessary that the model accounts for what meaning the elderly patient draws from the treatment identified, that is what meaning the product recipient—the customer—draws from the product information supplied. This is a statement of an *IS* model in the manner of customer-supplier model where information delivered is function of all three system components, namely, the source (supplier), process (medium included), and the recipient (that is the customer); and, as observed, it (*IS*) is critical for effective patient treatment.

3.6 Nuclear Medicine: *IS* View

And the case of nuclear medicine, which pertains to patient's exposure to radiation for diagnostic and therapeutic needs, only, further confirms this informational view of healthcare system. Indeed nuclear medicine is guided by a flow of information, which is used to control the process (e.g., to select the correct radio-pharmaceutical or patient), to monitor performance (e.g., to verify correct radio-pharmaceutical or patient selection), etc. Patient identification information is vital to a number of nuclear medicine tasks [Serig, 1994]. Some nuclear medicine subtasks or task elements require that patients themselves provide this information (e.g., when the patient does not have an identification bracelet or when verification of identity is not required). Similarly, processes of checking requisition, patient charts, and identification bracelets use information flowing through the system to verify the results of certain subtasks and the task elements.

3.7 Reorganizing A Systems Definition

Thus, healthcare in each of its forms discussed here emerges having *IS* view. Right at the beginning, healthcare is described as comprising a large number of diverse and semiautonomous elements. If viewed from a physico-technical angle in which the system engineering discipline defines system traditionally, healthcare organization can then be defined as "collection of objects united by some form of interaction or interdependence". With identifying informational view for each of its forms (components and elements) as above, however, any such healthcare system description is inadequate. Specifically, every material object contains no less than an infinity of variables (facts – data and, when processed, information), and, therefore, of possible systems. What is then required is to cull out – not necessarily physically, but mathematically – and study facts (data and information variables) that are relevant to the identified system goal (Usefulness factor).

Within this framework of reorganization of systems concept and based on the informational view analysis of healthcare system as above, one can then define a healthcare system as a potential source of healthcare information in respect of its components and elements, and describe it as a network of healthcare information variables in causal relationship to one another and in situations even to themselves [Cellier, 1991; Dörner, 1996]. Starting from diagnosis, treatment decision and execution (administration), to follow-up of treatment, the healthcare process can be seen as the supply chain of a generic business process from concept to delivery. A competitive business strategy calls for a good understanding of business process, which in turn requires a good business model. Depending on the research need such models could emphasize different facets such as material, equipment, fluid, energy, money, information, etc. With a socio-technical character of healthcare system characterized by open system components and elements loosely coupled in an intricate information network, for efficient and economic information processing it then becomes necessary to obtain and process data and information on current basis and to manipulate it 'smarter' (continuous validation) for achieving healthcare goal [Mandke and Nayar, 2000]. Specifically, what this leads to is an information and control system model of which healthcare process is an integral part. This is the generic business process *IS* view of the healthcare system in the presence of uncertainty, and, as argued at the end of Section (2), effective patient care is obtained by systematically controlling information processing under this business *IS* view (See Figure (1)).

4. Healthcare *IS* – A Multiple Stage Decision Process

This requires a clearer perception of the nature of information processing. Most information processing involves some type of data conversion to information *in use* and, therefore, is closely related to a decision process with an objective. Even when the information is transmitted without changing form, as in a communication system, the issue is to decide the purpose or objective of the transmission.

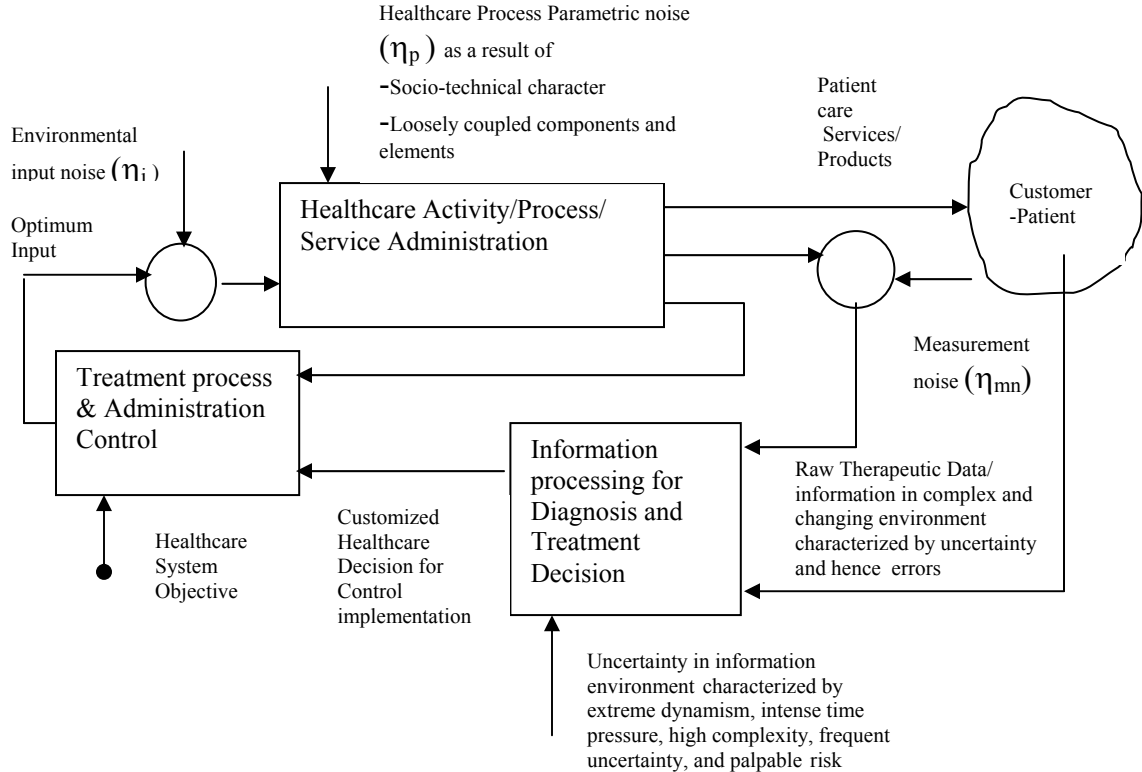


Figure (1): A Healthcare IS View as a Business IS View - A systems representation of a healthcare process viewed as a generic business process integral to a closed loop information and control system.

Traditionally, within the system-engineering framework, decision process is viewed to comprise of stages of forecasting (prediction), evaluation of alternatives and selection. Allowing for input noise, process parametric noise and measurement noise, system engineering treats it as information processing comprising decision problem in the presence of uncertainty. However, information and control system based model of a healthcare process is an open system. For it more workable model of a decision process spans multiple stages. They are: based on patient care goal set, *obtaining* ‘many factors’ & ‘multiple criterion’ characterizing problem (task) complexity; from multiple criterion, *recognizing* (i.e., deciding on) patient care problem (operable goal setting); from operable goal statement, *defining* healthcare planning & design constraints and opportunity spaces; from ‘many factor’ information variables characterizing problem complexity, *culling out* useful (relevant) healthcare information variables; *recognizing* relationships (interdependencies) between culled put healthcare information variables; *developing* state transition models defining dynamic behavior of culled out state (information) variables; and undertaking customized (patient-centered) planning & design for *generating* healthcare solution alternatives for evaluation and final choice (selection) of customized (flexible) healthcare service (information) decision for control implementation.

Development of this multiple stage decision process IS is outside the scope of the present research and for it one may refer elsewhere [Mandke and Nayar, 2001]. What is of utmost significance here is to observe that *all* of the above stages from operable goal setting to final choice of flexible information decision for control implementation involve information originating and processing activities with reference to their

respective information bases - a structural variant from traditional view of decision process, which is concerned only with alternatives and information that are already “generated” and does not anticipate (or in the manner of a closed system, rather, has no need for) “origination” of information and “generating” alternatives. In other words, traditionally, decision process has been defined in the gamut of alternatives identified “exogenous” to the *situation* of decision making and, hence, is termed as “collective” decision process. Against this, in the wake of open system based *IS* view of a system, the decision process has a requirement to identify operable goal, originate information and generate alternatives, all, “endogenous” to the *situation*, thereby making it (decision process) a candidate for designating it as an “individual” decision process.

Thus, what we have before us is a healthcare *IS* view comprising multiple stage “individual” decision process — that is a healthcare *IS* as an *individual information originating and processing situation*. Certainly, as with the traditional information system which is a “collective” decision process based information processing, the “individual” information originating and processing situation is also characterized by uncertainty due to input noise, process parametric noise, and measurement noise, thereby introducing information errors and, hence, loss of Information Integrity [Figure (1); Mandke and Nayar, 1998]. But, of still greater implication is the reality that at each decision stage these information originating and processing activities are further affected by uncertainties due to the system environmental factors of 5“C”s; namely, complexity, change, communication, conversion, and corruption. This results in errors in information processed from stage to stage [Mandke and Nayar, 2001].

5. *IS* Error implications of 5“C”s

When patients enter a hospital, they reasonably assume that their treatments will make them better, or, at the least, not make them worse. But modern hospital medical care is a complex network comprising a large number of diverse, semiautonomous and interdependent informational components and elements (variables). The more the variables and greater their interdependence, the greater that system’s complexity. Complexity places high demands on the information system’s (*IS*’s) capacities to set operative goal, originate information, develop information structure dynamics model to integrate findings, and design effective customized actions; resulting in errors at various stages of the multistage decision process that the Healthcare *IS* view is.

As a socio-technical system, healthcare service product is subject to change due extrinsic as well as intrinsic events: societal pressures, legal and regulatory rules, component change, etc. Further, the healthcare system must cope with very rapid advances in medical technology and practice. In this context, it may also be mentioned that change in the healthcare system is accomplished laterally across several subsystems in which decision-making are distributed across many people and units. In such a diffused system, change is slow, often difficult process [Van Cott, 1994]. There is yet another point of extreme significance: a system such as healthcare operates in the real world and it so works out that the real world is not passive but active; in turn invariably creating time pressures [Dörner, 1996; Madke and Nayar, 2001]. All these change features leading to dynamics in components and elements of the healthcare organization make it important to understand developmental tendencies therein. Further, it is not sufficient to observe and analyze (forecast) component and element information variables at any single moment of time but instead it must be determined as to, over a time, whereto the whole system is headed (trend or directional information). These change factor related demands on healthcare *IS*, resulting in further requirements of information originating and processing, contribute to errors in *IS*.

Then, as mentioned earlier, complex, modern hospital medical care involves many human and machine interfaces between patients and nurses, nurses and devices, doctors, pharmacists, technicians and equipments, and others. There are also requirements of diagnostic or therapeutic manipulation. All these

introduce system environmental factors of conversion (consolidation, decomposition or transformation of data), communication (movement of data/information within or across enterprise) and corruption (poor motivation, desire for personal gain, carelessness, actions of people) in healthcare *IS* environment. What is important for the investigation at hand is each encounter as this, indeed, each treatment, diagnostic maneuver, human-machine interface, or human information processing presents an opportunity for error. Even doctors, nurses, and pharmacists who are trained to be careful sometimes make mistakes.

It is these system environmental factors of 5“C”s, namely, Complexity, Change, Conversion, Communication, and Corruption [Mandke and Nayar, 1998], acting externally as also internally, contribute to information errors at each of the multiple stages of decision process constituting the healthcare *IS* view; in turn leading to loss of Information Integrity (I*I) in *IS* and in information there from. Medical research literature reports an exhaustive categorization of healthcare errors under the categories of: medical decision making errors, errors in laboratory reports, technology usage errors, medication administration errors, errors due to confusion about drug names, errors in situated environments, management errors, etc. Indeed, it is not one bit intention of the present research to as such study exhaustively the errors in healthcare delivery system. But, what is argued is, in the light of the healthcare system modeling based on informational view, it is important to realize that these healthcare errors are in fact due to information errors in each of the multiple stages of decision process constituting healthcare *IS* view phases. Specifically, these information errors are at input (data origin) step, at process (data transformation) step (medium comprising communication channel and people included) and at output (information use) step, and are caused by the impact of the internal and external system environmental factors of 5”C”s.

6. Healthcare *IS* – A continuous individual information originating & processing situation in the presence of uncertainty: Qualitative statement of Demand for Information Integrity

In other words, healthcare errors can be seen not as medical errors but as rather information errors made in medical setting. This recognition brings in two relevant modeling aspects of informational view based healthcare system definition, which need attention at this stage.

Firstly, it is mentioned in Sub-section (3.7) that to define a system “what is then required is to cull out – not necessarily physically, but mathematically – and study facts (data and information variables) that are relevant to the identified system goal (Usefulness factor)”. Also, in Section (4), it is argued that *IS* such as healthcare comprises multistage “individual” decision process. This requires treating information processing in healthcare system as an individual situation involving information origination. Secondly, there comes the question what if the “goal” leading to Usefulness factor, though given, continuously needs adjustment due to constantly changing environment (as very well can be the situation, for example, in healthcare of elderly patients) or is not known or is out of date or is by itself complex (all these are the conditions to be observed in the real world problem solving). Even if one takes a conservative view, a large, semantically complex, time-pressured, tightly coupled, high consequence, high-reliability engineering system, in the wake of unclear goal statement (implicit goals inclusive), is observed to run a risk, in the fashion of an open system, of taking a life of it’s own [Dörner, 1996; Cook and Woods, 1994; Mandke and Nayar, 2001].

In such case then the task of culling out the relevant facts (data and information variables) cannot be treated as a static one determined uniquely and exogenously as in case of closed systems, but would acquire a dynamic - open and endogenous in that – character in the presence of 5“C”s and they (data and information variables) would need to be *continuously* originated and processed.

This modeling reality has a far reaching implication for the *IS* modeling exercise underway as what it does is to model information processing under the healthcare *IS* view as a *continuous individual*

information originating and processing situation in the presence of uncertainty, so as to account for demands of continuously determined specific goal based individual situation in a complex and changing environment. In other words, in view of open system character of the healthcare *IS*, the requirement, in the presence of 5“C”s, now *is* to continuously originate (extract), store, validate, process, communicate, and store for future use or discard information. Thus what one is faced with is a requirement to deal with an information development and implementation life cycle (IDILC) model in the presence of uncertainty.

Before we proceed further, it may be mentioned that the information processing cycle requirement of IDILC is often attributed to rise of data-driven technology keyed to the flow of information across the supply chain and on the Net. Yes, certainly, system integration technology of today has contributed to this requirement. However, it would be a gross error to see this issue only in the light of integration technology. This information processing cycle requirement — starting from information origination stage — in actuality has always been there, even when integration was minimum, *except* that the frequency of the repeat of this information processing cycle was not high; information being viewed as a function of “source” (or at the most “source” and “process”) *only* and not as the function of the “source”, “process” and the “recipient.” This led to seeing information errors in respect “source” and being termed as “data” errors perceived as to be of that moment having no significance beyond themselves, and integrity view was ad-hoc and in parlance of DBMS limited to data integrity only. Given the difficulty *IS* designers have in relating events/situations from different time intervals [Dörner, 1996; Mandke and Nayar, 2001], it is these large time intervals between the re-occurrences of information processing cycle requirements that has led to the *IS* being modeled as a closed system with assumptions of static environment.

But over time, under the open system view and the impact of 5“C”s, the business *IS* view so modeled has begun reeling under the pressure of information errors (pollution) and, as in case of a statement of nosocomical infection described in Section (2), leading to low integrity information decisions, adversely affecting a customer, if not an entire market, and therefore loss of competitive advantage. This makes continuous maintenance of desired Information Integrity (I*I) a *must* for efficient and economic functioning of the *IS* so as to achieve competitive business advantage [Mandke and Nayar, 2000], thereby offering I*I as a bottleneck and, hence, as a critical resource for business advantage. This establishes demand for Information Integrity.

Figure (2) gives a systems view of a healthcare process represented as a generic business process *IS* view as developed here and as integral part of a closed loop information and control system characterized by continuous information originating and processing situation in the presence of uncertainty and the emergent all encompassing view of Information Integrity. In search for effective patient care, it is this healthcare *IS* view, characterized by uncertainty and, hence, information errors due to open system view and 5 “C”s, that should then process information efficiently and economically. Towards this objective, in what follows the paper develops “Usefulness- Usability- Integrity paradigm”.

7. Usefulness- Usability- Integrity paradigm

Construction of integrity structure amenable to Information Integrity analysis has at the core a requirement of modeling “informational work” (IW), i. e., modeling quantum of “information use” (IU) achieved in the wake of information processed. And, the *IS* of concern here is a continuous individual information originating and processing situation characterized by uncertainty and, hence, by, accordingly, accompanying information errors and the loss of Information Integrity. In its representation this *IS* can be seen as comprising a number of core *IS* models having data origin stage, data transformation/ conversion/ processing (decision) stage, pre- and post- processing communication channels (comprising medium and people), and output (i.e., data product that is information representation and use) stage. These core *IS* models may be repeated, paralleled, and interrelated. Output from one core *IS* model may become input to another [Mandke and Nayar, 1999].

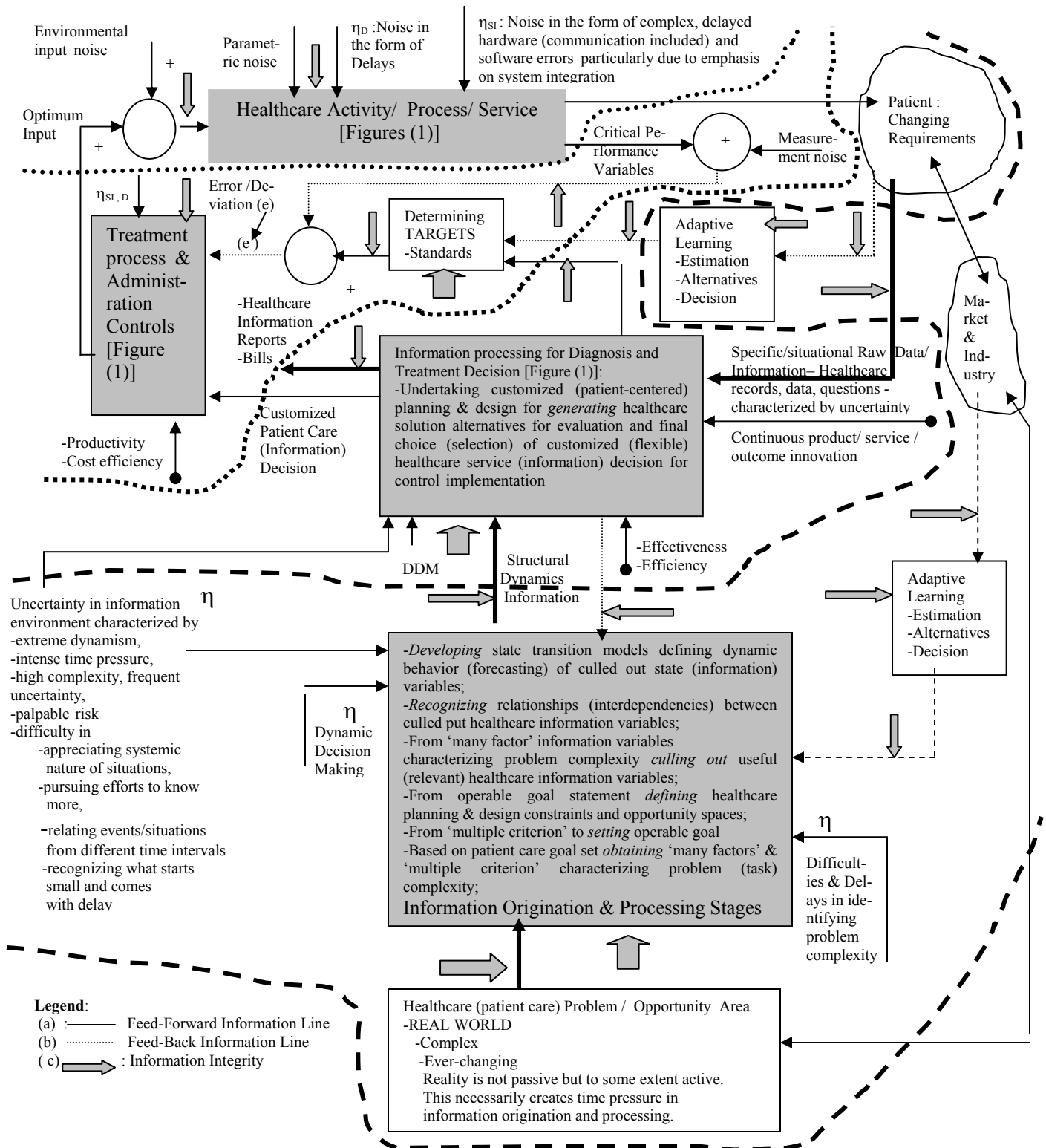


Figure (2): A systems view of a healthcare process represented as a generic business process *IS* view and as integral part of a closed loop information and control system characterized by continuous information origination and processing in the presence of uncertainty and the emergent all encompassing view of Information Integrity.

In the analysis of databases and the integrity objective, on the one hand, this *IS*- based visualization necessitates viewing databases along with their data acquisition and information utilization cycles, while on the other hand it requires information always to be identified in the context of its objective or goal [Redman, 1996; Mandke and Nayar, 2001]. In other words, for the study of integrity objective, firstly it becomes meaningful to go beyond the subject matter of data integrity and *further* cover the requirements of data origin integrity, process integrity, medium integrity, people integrity, and output integrity, integrity of the overall system being achieved if the integrity of all parts of the system are achieved, and secondly, data and information requirements - whatever may be the level at which the *IS* is considered (strategic, control or operational) – are required to be modeled in the context of their respective goal(s). This leads to the need to take a systems view of integrity [Rajaraman, 1995].

In search of a structure for integrity objective, the above then provides a basis for the *Usefulness–Usability–Integrity paradigm*. Specifically, usefulness refers to the *relevance* of the information for its intended purpose. For example, the recent history of a stock's price may be useful in deciding whether to buy or sell a stock. However, the recent history of the price of corn or oil may not be useful at all in deciding whether to buy or sell the stock. Against this, usability refers to *feasibility* factors such as availability, accessibility and understandability, which help make it possible and easy to use the information. For example, information may be usable because it is available on the Internet, because it is presented in an intuitively obvious format or because it can easily be imported into a spreadsheet or database.

Literature identifies a universe of information attributes. Appropriate attributes from these concerning context, goal, and nature of information use, i.e. relevance and feasibility of use, then can be categorized under the Usefulness and the Usability objectives. Drawing on integrity research investigations in security, auditing and quality arenas and in the information systems area, architecture for the information attributes' universe then facilitates a workable framework for defining intrinsic integrity objective in the form of accuracy, consistency and reliability attributes of information covering correctness and appropriateness aspects [Mandke and Nayar, 1998]. Information requirements of Usefulness, Usability, and Integrity are, then, the determinants of information value (V(I)). Integrity attributes of accuracy, consistency and reliability are fundamental or basic to the information requirements of usefulness and usability and, therefore, to the value of information; and as a result a critical requirement of an *IS*. As information value can be seen to define information use (IU), the integrity objective then can be seen as to optimize "IU" quantum for a given information-processing situation, so as to offer competitive advantage.

We are concerned with information system, which is a continuous information originating, and processing situation and which delivers information for use, *say*, for better decisions (here in our case better healthcare service decision). Literature reports extensive work on theories of collective and individual decision making. These theories have developed concept of "information value" based on which there is a mainstream information economics which attends to the concerns of comparison between two information products or product factors, thereby rendering economic framework of information economics amenable to quantitative analysis of value of information [Tallberg, 1999]. As, in our search for integrity objective structure, we also have *now* stumbled on to an "Information Value," it then offers us a clue that for the analytical study of Information Integrity, we too could opt for exploiting the economic framework for Information Integrity.

With framework for integrity analysis identified in the nature of Usefulness-Usability-Integrity paradigm for integrity objective, the crucial significance of above observation, apart from putting the model building exercise - we are at- in correct perspective, is that it suggests *what* could be the methodological approach for exploiting the paradigm; the methodological approach being that of the cost-benefit analysis of Information Integrity. As observed earlier, integrity objective is critical to the value of information,

and, as a result, a critical requirement of an *IS*. Trivial as it may look, this observation is not *that* obvious as to be found from the difficulty that researchers from the fields of EDP, auditing, data quality, computer science and information systems have in convincing the business managers to put their dollar on improving integrity of their information systems and of information there from.

This points to the need to detail the methodology for cost benefit analysis of Information Integrity so as to scientifically arrive at the demand for I*I and to find methods, techniques and technologies to develop its attributes for their implementation for competitive advantage in business decisions at strategy, control and operational levels.

8. Cost Benefit Analysis of Information Integrity: Analytical Statement of Demand for Information Integrity

The cost-benefit analysis of Information Integrity needs to be undertaken with reference to a continuous individual information originating and processing situation under uncertainty that a healthcare *IS* view represented as a business process *IS* view is. This is a complex *IS*, open system in that at all levels, and comprises multiple stage decision process as shown in Figure (2).

Consider any information originating and processing stage (S_i) of this *IS* view. As argued in the beginning of Section (7), such *IS* can be viewed as formed by a number of core *IS* models connected in series and parallel. It is recalled that core *IS* model to which data and information are integral is modeled as a decision process (see Section (4)). To outline the cost benefit analysis methodology of Information Integrity, one can consider such decision process.

The decision purpose can be taken to process/transform/convert data as in core *IS* to deliver information decision (by itself an information) which can be seen as a decision outcome so as to achieve better information use (for example better control for improved patient care). Thus the purpose of processing data/information through the core *IS* can be taken as “improvement in information use”, which in turn then can be considered as the strategic or competitive advantage.

It is understood that this “improvement” (shown as “ Δ ”) will be a function of the information (I) being processed under the stage $\{S_i\}$ and, accordingly, it can be represented by $[\Delta IU(I)]$, where $IU(I)$ denotes the variable giving the upper bound of information use as function of “I” (given that such function can be defined). Let “ $\alpha(I)$ ” denote Usefulness factor and “ $\beta(I)$ ” Usability factor. Both factors, functions of “I”, may take values between (0,1] and, accordingly, can be seen as appropriately defined proportionality variables. Then, the improvement in information use at stage (S_i) is given by Equation (1).

$$\Delta IU(I) \mid_{S_i} = [\alpha(I) \times \beta(I) \times IU(I)] \mid_{S_i} \dots\dots\dots \text{Equation (1)}$$

On the face of it, Equation (1) would seem to give the benefit from the stage (S_i) core *IS* viewed as a decision process. But, reality is different as one is dealing with core *IS* models that are complex, open and impacted by 5“C”s and they *have* errors. As a result there *is* a question about the integrity of information “I” at the stage (S_i) – a first analytical expression of demand for I*I.

Specifically, suppose there is a question regarding the accuracy of information, and let $[A(I)]$ denote the concerned integrity quotient, which takes values between (0,1]. Then, the “benefit” or improvement in information use from information processing at stage (S_i) would get modified to as in Equation (2).

$$\Delta IU(I) \mid_{S_i} = \{ [\alpha(I) \times \beta(I) \times IU(I)] \mid_{S_i} \} \times \{ A(I) \mid_{S_i} \} \dots\dots\dots \text{Equation (2)}$$

Of course our main objective is to outline an approach to cost benefit analysis of Information Integrity. Having considered the benefit, this then brings the question to that of costs. As can be seen, the correct assessment of benefit from the information processing at the core *IS* model under consideration can be done *only* when, from the benefit as accruing under Equation (2), the costs of information processing are accounted for. In other words, result of Equation (2) does not correctly state the benefit. What are these cost components then?

Consistent with the individual information originating and processing nature of *IS*, it is suggested that these cost components are those of originating information “I” [denoted by $COST_{OI}(I)$], of analyzing integrity quotient of $A(I)$ [denoted by $COST_{ANAL}\{A(I)\}$], and the opportunity cost of analyzing $A(I)$ [denoted by $COST_{OPPORT}\{A(I)\}$] [Tallberg, 1999]. Accordingly then the “net benefit” in the form of improvement in information use as accruing at the information processing stage (S_i) is as given in Equation (3).

$$\Delta IU(I) \Big|_{S_i} = \{[\alpha(I) \times \beta(I) \times IU(I)] \Big|_{S_i}\} \times \{A(I) \Big|_{S_i}\} - \{COST_{OI}(I) \Big|_{S_i} + COST_{ANAL}\{A(I)\} \Big|_{S_i} + COST_{OPPORT}\{A(I)\} \Big|_{S_i}\} \dots\dots \text{Equation (3)}$$

Accounting for dynamic situations characterizing the information flow, if one considerably simplifies the query at hand and assumes $\alpha(I)$ and $\beta(I)$ to be given (something not to be the case in real world problem solving), the functions $IU(I)$ and $A(I)$ having their own respective first order transients with corresponding steady state values [here of upper bound value for $IU(I)$ and value equal to numerical one for $A(I)$], and assumes all cost functions to be exponentially increasing with time, then what emerges from Equation (3) is that $\Delta IU(I)$ at the stage (S_i) under consideration *will* have a maximum value at a given time, and, among other things, *for* a given (what can be seen as an optimum, i.e., desired or, say, intended) value of integrity quotient “A”. In other words there *is* an optimum I^*I at which overall increase in information use benefit is maximum; achieving that I^*I (implying accuracy, consistency, and reliability - if they can be quantified) is a costly process; and, to meet the demands of competitive advantage, resource commitment for achieving improved I^*I , preferably optimum I^*I , is critical.

Equation (3) (with $A(I)$ substituted by $I^*I(I)$) thus gives the *IS* model of the continuous individual information originating and processing situation under uncertainty. Specifically by modeling information origination as a costly process, the model presents $I^*I(I)$ as a bottleneck and, therefore, as a resource for improved information use, i. e., competitive advantage, i. e., improved patient care. This then analytically establishes demand for Information Integrity.

9. Determinants of Information Integrity Attributes

With demand for I^*I established, it is of interest to have a brief look at the determinants of Information Integrity. As Information Integrity gives a measure of extent of information errors present in *IS* and in information therefrom, we may start by defining error. What can be construed as an error? From the viewpoint of an external observer, an error can be seen as a failure to ensure an optimum, desired, or intended value (for a view, format, variable, or process etc. as the case may be) that is correct given the circumstances (situation), the cause and form of error notwithstanding. An error can occur only if there is an appropriate identified source of value (standard) to ensure on the basis of a documented state of events.

Within above framework then this section defines the attributes of Information Integrity, namely, accuracy, consistency, and reliability identified in Section (7). Specifically, Accuracy attribute, then, can be defined as the degree of agreement between a particular value and an identified source. It can be

assessed by identifying the relevant established source (standard) and by determining an acceptable tolerance. Specifically, the identified source provides the correct value – preferably the value corresponding to the optimum Integrity (see Section (8)). For those with appreciation for concrete, it can be an object or relationship in the real world; it can also be the same value in another database, or the result of a computational algorithm.

In the days of system integration, one comes across repeated instances of the information object at the same point in time (e.g., a product code in multiple databases). Similarly, there are also repeated instances of the information object over time. These can be the occasions for “spatial” and “temporal” consistency errors in information objects, and accordingly one then has the consistency requirement for “correctness” of information content, which in turn then identifies the “consistency” attribute of Information Integrity.

Specifically, Consistency is the degree to which multiple instances of a value satisfy a set of constraints. As described above, the multiple instances may exist across space (such as databases or systems) or over time. Consistency is then with respect to a set of constraints and data/information is said to be consistent with respect to a set of constraints if it satisfies all constraints of the data/information model. Constraints can apply to the same attributes in different entities (such as the salary attribute in the entities of several employees); they can also apply to different attributes in the same entity (such as the salary level and salary attributes in the entity for a particular employee).

Finally, “correctness” requirement of information content identifies yet another attribute of Information Integrity, namely, reliability. Traditionally a large concern in the system development lifecycle model, reliability is a little complex attribute to define as it has a dual meaning in modern technical usage. In the broad sense, it refers to a wide range of issues relating to the design of large systems (complex computerized information system [CIS] included), which are required to work well for specified periods of time (the subject matter of reliability engineering).

In a narrower sense, however, reliability is a measure denoting the probability of the operational success of an item under consideration. The notion of reliability, in this case, may be applied to a single component (e.g., a diode or a light bulb); a complex system (e.g., a complex medical equipment, a computer or a network of computers); a computer program; a procedure (e.g., conversation between a doctor and an elderly patient); an element of an *IS*, namely, data, i.e., *IS* input, or *IS* output which is “data processed”, i.e., information; or even a human. Specifically, reliability analysis is concerned with occurrences of undesirable or unanticipated events during the course of operation of a system or an item and the impact of these events on the system’s behavior or the item’s use. And the undesirable events may be failures of components - and, for information systems, failures of resulting data and information in the form of data/information errors - caused by deterioration or wearing out of components due to age and usage, or even design, implementation, or operational problems and inadequacies due to 5“C”s, etc. surfacing in the course of the use of the system.

In view of the *IS* function of delivering information for use, reliability of each output item delivered, i.e., the reliability of “information”, which is the element of the *IS*, becomes significant and, keeping in mind the needs of user domains, the same can be heuristically defined as follows: “Reliability refers to completeness, currency and auditability of data/information. Specifically, data/information is complete when all component elements are present. Information is current when it represents the most recent value. And, information is auditable if there is a record of how it was derived and that record allows one to trace information back to its source.”

What we have described above are attributes of I*I for information value, i.e., for the content of information. In Section (7), it is observed that integrity is a systems concept. This implies similarly one should develop descriptions of accuracy, consistency, reliability in respect of process integrity and,

system integrity. Then there are also the requirements of developing descriptions of accuracy, consistency, reliability attributes in respect of design, development, implementation, and maintenance integrity. And further there is the area of quantifying these I*I attributes by defining appropriate metrics for the purpose. All these and many other related areas then constitute the further I*I research areas for effective, efficient and economic business management in different application domains; healthcare sector being one such.

10. A Systems View of Information Integrity Technology – A Conceptual Schematic

This brings one directly to the question of visualizing Information Integrity (I*I) Technology. Indeed, this query itself is a subject of separate research investigation. However, for the purpose of presentational completion and in the manner of indication of methodology in outline, the paper considers this query not in complete, and only in an illustrative manner for a managerial level activity (for example, in healthcare system, surgeon in an operating room (OR) can be seen as a manager of the individual project situation at hand). Specifically, the section enumerates only main steps to view I*I Technology development and that, too, in a generic fashion. Consistent with description of I*I attributes as in Section (9), all through this systems logic, it is kept in mind that the main task at hand is to develop “standards” at various levels for the functional activity pursued. This is because it is deviation from standards that offers a workable mechanism for studying I*I attributes of accuracy, consistency, and reliability.

Step 1: Consider developing a conceptual systems schematic of I*I Technology for a managerial level business functional activity of “monitoring and maintaining delivery of product and/or service (information product/ service inclusive)”. It is noted that this is an informational activity representing a continuous individual information originating and processing situation in the presence of uncertainty.

Step 2: The *task* at hand, therefore, can be described as “Monitor and maintain service and product delivery.” Certainly, this is a positive goal, but it is not clear in that it is ridden with uncertainty as to what exactly is to be achieved, there being *multiple criteria* and *many information variables* describing this *complex task*. These (multiple criteria with many embedded information variables) are: (a) Establish and agree customer requirements, (b) Maintain operations against specifications, (c) Monitor and maintain the availability and condition of resources, (d) Contain and minimize factors, which disrupt operations, and (e) Establish and maintain the quality of services and products.

Complex the task is, what is interesting to note is each of the above represents an operable goal. For the illustrative query at hand, one could thus proceed with one of the operable goals, say, that at (d) above. This *operable goal* is clearer, less ambiguous than the statement of functional task, and actually provides a *performance standard* for the task at hand; other standards being given by criteria (a), (b), (c) and (e).

It may be mentioned that choice of this operable goal (Contain and minimize factors which disrupt operations) is made here as it presents a seemingly more concrete visualization of requirement for error reduction in the function under consideration, and therefore a more concrete statement of I*I Technology. But, as we have clearly shown through this paper, due to open system view and impact of 5“C”s errors are present in the context of every other operable goal, i.e., performance standard and requirement of I*I Technology for competitive advantage is present in an all pervasive manner therein, too.

Step 3: Performance standard under consideration could then be described by *performance criterion*, describing “process” standards for *factors & measures, actions, optimality conditions*, and for *information reports* offering a mechanism to evaluate and measure if the work output (informational work included) delivered meets the expected performance standard.

Step 4: When one talks of “work output”, along with “processes”, one is *also* concerned with requirements of “productivity” and “efficiency”. Accordingly, need is *also* to evaluate and measure products and services delivered. This then calls for defining performance “evidence” standards in terms of work targets.

Step 5: For competitive advantage, within the boundaries defined by the “standards” developed at various levels (Steps 2, 3 & 4), the requirement is that the performer (here manager) undertakes a work method & activity (WM&A), which necessarily is an individual information originating and processing situation. To explain, for manager level functional work activity of “monitoring and maintaining delivery of product and/or service”, the *context, specificity* or *individual situation* may be defined by system parameters such as types of alternative equipment available and extra supply availability there from, details of physical/material resources (including energy supply), and capital, people and knowledge expertise availability, etc., which can be expected to vary from project to project, work to work, space to space and time to time.

Based on standards at different levels and based on defining of WM&A and their *context or specificity parameters* as above, then develop standardized WM&A instruction (i.e., algorithm) for undertaking continuous individual information originating and processing situation based problem solving.

Step 6: However, various factors external and internal to the system, i.e., *system environmental factors of 5“C”s*, will affect the standards and the context and specificity factors so developed at various levels.

Identify these system environmental factors in respect of each of standards. This then gives the systems presentation of continuous individual information originating and processing situation in the presence of uncertainty due to 5“C”s that one is faced with.

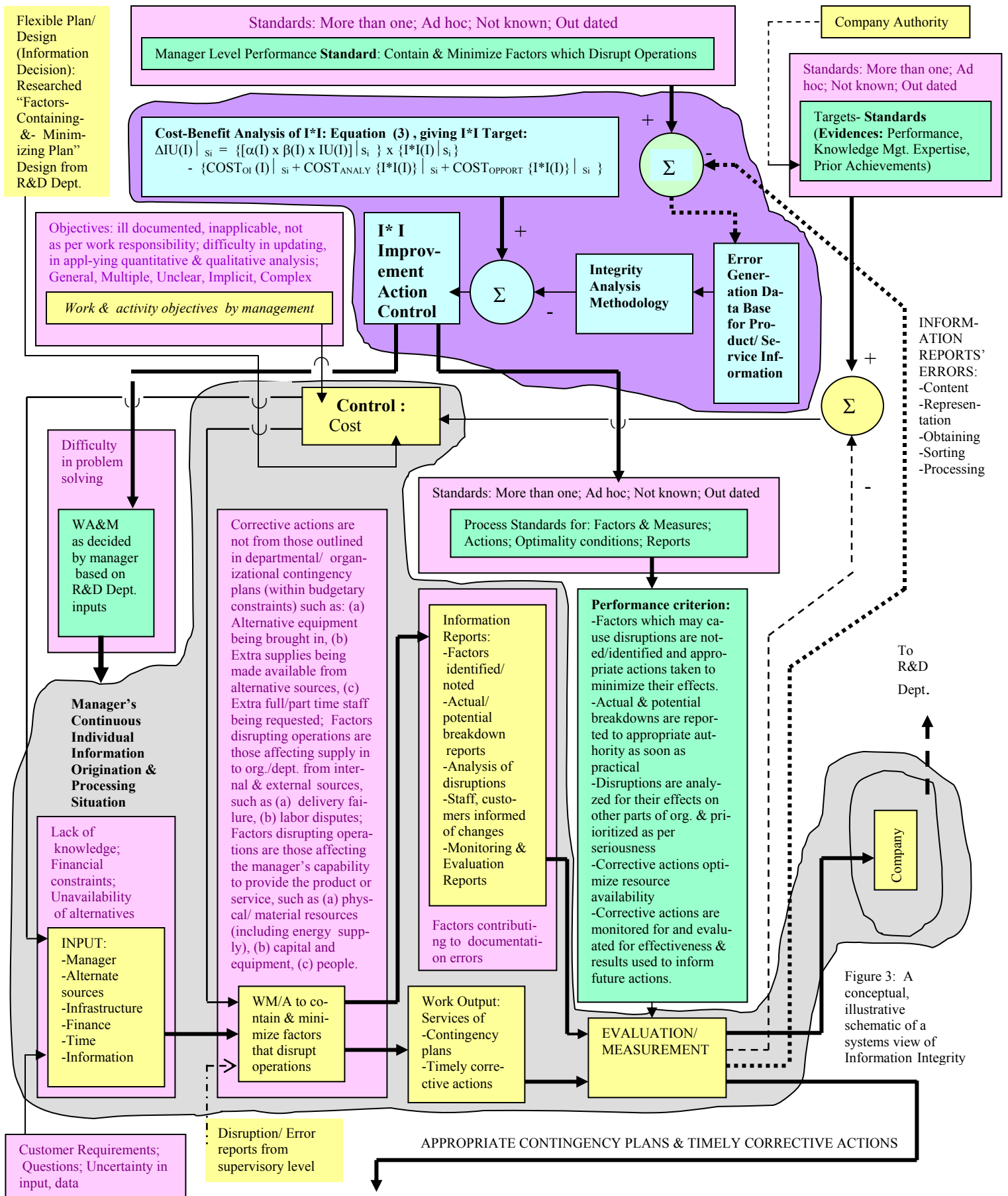
Step 7: It is these system environmental factors that will then lead to informational errors and thereby to loss of I*I; in turn leading to the systems view of I*I Technology (see Figure (3)).

As can be seen from Figure (3), defining of standards at various levels, identification of system environmental factors of 5“C”s at all levels, development of Error Generating Data Base (EGDB), undertaking Integrity Analysis Methodology (IAM), identifying I*I Target from the Cost-Benefit Analysis Equation (3), and implementing I*I improvement action through control are the components and elements of the I*I Technology system. Understandably, even within the scope of this only illustrative example, each of these components and elements of I*I Technology system presents opportunities for further research. Also, this entire exercise will have to be developed at supervisor and worker levels, as along with manager they form the total team for the task at hand. Further, for the task under consideration, the performance standard illustrated is *only* one of the five performance standards governing the functional work activity. The other performance standards thus also need to similarly consider the development of I*I Technology.

There are more things. What Figure (3) has described is the I*I Technology system for the *IS* under consideration. But this *IS* also has its components and elements and for overall I*I, it is necessary to develop I*I Technology systems for each of these components and elements. And then there are other functional business activities. Indeed, it is not the intention here to exhaust even in the form of a list all these issues, but only to point out that I*I Technology need is a global requirement. This provides a pointer to further research and development issues and opportunities, offering Information Integrity Space as a very promising knowledge, technology and business growth area [Nayar, 2001].

11. Conclusion

Healthcare system is made up of things, people, information, and the relations and interactions among them. This is a view of an open system and for effective system performance it is required that it processes information within and between system components and elements efficiently and economically. However, it is this open system view along with system environmental factors of 5“C”s that introduces information errors in healthcare system giving rise to medical errors. More importantly this renders the healthcare *IS* view to be a continuous individual information originating and processing situation characterized by information errors and resulting loss of Information Integrity; in turn making the activity



of information “origination” a costly activity. The cost–benefit analysis of Information Integrity shows that *IS* as this can deliver maximum “information use” in respect of information processed *only* by controlling I*I. This demonstrates analytically that optimum I*I is a must for efficient and economic processing of information and therefore for competitive advantage. Further, this facilitates designing I*I Technology for error reduction in systems such as medical systems based on systems approach.

Information is higher-order of matter and energy on which it depends for its existence. It has *always* been there, only requirement being recipient has to make a meaning out of it. Even with technological innovations dating back to 16th century, it is only around first quarter of 20th Century that in response to Maxwell’s demon the significance of “information” was recognized. Indeed, the informational processes demonstrate difficulties in originating information with reference to goals or phenomena, particularly when they are implicit. Information Integrity is the implicit goal of an *IS* and of information there from, so that *IS* can oppose entropy and put *off* for a time the inevitable heat death. Like information, requirement of Information Integrity has also been *always* there. In the wake of incessant performance pressures as a result of system environmental factors of 5“C”s, this implicit goal has begun surfacing in the view of the recipient at the risk of otherwise loss of competitive advantage. This creates enormous and exciting opportunities for academia, industry and government to create new knowledge and market space in every sphere.

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