INFORMATION INTEGRITY A CRITICAL FACTOR IN STRUCTURE SAFETY, SECURITY AND RELIABILITY

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Abstract: Safety, security and reliability are essential requirements for competitive construction business. Information Integrity is dependability and trustworthiness of information and is a key factor determining strategic business advantage. Its determinants are accuracy, consistency and reliability of information. Infrastructures and buildings have changed a great deal but it is the processes by which structures are designed and constructed that have changed the most. The majority of structures are still comparatively simple, but internal as well as external user aspirations are becoming increasingly local and instant. In an industry traditionally geared to work under exogenously generated alternatives and information, need - in the presence of the reality of ever-present external and internal system environmental factors - is now to continuously and locally (endogenously) generate alternatives and their information requirements. This dynamic decision-making process model is demanding informational work activities, hitherto not considered, namely, information processing for observation, storage, retrieval, verification, prediction of future states, precompiled responses and abstract reasoning, manipulation, communication, *use* and discard or storage for future *use*. And in the presence of system environmental factors all these activities assume complex and changing character besieged with uncertainty. Even one generation ago, large complex buildings were erected quickly and with very little documentation, but as a result of these new information processing demands today the whole industry is increasingly burdened with the data and information, that too fraught with uncertainty, which in the wake of information processing methods of yesterday not only tend to become ends in themselves, but also slow down the process and increase the risks of failures. These informational failures, which can now be seen as an increasing problem as industries move from crisis to crisis call for simplification and speed. Within this framework this paper examines the process of information processing in design and construction and presents a systems design for Information Integrity, i. e. correctness requirement of information, as an approach to ensuring safety, security and reliability of structures.

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1. AN EXAMPLE: STRUCTURE FAILURE–AN INFORMATIONAL VIEW

1.1A Drafting Error

When people, i.e. clients, decide to construct a house or a structure, above all, they expect a safe, secured and reliable shelter or facility. The roof of the cafeteria of a Junior High School in Charlotte, N. C. had stood for some four years. In January 1968 during a storm it experienced accumulation of four in. of snow and ice (system environmental factor) resulting in the collapse of 4200 ft^2 of roof. Subsequent investigation into the structure failure showed that the roof framed with open web steel joists (supported on intermediate line of girders) had two of the columns under the girders *omitted* when the construction plans were finalized to incorporate fireproofing (change) requested by the insurance division during state review.

The architects publicly admitted the drafting error when they checked the plans following the accident, which came after the cafeteria had been in use for over three years (note the on-going risk the structure carried through). It is inconceivable how such an omission was not detected in checking of structural plans by various agencies or how the steel could be erected without the necessary number of supports.

1.2What went wrong?

What went wrong through all these chain events? Was it the drafting error, i.e. error in the process of drafting that led to this failure? Or was it the faulty checking process? Or was it the lack of skill or accountability by those participating in plan preparation, drafting, reviewing and construction activities?

No, all such are post-event observations. In fact what went wrong is, during the drafting-cum-construction-plan-checking-and-finalization-cum-erection phase, drafting information on number of columns under girders was assumed correct, i.e. with integrity, as validated while incorporating the changes for "fireproofing" requirements.

1.3Information Origination and Processing Errors

1.3.1 Resulting in loss of Goal integrity

To elaborate, the error *here* is at various stages. Firstly, the error is *that* of information *origination* during the drafting activity while incorporating the change. The information-processing flaw *here* is that, in ballistic behavior, taking information decision on reduction in number of columns supporting the girders and not to anticipate, in the wake of change requirement and, hence, in the wake of change in operable goal(s), error(s) in *origination* of information requirements; i. e. loss of Information Integrity (I*I) in goal defining, aptly termed Goal Integrity.

1.3.2 Resulting in Loss of Design Integrity

Secondly, the error is *that* of information processing during checking-and-finalizing-of-plans; the information-processing flaw being assuming drafting phase information decision on number of columns under girders correct as validated earlier while incorporating the changes for "fireproofing" requirements; that is without its (information decision) validation at the 'plan finalization' phase; that is without ensuring required Design Integrity.

1.3.3 Resulting in Loss of Implementation Integrity

Finally, the error is *that* of information processing at the phase of erection of steel. Once again, *here*, the information-processing flaw is of assuming plan review phase information decision or final design decision on number of columns under girders correct as validated earlier; that is without its (information decision) validation at the 'steel erection' phase; that is without ensuring required Implementation Integrity.

1.4 Resulting in Delivery of Unsafe Roof Structure: Information processed as function of Condition of Recipient

Instead of the expected safe roof that the construction was to deliver to the client, *this* resulted in making the roof structure vulnerable, rendering it unsafe and unreliable. That is, in addition (a) to the drafting work, which in *this* example is the source or point of *origination* of information on number of columns in the wake of change due to "fireproofing" requirements and (b) in addition to the construction-plan-checking-and-finalization-cum-erection departments, which *here* represent the processors of information (or information decision) for *use*, the information processed turned out to be *function* of (c) the condition of the recipient, which *here* is the roof with two supporting columns *omitted*. After being in use for over three years and after four years' since its erection (i.e. with delay), it is on *that* day in January 1968, when due to a storm four in. snow and ice (system environmental factor) accumulated on *so* erected roof, that it led to its collapse.

1.5 Complex Error Mechanism coming with Delay

Stated differently, it is the combination of information errors under the information *origination* and processing stages (building failures then can be seen as the informational errors in building construction setting) that in a delayed combination with the system environmental factor (in this case of accumulation of four in. snow and ice on the roof) formed a complex error mechanism. This as described above led to the collapse of the roof (adverse event (AE)), rendering the roof unsafe. Of course, the reality was *the* roof was a candidate for this failure right from the day when (in the process of incorporating change in the manner of the "fireproofing" requirements) the desired Safety Goal Integrity was not ensured.

1.6 What was needed?

For construction of a safe structure (roof in this case), therefore, what was needed was:

- Given the situational factors of (a) change requirement in the manner of "fireproofing" objective, (b) in that case the difficulty in ensuring adequate Goal Integrity, and (c) of the system environmental factors such as storms:
  - To *originate* at drafting phase, construction-plan-checking-and-finalization phase and at erection phase the information requirements (I) in respect of: respective operable goal set, fireproofing requirements, and the roof structure (recipient) safety condition, and
- To obtain (originate) and control (improve) to desired level Goal Integrity (at drafting phase while accommodating "fireproofing" requirements), Design Integrity (at construction-plan-

checking-and-finalization phase) and Implementation Integrity (at Erection Phase) for information (I).

2. SAFETY, SECURITY, RELIABILITY OF STRUCTURE - A CRITICAL CONSTRUCTION INDUSTRY REQUIREMENT FOR COMPETITIVE ADVANTAGE

2.1 Safety, Security and Reliability of Structure

Safety of infrastructure and building has two aspects. One is that of the failure free structure that the client and people using it desire so that it causes no accidents and other is that the construction business can deliver the infrastructure and building products and services to its client effectively, economically and profitably. There is often a relationship between security and safety. Lack of security at construction site can result in inadequate safety for workforce. It can also result in loss of material and damage to equipment. All this results in losses to business and client.

The term 'reliability' 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 engineering system that a complex construction project comprising systems, sub-systems and components is, which is required to work well for a specified life cycle. It often includes descriptors such as quality and dependability and is interpreted as a qualitative measure of how a system matches the specifications and expectations of a user. In a narrow sense, reliability is a measure of denoting the probability of the operational success of an item (system, sub-system, or component) under consideration. Understandably, reliability of systems, their sub-systems, and components and the structure itself is important to ensure the requirements of secured and safe structure. Together these infrastructure and building requirements go to define the competitiveness of construction business.

2.2 Safety and Security Statistics and Causes of Observed Failures

Accidents statistics show that construction is one of the most dangerous industries in the world. The National Institute for Occupational Safety and Health (NIOSH) reports indicate that, on the average, between 1980 and 1993, 1079 construction workers were killed on the job every year. Some contributing factors to this condition are obvious: incomplete structural connections, temporary facilities, tight work areas, varying work surface conditions, ever-changing work sites, multiple operations, and crews working in close proximity. However, several easily overlooked factors, such as lack of preplanning, inadequate selection of contractors, and laissez faire attitudes are significant contributors to these statistics. Injury free working environments are important to business because they eliminate financial losses associated with injury claims, lost work time, and schedule delays.

Principle causes of construction industry fatalities are: Falls (29%); Over-the-Road Motor vehicles (16%); Industrial Vehicles & Equipment (13%); Electrocution (10%); Caught In, Under, or Between Objects (9%); Heart Attacks (8%); Struck by objects (6%); Explosions (3%); Fire (2%) (Note: Industrial causes responsible for less than 1% of fatalities not included). Any contractor who allows accidents to increase his costs puts himself at a competitive disadvantage, because he has to bid for more jobs to get the same amount of business, and he may end up doing work that other contractors do not consider attractive. In addition to the foregoing costs to contractors, design professionals, and owners, injured workers bear many of the costs of accidents.

Coming to security, no matter how thorough site security may be, losses can still occur through either internal or external influences. One estimate suggests construction losses in 1982 due to theft and vandalism at building sites to be over 1 million pounds per day. Main causes of losses on construction sites, not necessarily in this order of priority, are: Thefts involving employees, short deliveries, bad site storage, thefts by outside agencies, vandalism and damage, avoidable wastage (by adapting sound practical supervision and good site husbandry). Thus, various phases in building project warranting security considerations are: Company procedures; Material Stock Controls; Security at pre-contract planning stage, deliveries, acceptance, checkers and checking; Physical Security on Site; Out of hours security; Safes, Cash, Wages, etc; Damage; Security of Plants and tools; Bonus targets, Payments, Day-works; Labor relations; Sub-contractors; Liaison with Police, Fire Service, Public, etc. and Protection.

2.3 Informational Failures and causes of lack of Safety, Security and Reliability in Structures

The above are then the observed realities of safety, security and reliability issues and, in their absence or lack of them, of failures in building and infrastructure products and services in whose market the construction industry functions. In classifying above causes, there is no real need to distinguish rigorously between direct, indirect and contributing causes of accidents, but it is important to recognize that accident might be the result of two (or more) concurrent events (see Section (1.5)), neither of which necessarily be dangerous in itself. Some analysts distinguish between mechanical and human failures as causes of accidents. Material defects and equipment failures are thus considered mechanical causes, and errors of judgment or illness as human causes. But is it a mechanical or human failure when an inspector fails to observe something that is wrong with a machine? Why is it that in the drafting error example enumerated in Section (1), goal, design and implementation integrity were not ensured? Why is it that the architects noted the error when they checked the plans following the accident, which came after the cafeteria had been in use for over three years?

Seen critically, as observed in Section (1) these indeed are information *origination* and processing errors. Requirement for information *origination* and processing comes into play as field (real world) operations are impacted by ever-present environmental factors – internal as well as external. For example, in example under Section (1), external environmental factor of change requirement of “fireproofing” at the state review stage necessitated need to originate drafting information and process it, when loss of safety goal integrity and of design integrity occurred. The construction industry identifies following information *origination* and processing issues as factors causing these failures: incompetent men in charge of design, construction, or inspection; supervision and maintenance by men without necessary intelligence; assumption of vital responsibility by men without necessary intelligence; competition without supervision; lack of precedent; lack of sufficient preliminary information; economy in cost, in maintenance; lapses and carelessness; and catastrophic occurrences: earthquakes, extreme storms, fires, etc.

2.4 Absence of a systematic process to originate and process information locally

Catastrophic failures certainly cause serious losses. However, in normal times, catastrophic construction-related incidents that are the subject of front-page news such as the high-rise hoist collapse at Times Square on July 21, 1998, when 300 ft of hoist mast was hurled into the street and building below, killing an 85-year-old women is not the sort of occurrence that is the source of the majority of losses suffered by contractors. The losses that are crippling the construction industry and those that most seriously impact the majority are the multitude of minor injuries and on-site crimes that occur on regular basis. The most cause of the majority of “safety, security, reliability - related” losses *is* in the absence of a systematic process to identify and mitigate workplace hazards and unsafe work practices. It’s the result of the failure of systems, their sub-systems and their components to recognize the impact of ever present external and internal on-site environmental factors on integrity of informational stages of system life cycle and to effectively “*originate* and process information” in the context locally and communicate the importance that safety, security, reliability have on the continued economic viability of the organization employing them and the importance of maintaining the workforce, material and machine health so that there are qualified individuals, quality material, and reliable machines to do the structural design and construction work effectively.

2.5 Defining Construction Failure – Not Observed Construction Failure but rather Information Error in Construction Setting

As pointed out under Sub-section (1.3), the issue is then of information *origination* and processing errors. This recognition warrants paradigm shift in defining construction failure. If construction failure is defined as observed collapse, there would be few failures. But construction informational failure, where the observed failure, i. e. observed collapse, i. e. accident or adverse event has yet not occurred, is defined by nonconformity with design/drafting/plan review/erection specifications or expectations or defined standards, and this is more scientific approach, and if one takes the trouble to measure the shape, position, and condition of structural products (intermediate products inclusive) at the delivery of each of informational products and services delivered during construction system life cycle stages, there are many failures – far more than the list of incidents that are covered by the media, both technical and public. This statement is more applicable to the complicated space framings than to the simple or pin-connected structures. Unwanted displacements, unexplainable deformation, are often found and it is questioned whether they are failures or normal (but unexpected) strains or merely "incidents," using a foreign term to describe the unexpected results.

For the purpose of clear distinction of this informational view of failure as against the observed view, in what follows informational failure is designated as "informational error. " This informational view permits defining construction failures as behavior not in agreement with the standard conditions of stability or as lacking freedom from necessary repair or as noncompliance with the desired *use* and occupancy of the completed structure. Informational errors occur in all types of structures, small and large, low and tall, minimal and monumental, whether framed or wall bearing, whether with timber, steel, or concrete as the basic supporting material. Continuous pressure for greater economy, from private financial competition as well as from public demand that budgets be met, both in design and construction, has resulted in safety being reduced below the minimum sufficiency. Failure of part or even serious collapse of a structure usually comes during construction, when the latent uncalculated space frame strength is not yet available. The boundary between stability and instability, between sufficiency and error, is a thin line. Ignorance of the boundary is no excuse when a error occurs.

3. BUILDING STRUCTURES AND INFRASTRUCTURE-AN OPEN SYSTEM INTERPRETATION

Buildings and infrastructure are the end products – something that are constructed on the ground, useful and acceptable. Construction comprises of materials; components; structures; services; equipments; architects; engineers; contractors, sub-contractors and suppliers (civil, building, mechanical); their management; deliveries; and clients. Each of its many component subsystems 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, construction, 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. And, thirdly as a result, a construction 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. This makes for an informational, open system statement for the construction system and its loosely coupled components and elements, 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.

4. CONSTRUCTION SYSTEM: A POTENTIAL SOURCE OF CONSTRUCTION INFORMATION

If viewed from a physico-technical angle in which the system engineering discipline defines system traditionally, construction activity/organization can 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 construction 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. To meet the system goal, 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. Within this framework of reorganization of systems concept and based on the informational view analysis of construction system as above, a construction system can be seen as a potential source of construction information in respect of its components and elements, and described as a network of construction information variables in causal relationship to one another and in situations even to themselves.

5. BOTTLENECK CHARACTER OF INFORMATION IN CONSTRUCTION BUSINESS MODEL

From business standpoint, construction can be taken as the sum total of project concept, choice of materials, structural design, production of materials, erection of components, and even final clean-up and equipment installation. This is a 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 investigation need such models could emphasize different supply chain facets such as flow of material, equipment, fluid, energy, money, etc. By recognizing the construction organization as a potential source of construction information in respect of its components and elements, here, it leads to the construction business model *emphasizing* "information" and comprising informational and physical work systems in that it has a requirement to optimizes data and information for improved decision making for competitive advantage (see Figure (1)).

Specifically, the requirement is to maximize informational work (*IW*) comprising activities of: (a) originating from business process activities (both global and local) raw data/information in a complex and changing real world environment characterized by uncertainty and hence errors, and (b) processing this information on current basis for undertaking planning and evaluation of business process design alternatives and delivering selected information decision for control implementation at the physical work system. This leads to an information and control system model of which construction activity/process/procedure is an integral part — a Construction Process *IS* View; thereby establishing the bottleneck character of construction process information as the construction organization is viewed in its open system, that is, in more complex and real world character (see Figure (2)).

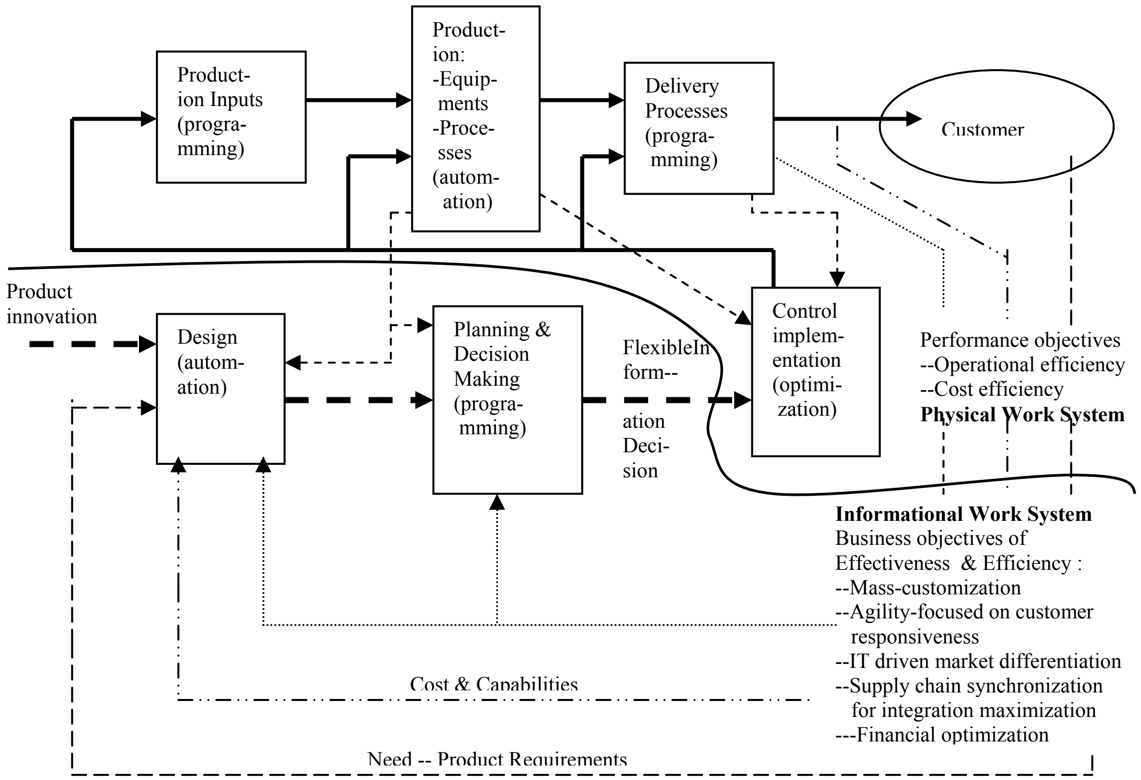

Figure (1): A Systems representation of a business process enterprise showing interrelationship between informational and physical work systems.

6. CONSTRUCTION PROCESS *IS* VIEW – A MULTISTAGE DECISION PROCESS

What is significant is this open system construction process *IS* view is a multistage decision process spanning decision stages of: *setting* construction goal (long term goal); based on construction goal set *obtaining* ‘many factors’ and ‘multiple criterion’ characterizing task (construction requirement) complexity; from multiple criterion *recognizing* (deciding) on construction problem (specific and operable goal setting); from operable goal statement *defining* construction process planning & design constraints and opportunity spaces; from ‘many factor’ information variables characterizing problem complexity *culling out* useful (relevant to the operable goal) construction process information variables; *recognizing* relationships (interdependencies) between culled out construction information variables; *developing* state transition models defining dynamic behavior of culled out construction problem state (information) variables; and undertaking customized (site-centered) planning & design for *generating* construction solution alternatives for evaluation and final choice (selection) of customized (flexible) construction service (information) decision for control implementation.

7. CONSTRUCTION PROCESS *IS* VIEW – INDIVIDUAL INFORMATION ORIGINATION & PROCESSING SITUATION

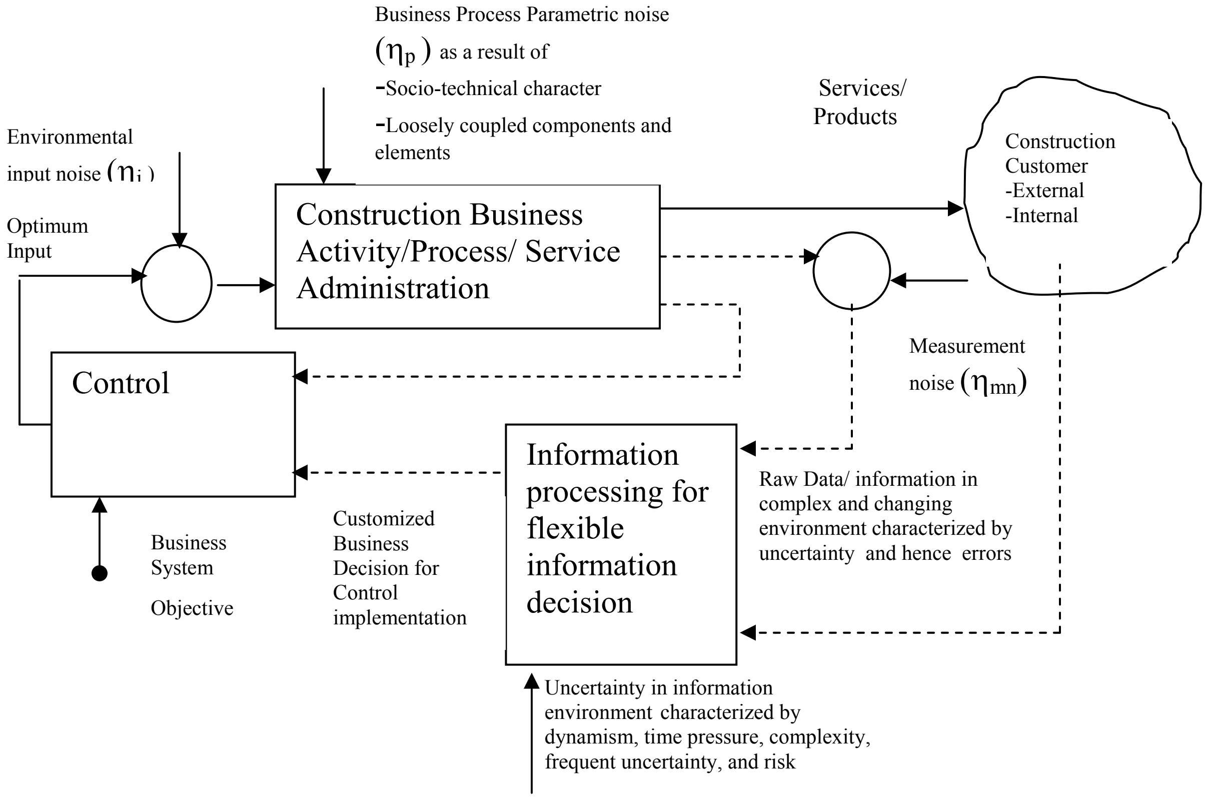

Figure (2): A construction system represented as a generic business process modeled as integral to a closed loop information and control system.

While development of this multiple stage decision process *IS* is outside the scope of the investigation proposed, 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 as under construction process *IS* has a requirement to identify operable goal, originate information and generate alternatives, all, "endogenous" to the *situation*, thereby making it (construction process *IS* comprising decision process stages) a candidate for designating it as an "individual" decision process.

8. SYSTEM ENVIRONMENTAL FACTORS OF 5"C"

8.1 *Complexity*

As with traditional *IS* which is a "collective" decision process, this multiple stage decision process *IS* is also characterized by uncertainties due to system environmental factors of 5"C", namely, complexity, change, communication, conversion, and corruption. As argued, modern business enterprise 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 Business Process *IS* view is.

8.2 *Change*

As a socio-technical system, business service product is subject to change due extrinsic as well as intrinsic events: societal pressures, legal and regulatory rules, etc. Further, the business system must cope with very rapid advances in technology and practice. In this context, it may also be mentioned that change in the global business system is accomplished laterally across several subsystems in which decision-making are distributed across many people and units. In such a diffused system, change can be slow, often difficult process. There is yet another point of extreme significance: a system such as global business 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. All these change features leading to dynamics in components and elements of the business 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 business *IS*, resulting in further requirements of information originating and processing, contribute to errors in *IS*.

8.3 *Conversion, Communication, Corruption*

Then, as mentioned earlier, complex, modern business enterprise involves many human and machine interfaces-cum-interactions between vendors, designers, developers, decision makers, production, operation, maintenance, people and devices, technicians and equipments, and others. There are also requirements of 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 business *IS* environment. What is important for the investigation at hand is each encounter as this, indeed, each operation, technical maneuver, human-machine interface, or human and machine information processing presents an opportunity for error.

9. UNCERTAINTY IN BUSINESS PROCESS *IS* VIEW

As with traditional *IS* which is a "collective" decision process, this multiple stage decision process *IS* is also characterized by uncertainties due to system environmental factors of 5"C"s, namely, complexity, change, communication, conversion, and corruption. Specifically, acting externally and internally, 5"C"s introduce in *IS* uncertainties observed traditionally and beyond.

9.1 *Uncertainty at Physical Work System Level*

9.1.1 At Operations Stage and at Physical Variable Control Stage

Thus, at the physical operations stage and at the physical variable control stage, uncertainties are introduced due to input noise, process parametric noise, and measurement noise.

9.1.2 At All Control Levels

At all the control levels (physical variable, transaction processing and management decision controls - which in the wake of "application" emphasis are so impacted), uncertainties are due to information overload, lack of standardization, lack of relationship in data in several applications, errors in hardware, software errors, data entry errors, or accidental or intentional failures, etc.

9.1.3 At Managerial Decision Level Controls and at Higher Level Controls

Further, uncertainties are also introduced due to incomplete knowledge of system dynamics and due to judgmental errors both at managerial decision level controls comprising human-machine interfaces and at higher level controls like production control, which apart from human-machine interfaces, in all probability, may even include humans as part of the process to be controlled.

9.2 *Uncertainty due to Complexity at Informational Work System Level*

9.2.1 At Operations Stage

And then there are the multiple individual decision process stages, which are also impacted by 5"C"s. Briefly, the business process *IS* view is a complex *IS*. This complexity introduces at the operational level, hitherto unknown complex error mechanisms coming from system development and implementation life cycle phases and that, too, coming with delay.

9.2.2 At Operations Stage and at Controls Stages

At the stages of operational level and at control levels, it introduces errors that arise due to failures of embedded systems; and, at all business *IS* stages, errors due to emphasis on system integration maximization. The later category of errors is on count of resulting system interfaces exposing innermost system modules to uncertainties due to external system environmental factors and vice versa.

9.2.3 At Decision Process Stages Endogenous to Decision Situation – From Long Term Goal Set Obtaining Multiple Criteria To Selection of Flexible Information Decision

Further, particularly at the decision process stages endogenous to decision situation, the complexity introduces errors due to information processing under: multiple goals (implicit goals included); multiple factors & multiple criteria (goal descriptions); a large number of interdependent information variables, varying with time and not completely and correctly observable; and system dynamics not well understood (reality is not passive but – to some extent - active). All this results in information errors leading to loss of Information Integrity in business process *IS* view and in information there from.

10. CONSTRUCTION FAILURES – INFORMATIONAL ERRORS IN CONSTRUCTION SETTING

It is these uncertainties due to system environmental factors of 5"C"s, namely, Complexity, Change, Conversion, Communication, and Corruption, acting externally as also internally, that contribute to information errors at each of the multiple stages of decision process constituting the construction process *IS* view; in turn leading to loss of Information Integrity (I*I) in construction process *IS* and in information there from. In the light of the construction system modeling based on informational view, it is important to realize that the construction errors are in fact due to information errors (at input (data origin) step, process (data transformation) step (medium comprising communication channel and people included) and at output (information use) step) through each of the multiple stages of decision process constituting construction process *IS* view phases from initial construction problem recognition (operable goal setting) to undertaking customized (site-problem-centered) planning & design for delivery of flexible construction service (information) decision for control implementation. Sections (1) and (2) have argued this visualization taking an example of a drafting error. In what follows this section offers further construction failure examples to build on this visualization.

10.1 Design Error Example I - A Case of Judgmental Error leading to Loss of Design (Decision) Integrity

A six-story steel frame for new Business Administration School at Georgia State College was erected in 1966 when the architect notified the owner that an additional $2000 was required to pay for adding beams at the elevator penthouse level to support machinery and to frame escalator openings, for some added reinforcing steel and changes to the metal deck forms. The college engaged an outside consultant to review the request and check the structural plans. The report cited a number of computed weaknesses in the existing frame based on the requirements of the AICS Structural Steel Code, especially in some half of the columns in the first and second stories. One major difference in design approach was the assumption that the masonry walls prevented sideway and therefore much more slender columns could be used. Overstress under full load was also indicated in roof girders, floor beams, and foundations. Among the corrective work necessary was the removal of concrete fireproofing from 34 columns so that cover plates could be welded to the flanges.

10.2 Design Error Example II- A Case of Error due to Incompetence (incorrect information origination) leading to loss of Design Integrity and resulting in adverse event

In 1964 a completed concrete church roof collapsed during Sunday mass in Rijo, Mexico, killing 55 persons and injuring 63. The roof had been designed by the brother of the parish priest and to complete the building in time for the Christmas holidays, with insufficient money available, the required bars had been changed to ½ in. throughout.

10.3 Design Error Example III – A Case of ballistic information processing to save on information origination effort leading to loss of Design Integrity

For simplicity of detailing and assembly of reinforcement it is sometimes expedient to use the same reinforcement for a roof slab as in the typical floor of a multistory building. This may explain why in a three-story school the main reinforcement of the floor was incorrectly copied from the design notes and the corresponding roof steel was shown on the drawings and so installed. Although this was one of several noncompliences discovered in the investigation, it may have had considerable influence on the large slab deflections, which required some repair and strengthening.

10.4 Drafting and Detailing Error Example – A case of impact of interdependent factor influencing the error

Another detailing error, of structural steel, caused by poor drafting resulted in all the corner stones of a limestone-faced courthouse in Queens, N.Y., rotating out of position under the thermal difference from sun-exposure on the adjacent faces. The contact drawings called for a steel angle lintel continuous at each face extending to 2 in. from each corner. Where angles met at a corner, the vertical leg of one was cut out to clear the 5 – in. stone thickness. Under each lintel angel was a lead joint to relieve any vertical compression on the stones covered with a 2-in. depth of caulked joint. The structural steel details followed the requirements and the correct dimension of 1 ft – 2½ in. was shown from the corner column center to the edge of the steel angles. The drafting was poorly done and the material list noted on the sheets, for the lintel angle lengths, took this dimension as 12 ½ in. As a result every lintel at the corners on all floors was short by 2 in. and the lead pads were similarly short. The corner stones had cement joints, which permitted some compression in the stack of the units. With temperature change on one face, the corner stones rotated and opened up the vertical joints. The distress was not stopped until the cement joints were raked out and the stones reset on a flexible joint.

10.5 Production Deficiency Error – Errors of Omission and Commission leading to loss of Implementation Integrity

Errors of omission and commission in performance phase of the construction industry probably are the major causes of failures. Some causes are a combination of minimal design with not too careful performance. Example: Collapse of the roof at the Minnesota State Fairgrounds in 1967. The elaborate report of the investigating committee cites a list of deficiencies stemming from poor structural design, field changes in the contract drawings, deviation from plans and specifications, and sloppy fieldwork. Some 33,000 ft2 about two third of the total, collapsed under a roof loading less than the 40 psf live load used in the design. Thermal change in the unheated one-story exhibition hall was the trigger of the failure in the 18-month old building. Columns are set in 30x40 ft. array with continuous steel girders on the 30-ft spans, and 40- ft long pre-cast pre-stressed channel slabs sitting on top of the steel girders. Bearing of the concrete channels varied between 1 3/8 and 2 in. with only a few imbedded shoe plates welded to the girders. The steel had been designed as laterally restrained, but not enough bracing was provided by the channels. Workmanship was deficient in bad field welding, bolts omitted in beam connections, misplaced anchor bolts compensated by burning large holes in base plates, substitution of plug welds for bolts and omission of some anchor bolts. In all not a complimentary record for design, the construction, and the inspection services at this project.

10.6 Infrastructure Safety: A Case of error due to insufficient inspection policies

Report in USA TODAY, Wednesday July 31 2002 page 3A by Fred Bayles entitled “Amtrak is told to slow down on hottest days” read as follows: ‘The CSX railroad on Tuesday ordered Amtrak and commuter trains that use its 23,000-miles of track to slow down following the derailment Monday of a passenger train outside of Washington, D.C. The order came after the engineer of the Chicago-to-Washington Capital Limited told federal investigators he saw a “misshapen” area of track 45 seconds before his double decker train ran off the rails 10 miles from Washington’s Union Station. Sixteen of the 101 passengers injured in the accident remained hospitalized Tuesday. The line was expected to re-open Tuesday night.

Cecilia Cummings, a spokeswoman for Amtrak’s Northeast Corridor, said Amtrak requires its trains to reduce speed to 80 mph when temperatures remain at 90 degrees and above. The speed limit on the stretch where the accident happened is normally 70 mph for passenger trains. Cummings said the CSX policy will be followed. “It would mean some delays during extremely hot weather, but we are happy to comply,” she said. Carol Carmody, vice chairwoman of the of the National Transportation Safety Board (NTSB), said a reading before the accident showed the temperature of the rail was 118 degrees. Investigators found rails 30 inches out of alignment. Carmody declined to say what caused the misalignment. “The alignment was existing before the derailment, let’s put it that way,” she said. Derailments caused by so-called heat kinks have been a cause for concern, especially after the introduction of longer sections of rail that can warp to a greater degree than short track in hot weather. But such incidents have waned over the past decade in large part to stricter speed limit and track inspection requirements. Federal Rail Administration records show that derailments caused by buckled track dropped to 44 accidents last year from 174 in 1980.

NTSB investigators have blamed similar accidents on insufficient inspection policies. Investigators say they will also look at the possibility the derailment is connected to rail work on the section of track four days before Monday’s accident.’

10.7 Infrastructure Safety: A case of error due to maps not updated

Report in USA Today Monday July 29 2002 by Traci Watson entitled “Miners saved in dramatic rescue” read as follows: ‘Somerset, Pa. - Nine coal miners were in good shape Sunday after spending three days in a flooded mine shaft they thought would be their tomb. The miners broke through an abandoned mine by accident Wednesday and had to flee 50 million gallons of frigid water that rushed into their mine in a 4-foot wall. Even as all miners were safely rescued, investigators were trying to find out why maps indicated the miners were a safe distance from a flooded 1950s mine. Officials said they would review how mining permits are issued and accuracy of old maps. "What you do with an accident is you learn," secretary of the Pennsylvania Department of Environmental Protection David Hess said."

10.8 Infrastructure Safety: A case of error disaster due to difficulty in originating and processing information in complex situation

On April 26, 1986, Reactor 4 of the Ukrainian atomic-energy plan in Chernobyl exploded, destroying its concrete roof (weighting thousands of tons) and polluting the surrounding territory and all Europe with radioactive particles. In the end analysis this accident is attributed to: difficulty in managing time, difficulty in evaluating exponentially developing processes, and difficulty in assessing side effects and long-term repercussions, that is, a tendency to process information in terms of isolated cause-and-effect relationships.

11. CONSTRUCTION *IS* VIEW AS CONTINUOUS INFORMATION ORIGINATING AND PROCESSING SITUATION CHARACTERIZED BY UNCERTAINTY

This recognition brings in two relevant modeling aspects of informational view based construction system definition, which need attention at this stage. Firstly, as mentioned earlier, 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, it is argued above that *IS* such as construction comprises multistage "individual" decision process. On the one hand, as mentioned, this requires treating information processing in construction system as an individual situation involving information origination. On the other hand, 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, incorporation of "fireproofing" requirement as in the example of Section (1)) or is not known or is out of date or is by itself complex (all these are the conditions to be observed in the construction situations). Even if one takes a conservative view, a large, semantically complex, time-pressured, tightly coupled, high consequence, high-reliability engineering system that a high-tech construction machinery/ instrumentation is, in the wake of unclear goal statement (implicit goals inclusive), may be observed to run a risk, in the fashion of an open system, of taking a life of it's own.

In such case then, that is secondly, the task of culling out the relevant facts (data and information variables) cannot be treated as a static one determined once and for all, and that too 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 construction *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 (see Figure (3)). In other words, in view of open system character of the construction process *IS*, the requirement, in the presence of 5"C"s, now *is* to continuously originate (extract) the information and store, validate, process, communicate, *use* and discard it or to store it for the future *use*. 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.

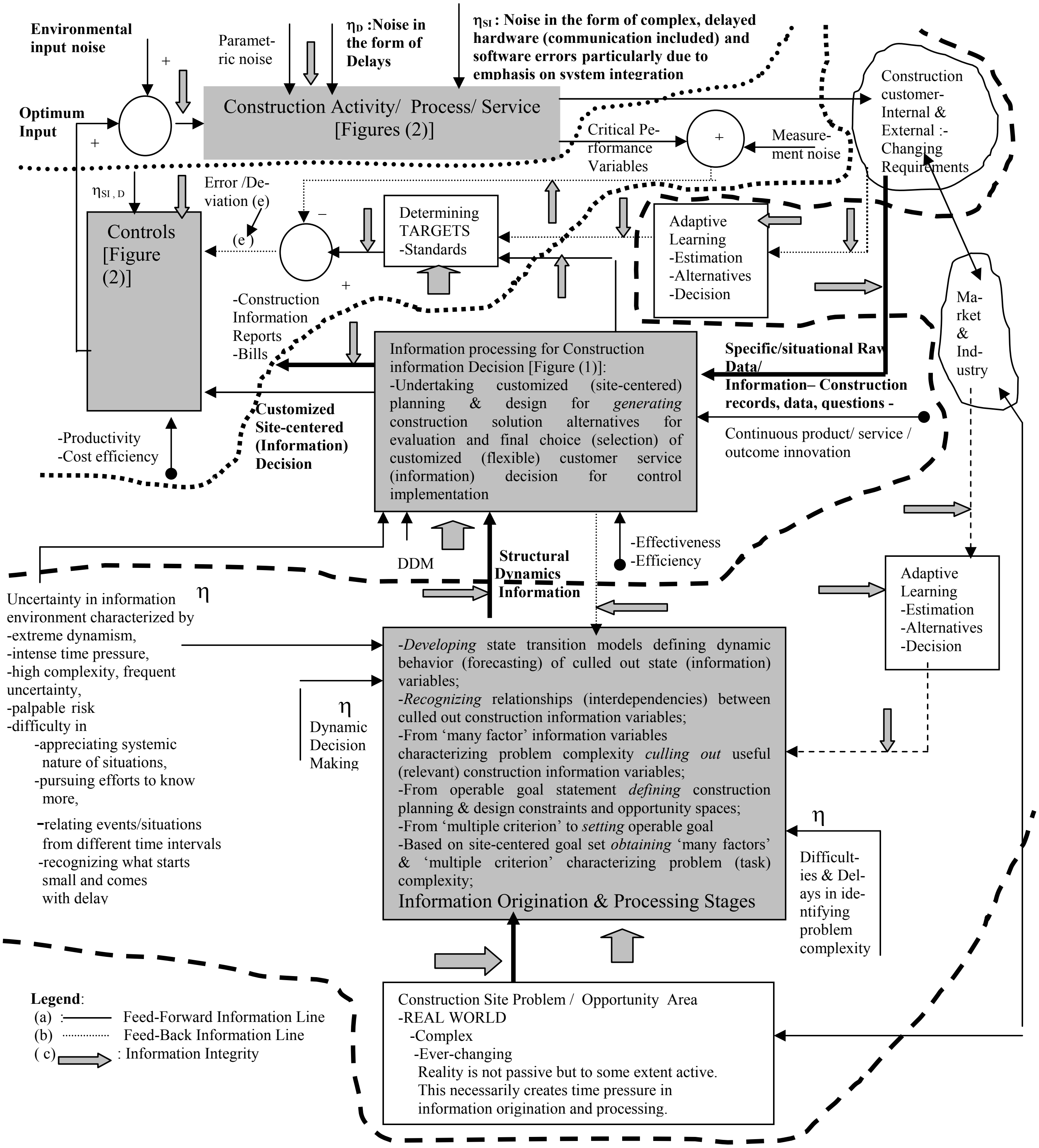

Figure (3): A systems view of a construction process represented as a generic business process *IS* view and as integral part of a closed loop information and control system characterized by continuous information origination and processing in the presence of uncertainty and the emergent all encompassing view of Information Integrity.

12. REQUIREMENT OF CONTINUOUS VALIDATION OF CONSTRUCTION INFORMATION — CRITICALITY OF INFORMATION INTEGRITY FOR SAFE, SECURED AND RELIABLE CONSTRUCTION

It is within the framework of reality of uncertainty ridden *IS* view of a construction process system, it emerges that in a construction system the assumption that the construction data is perfect, once validated, is *not* acceptable. In fact it is in the wake of this assumption that most information processing in construction operations do not anticipate defective data, resulting in information errors and therefore loss of Information Integrity leading to incorrect control implementation and delivery of incorrect and, in situation, even harmful product or service delivery to the client. This establishes the criticality of Information Integrity for safe, secured and reliable construction and product and service delivery to client. This provides an informational angle to Building and Infrastructure Safety, Security and reliability and construction error reduction. For effective construction safety, the problem of error reduction can be approached in two different ways. One approach — designated as first approach — can assume that if people are more careful, pay more attention, and in general take more trouble over what they are doing, that is if inputs and processes are controlled in a predetermined manner, then errors can be reduced and their effects mitigated.

13. APPROACH TO INFORMATION ERROR REDUCTION — INADEQUACY OF DATA INTEGRITY AND QUALITY APPROACHES

In its one form, the first approach views information as a function of "source" *only* and not as the function of the "source", "process" and the "*recipient.* " This leads to seeing information errors in respect of "source" and being termed as "data" errors perceived as to be of *that* moment having no significance beyond them, and integrity view thus is ad-hoc and in parlance of DBMS limited to data integrity only. In its another form, this approach presented through Quality paradigm, which sees information as function of both "source" and "process", has two aspects; namely, (a) quality assurance concentrating on the process and attempts to ensure that it is done correctly, and (b) quality control to ensure that the product delivered to customer (recipient) is correct, where the term 'product' represents a system or component or service. In practice, however, the quality paradigm operates in the 'standard' product/system/service and static environment mould, emphasizing incremental changes, and sees its operable goal as 'reduced defects'. The assumption is that product/system/service specifications' requirements are in respect of "exactness" (as against those of "*correctness*") and that knowledge about initial information is complete, the time incremental functions are linear, and that there is an access to unlimited (or say adequate) system (supply chain) resources.

Thus, the first 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. As a result, this approach, easier to pursue, on the face of it less costly on immediate basis, 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.

14. APPROACH TO ERROR REDUCTION — SYSTEMS APPROACH OF ACHIEVING INFORMATION INTEGRITY

The second approach - a systems approach – is based on the recognition that in the real world there *is* always incomplete knowledge of initial information, that the time incremental information functions *are* invariably non-linear, and that there is *always* the inadequacy of information *origination* and processing resources, that is, the supply chain resources. In other words, the information processing as in healthcare operations *must* anticipate defective data, resulting in information errors and therefore loss of Information Integrity leading to incorrect control implementation and delivery of incorrect and, in situation, even harmful service to the patient.

More specifically, the systems approach sees design, development and implementation 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 "construction" problem, but as that of (or more correctly as that of loss of) integrity, that is trustworthiness and dependability (here in a "construction" setting), of: information content, process and system; of each of system components and of 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. The paper observes that this Information Integrity based approach is systemic, analytical and holistic; takes time; costs user to implement; and certainly results in error reduction.

15. CONCLUSION

For the successful implementation of the organization of above informational capability of efficient and economic processing of construction process *IS* characterized by uncertainty, the *IS* specifically needs to incorporate integrity analyzers with the capability of generating and analyzing any deviation from standards in information origination, storage, retrieval, validation, processing, communication, *use* and subsequent storage or discard (as the case may be) under the *IS* and identifying its cause and of reporting it (deviation) and its cause to Integrity controller. In other words control of the business process should became centralized not in the information processing system (structured and periodic in that), as is the case currently, but in its Information Integrity controller, which will have detailed programs for:

(a) Standardized statement of the *IS* Task (problem), which is obtained from the functional work activity of interest and which in all probability will be a complex goal statement having multiple criteria with many embedded information variables,

(b) Standardized operable *IS* goal statements (performance standards that go to make complex goal statement as in (a)),

(c) For each performance standard as in (b), standardized performance criteria describing performance standard (Criterion would normally describe "process" standards for *factors & measures, actions, optimality conditions*, and for *information reports* offering a mechanism to evaluate and measure if the product/service output (informational work included) delivered meets the performance standard, i. e., the expected operable goal),

(d) For each performance standard as in (b), standardized performance evidences in the form of:
    (i) Quantity and quality of product/service delivered over defined time period,
    (ii) Demonstration of achievement of defined level of specialization in *IS* design and technology content,
    (iii) Documented record of relevant, proven prior performance achievements defined with reference to the *IS* task corresponding to the operable goal,

(e) Standardized information origination and processing methods,

(f) Standardized information system environmental parameters covering relevant contexts, specificities or individual situations with respect to:
    (i) Different decision process stages of *IS* as at (e), and
    (ii) Standards as defined under (c), (d) above,
(g) Standardized methods for reporting deviations from the standards at (c), (d) and (e). These deviations will be measured and reported as loss of Information Integrity (i.e., in the form of loss of Accuracy, Consistency and Reliability).

What is important to note is the Information Integrity controller here is designed to detect and correct errors in the information not only in respect of the *IS* (that is at (e)) but also in respect of information goals as to be seen by detection and correction of errors at (c) and (d). It is this facility ensuring goal integrity that goes to provide for Information Integrity controller the ability to reduce errors that creep in *IS* performance due to system environmental factors of 5"C"s, which characterize the construction site, i. e., local requirements, or situation or market as the case may be. Understandably, even long-term goal statement would also have system environmental factors affecting it. In such case it follows that Information Integrity controller would have to be similarly designed for it by referencing to the higher-level complex goal of which the long-term goal set is a part. This then introduces in the Information Integrity controller the facility of directional adaptability for the evolution of *IS*; thereby suggesting control and adoption capability in the Information Integrity Technology design approach so as to meet the customization demand.

Thus Information Integrity Analyzers and Controllers constitute the technology to be used as programmable, distributed decision makers in the control of fast-moving changes (in local market objectives, their information requirements, interdependencies between the information variables, and their non-linear dynamics) through the business process *IS* view system of the information flow whose scale and speeds otherwise preclude control by more centralized structures. The Information Integrity Technology in the form of integrity analyzer and integrity controller would thus extend the capability of *IS* from that of information storing and processing (characterizing structured and periodic information processing) to that of information origination, storage, retrieval, evaluation, processing, communication, *use* and subsequent discard or storage for further *use* (characterizing unstructured and a periodic information processing). In other words the Information Integrity Technology would develop processing of unstructured and a periodic information processing under uncertainty as a powerful tool for optimization of informational work for global business processes - which the construction industry very much aspires to be - for delivering products under localized internationalism of market place, which in 21st century would occupy a dominant market space.

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