APPLICATION OF INFORMATION MEASUREMENT THEORY (IMT) TO CONSTRUCTION

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The major objective of construction procurement systems is to minimize risk of construction nonperformance. The specification, low-bid process, has been unsuccessful in delivering a performing, sustainable construction product. The construction industry is attempting to increase the level of performance (on-time, on-budget, and meeting quality expectations) by moving toward alternate delivery systems. This research presents a theoretical foundation based on an extension of the information theory, the measurement of information. It identifies the correlation between the amount of performance problems in the current construction industry procurement systems and the amount of information used in the processes. The research also attempts to explain why the construction industry has difficulty in changing, which sectors of the industry will be resistant to performance information, and why it has become difficult to clearly identify liability and responsibility of nonperformance and minimize litigation.

Keywords: fuzzy logic, information management, information technology, measurement, risk.

INTRODUCTION

The construction industry has experienced low profit margins and low performance in a high-risk industry, a reduction of trained craftspeople, and performance and dispute issues (Post 2001, Kashiwagi 2001, Gibson 2001). The worldwide competitive marketplace has forced owners to become price sensitive. The facility and design managers representing the owners do not have performance information to minimize risk (minimization of risk: construction on-time, on-budget, or meeting their quality expectation). Therefore, in many cases, owner representatives have selected the low bidder. This has transformed the designer's role from producing documents showing a design intent to producing regulatory documents, which include~~s~~ design requirements, minimum standards, and means and methods. This environment becomes devoid of performance information (data that differentiates contractor's ability to minimize risk). It has allowed an industry to survive with poor performance, inadequate training, and irresponsible contractors who minimize their risk by transferring it back to the owners. As a result of this, owners are attempting to minimize their risk in construction by moving to alternative delivery systems including Design-Build, Construction Management @ Risk, and Indefinite quantity Indefinite Delivery (IDIQ) contracting. The authors propose that such delivery systems will not succeed unless an information environment is implemented where performance information and price are considered in the procurement.

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Information Theory

In 1948, Claude Shannon was credited with discovering the ‘information theory’. He stated that fundamentally all communication systems are the same. They all have a speed limit, measured in terms of binary digits per second. Above the speed limit, the information cannot be perfectly transmitted. Below the speed limit, the perfect transmission of information was possible, regardless of the strength of signal or the static and noise of the environment. He then proposed that all mediums could therefore pass ‘perfect information’ in digital bits (Waldrop 2001).

Shannon realized that the constraint of communicating or moving information was the transmission speed of the medium and not the noise of the environment. The author took the concept a step further. He postulated that it was not the lack of information, but the processing speed of an individual that creates the perception of the lack of information and use of bias that is the obstacle to understanding perfect information. He proposed that the human processor could be replaced by a faster processor, which would generate more accurate information (in terms of data) showing relative differences (Waldrop 2001). This information would be acceptable to all people, due to the fact that it was generated without bias. The author proposes that the technology of “information” can not only be used to communicate information, but to create information that can be understood by people with different levels of processing speed.

Information Measurement Theory

Information Measurement Theory or IMT was formulated in 1991 at Arizona State University as the structure to optimize information systems by creating information environments (Kashiwagi 2002). The purpose of IMT is to:

1. Minimize the amount of data required to accurately transfer information from one party to another.
2. Explain the relationship between the level of information and characteristics that define performance.
3. Minimize risk by transferring the right information.
4. Remove barriers caused by the lack of an information environment.

IMT is defined as: “A deductive logical explanation of the structure of an ‘event.’ It is the use of the measurement of relative and related data, in terms of ‘information,’ that defines the conditions of an event or an event object at a specific time and predicts the future outcome of the event.”

There are two major methods of problem solution, or logic, accepted by the scientific arena: inductive logic and deductive logic (Davies 1992). Inductive logic, also known as the scientific method, follows the following steps:

1. Setting up a hypothesis that defines an outcome.
2. Devising an experiment that tests the hypothesis.
3. Conducting the experiment to discover previously unknown information.
4. Identifying whether the hypothesis is true or false.
5. Hypothesizing where the results of the experiment can be used.

Deductive logic is defined as (Davies 1992): "The redefining or reordering existing information to define an outcome." Deductive logic differs from inductive logic in the following ways:

1. There is no new information or theories.
2. There is no experimentation to identify the results.
3. It is faster and simpler.
4. Requires less technical or specialized information, which is not understood by the average layperson.

IMT Theoretical Foundation

IMT is based on deductive logic. It is also deductive in nature, and allows individuals with no specialized knowledge to understand. IMT considers the following-concepts: the laws of physics, the definition of information, events with initial and final conditions, the process of learning in people, the relationship of characteristics that differentiate people and entities, and their relationship to the perception and use of information.

The first concept is of the laws of physics that defines the physical environment. "Laws of physics predict the future outcome in every state and at every time period. Examples of laws include gravity and combustion." (Kashiwagi 2002) Therefore, the number of laws of physics stays consistent over time. Scientists continue to discover more of the existing laws over time. It is also possible that science may unknowingly incorrectly identify a law at one period of time, and find out at a later time period that the law was defined incorrectly or incompletely. It is important to understand that laws are not created, but discovered. This definition is used in the Hawking's "no boundary theory" (Hawking 1988).

The second concept is information. It is defined as "the combination of laws and data (measurements of the conditions) which represents the existing conditions that can be used to accurately predict a future outcome" (Kashiwagi 2001). Hence, information is not what an individual may perceive, but an explanation of what actually exists. Therefore, a differential between two individuals would be the amount of information perceived and their relative ability to accurately predict the future outcome. The constraint is not that the information does not exist, but the information has to be perceived.

IMT defines an event as "anything that happens that takes time" (Kashiwagi 2001). The event has initial conditions, final conditions, and changing conditions throughout the event. The number of laws stays consistent throughout the event. The following are characteristics of events:

1. Every event has a unique set of initial conditions and a unique set of final conditions.
2. The number of laws of physics remains constant throughout the event.
3. Two individuals with different levels of perception may look at the same event and perceive a different event. However the event is still one event and will have one outcome.
4. There has been no event where the final conditions or outcome is not affected by the initial conditions or previous state. Nor have we found any segment of

the event that is not affected by the previous segment. All events and segments of events are bound by cause and effect.

5. Every event is constrained by initial conditions and laws and its outcome or final state is predictable if all information is perceived.
6. The change in the conditions of the event can be identified in terms of differential.
7. Randomness and probability are merely methods to estimate the final outcome when there is a lack of information about the initial conditions and laws. True randomness does not exist (Bennett 1998). The only reason the Hisenberg Theory is valid, is that we do not have methods or means to accurately measure two linearly related characteristics of particles at the same time (Feynman 1995). Einstein was criticized for not accepting the premise of randomness (Penrose 1989), but today it is understood that randomness is caused by the inability to measure. There is no actual random number, event, or object (Davies 1992).
8. Every person and every factor impacts an event to a relative degree. IMT does not explain why a person is in an event, but it states that the person is a part of the event and will impact the event. The person, the person’s decision making, and the person’s environment, all impact the event. Because every person is predictable or constrained (constraints make everyone unique), the person’s decision making is predictable, and therefore any environment with a person is also predictable with “all” information. Longer or more complex events require more information about the initial conditions and laws to predict the event outcome.

Change Process

One of the most difficult factors to predict are the future actions of individuals or organizations. Every individual is different (location in time and space being the most obvious). Every individual exists in an environment with all information. To change, individuals perceive information that they did not perceive before, process the information, and if they understand the information, apply it. The application of “newly perceived” information causes change, and by observation, change leads to the perception of more information. This is the Cycle of Learning (Figure 1).

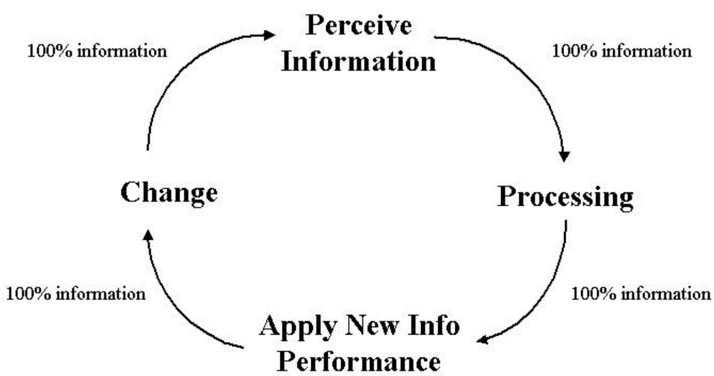

Figure 1: Cycle of Learning

By observation, the more times around the cycle of change, the faster the speed of the cycle. This leads to the following conclusions and the Rate of Change graph (Figure 2):

1. Application of information and ability to change can be measured more easily than perception rate and or processing speed.
2. The more information perceived, the faster the rate of change.
3. Those who do not change, have difficulty perceiving new information.

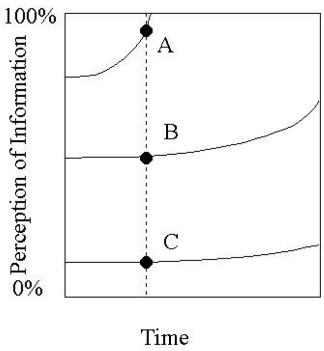

Figure 2: Rate of Change

Environment of Entity
Every person is at a unique level of perception of information (Hawking 1988). IMT identifies differential (criteria) between individuals. No two individuals will have the same combination of values for the following factors. The differences include:

- Education level: 21
- Salary and financial status: $100K/year.
- Location: USA, 10/10
- Time of birth: 1950
- Type of government in environment: democratic, 10
- Culture: Midwestern, 10
- Family size: 10
- Birth order: eighth or last
- Genetic makeup: 10
- Occupation type and performance: 10
- Communication skills: 10

KSM Two Way Charts
The values for the criteria make a unique performance line for an individual. All the above factors have a relationship or impact with a level of information, the ability to process information, or the opportunity to access information. Figure 3 shows the Rate of Change Chart with two-way Kashiwagi Solution Models (KSM). The KSMs have the following characteristics:

1. They represent two sides of each characteristic in terms of information.

2. As a person moves from a lower level to a higher level, the level of the characteristic must represent an increase or decrease in information.
3. All factors are relative and related.
4. The slope of the line separating the two opposites is not significant when the amount of information is not an issue.

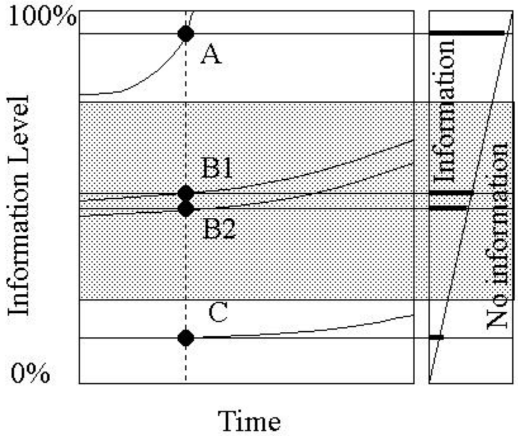

Figure 3: Change of Rate/KSM

Figure 3 shows two individuals (B1 and B2) who are very similar in terms of processing speed, amount of information perceived, identified level of performance and change rates. To differentiate and predict the difference in a future time period would require too much information (data that differentiates). This would require within our current methodologies and measuring tools, extensive statistical analysis with large amounts of data from representative, random sampling. IMT is interested in the movement from one level to another, and to identify the top and bottom levels of the graph. KSMs use the principle that all factors are related and relative that Hawking proposed in his “no boundary” proposal. To avoid requiring extensive statistical sampling, the environments of study will be the extremes to validate the top and bottom areas of the KSM (or left or right side) and not the middle sections. The critical factor in this objective is then not the slope of the line representing the change in the degree of relativity of a factor, but identifying the predominance of one factor relating to either a high level of information or low level of information.

The “Type A” person or entity is labeled as one, which perceives, uses, and passes a high level of information (Figure 4). According to the Rate of Change model, the “Type A” person will perceive more information, process faster, apply more correct principles, and change faster than the “Type C” entity. This is defined by the KSM, which shows ‘perceived information’ on the left side and ‘no information’ on the right side. As someone moves from a lower level to a higher level, they will increase in the amount of information perceived and used.

The KSM decision model is next. Decision-making is defined by IMT as when a person does not know the outcome to an event, and therefore thinks that there are two or more possible outcomes. Those who make decisions are therefore defined as not having enough information to predict the event outcome, thus defaulting to their own subjectivity. Therefore, decision-making is on the right side of the KSM. As someone gains information, they will make fewer decisions.

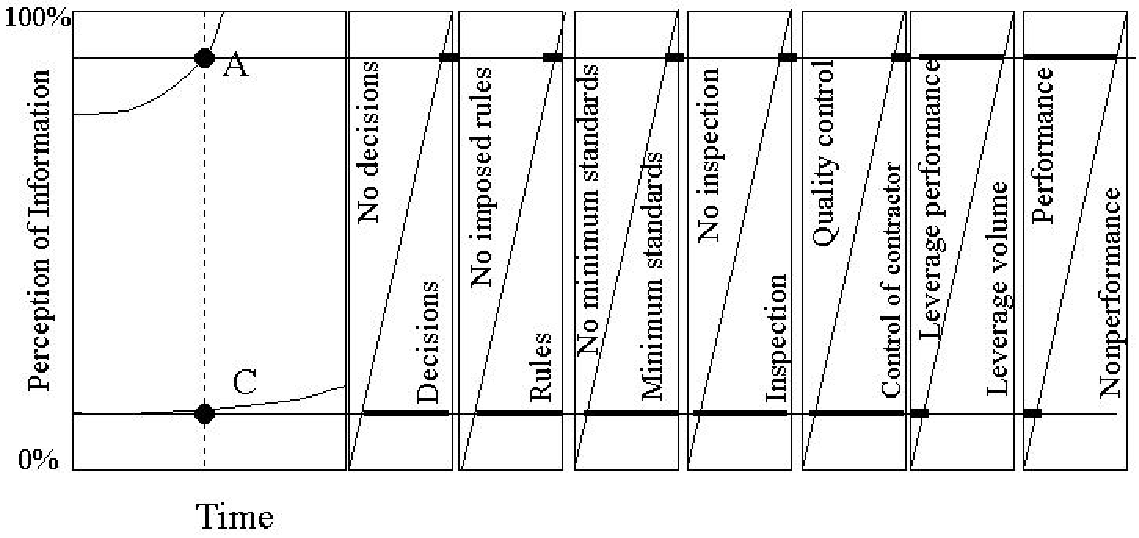

Figure 4: Level of Information of Performance Criteria

The following supports this:

1. The more information one perceives, the easier the decision becomes.
2. If someone perceived all information, they would know the event outcome.
3. People make decisions when they don't have all information.
4. If a person knew the event outcome, they would know the optimal action to use, and not make a decision.

The KSM model puts rules on the right hand side. Rules slow people from changing and direct people to respond the same way for slightly different events. Rules are also for people who may have less information and are used as a guide on how to perform their job. The Type C entity will have more rules, make more decisions, and use, perceive and pass less information. This defines the low-bid award process in construction which, when making a selection, cannot differentiate between alternatives (low level of information), and forces the use of subjective minimum standards. It also forces the user representatives to make the decision if an alternative meets the minimum standards and when work is acceptable or unacceptable. Therefore, a KSM model on minimum standards shows that it is on the right side. With minimum standards, which have very little correlation to performance (by definition and KSM location), inspection is required. This concurs with decision-making, as inspectors must now decide if the minimum quality work meets the minimum standards. It can also be deduced that on the low information side, control is also required to ensure the outcome of decisions. Demonstrated by the movement to 'construction management at risk' this is as an alternative form of delivery of construction.

IMT proposes that high performance contractors with highly trained craftspeople do high performance work without the use of minimum standards, but rather work based on performance. They need little inspection (they quality control their own work), they are inspected on what they did rather than how they did it, they minimize the risk on nonperformance by knowing how to do their work, and are not price based or low-bid. Therefore, by definition they are not volume based. They need very little instructions on how to do their work.

The Type A characteristics, using performance information, owner making very few subjective decisions, selecting based on value (price and performance), allowing the contractor to perform, requiring minimized minimum standards and inspection, is the definition of performance based procurement. The Type C characteristics, using minimal standards, selection based on price, requiring inspection and control, making decisions on acceptable work, is the definition of construction awarded based on the low bid. What is important is that everything is relative, and almost no case is either one or the other (left side or right side).

Verification of these concepts have been made in the manufacturing and management sector by Deming's continuous improvement (1982), Crosby's quality (1980), Ohno's lean manufacturing (Ohno 1988, Womack 1990), and Buckingham's Break All the Rules philosophies and Welsh (Trout 1986). The movement toward high information, quality control, value, and continuous improvement has been going on in the manufacturing sector for the past 30 years.

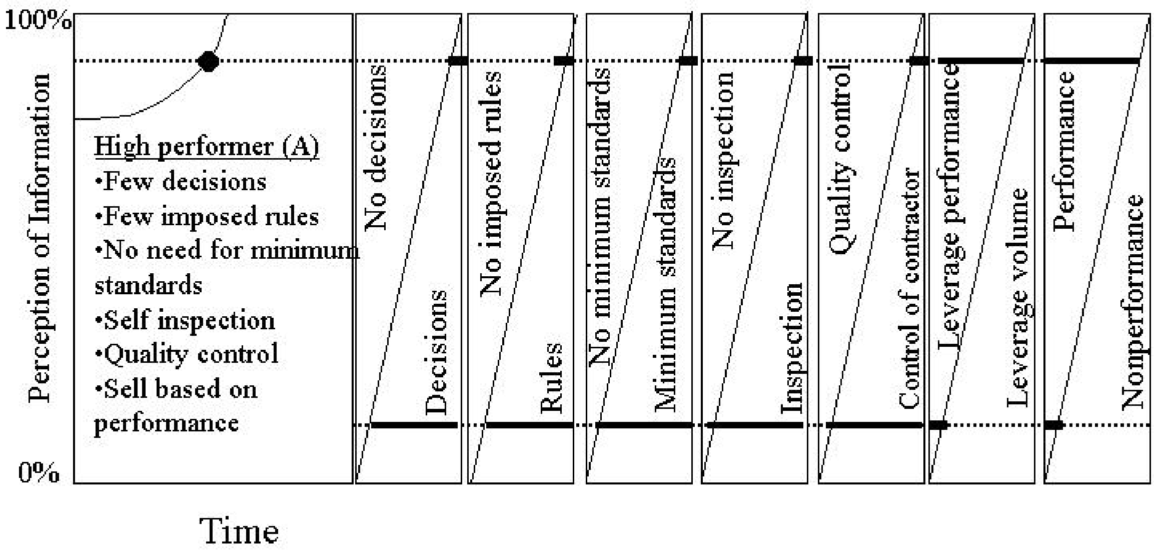

Figure 5: High Performance Contractor

Environment Is Defined By Characteristics

IMT states that a major use of information is to predict the future outcome. Each entity is an environment and an event. For example, a very high performer has certain characteristics (Figure 5). It makes the expected outcome predictable. High performers will do quality control of their own work to minimize their own risk regardless of an owner's inspection. Contractors, who leverage volume and low price, do the majority of their work in the low bid arena. These contractors use less quality control, use lower skill craftspeople, and depend on the owner to control the quality of the work by inspecting if minimum standards have been met. IMT identifies that owner inspection and control, use of minimum standards, award based on price alone, and subjective decision making is related to low quality work. IMT does not state which factor causes or is the major cause of the low quality work.

Industry Structure

The construction industry structure can be defined based on performance and competition (Figure 6). The worldwide competitive price pressures have made low competition environments unstable as owners continually seek to lower costs through increased competition. Quadrant I is the specification, low bid environment that uses minimum standards, award on low price, inspection, and accepts minimum quality. It drives contractors to leverage price or volume (do more work for less profit). Quadrant II is the performance based or best value environment. It is defined by high performance and high competition. Performance information is required to identify value (performance and price). In this environment, quality control, craftsperson skill, high performance products and performance are required. Due to the performance of the contractor, the value of minimum standards, user inspection and control, is minimized. In this information environment, if a contractor cannot compete based on performance and price, they will eliminate themselves.

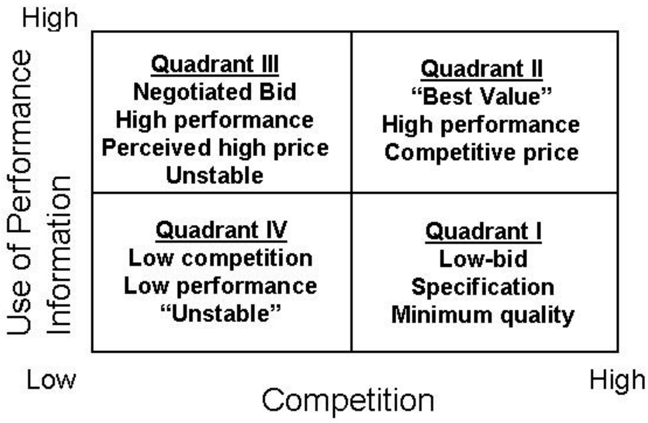

Figure 6: Construction Industry Structure

The current construction industry is based more on Quadrant I than II (Kashiwagi and Massner 2002). It is a price based industry and its shortcomings can be identified as a lack of skilled craftspeople, quality and business practices. Designers and project managers who regulate contractors instead of designing and facilitating will not be as effective in Quadrant II as in Quadrant I. Contractors who successfully compete in Quadrant I may not be able to be as successful in Quadrant II. A movement to Quadrant II may be considered as threatening to these parties. However, the intent of research, information systems, and continuous improvement is to increase performance. A move from Quadrant I to II is inevitable. However, the industry expertise is controlled by contractors, designers, and consultants who have been in the industry for many years (Gibson 2001). Construction decision makers have not been brought up with the information age principles. These decision makers are attempting to create a new environment of performance that they can continue to practice their expertise, which was developed in the current environment. This makes the move to a performance-based environment very difficult. Best value is in the owner's best interest. However, the owners are represented by designers, many of whom have become expert in the use of specifications with minimum standards and means and methods. Designers also derive income from inspections and project management. This has the potential of putting the designer in conflict of interest in terms of delivering value to the owner. From a different viewpoint, the more non-performing the contractor, the more value the designer brings to the owner. This conflict can only occur in an environment, which has a very low level of information.

Testing of Concepts

The Performance Based Studies Research Group at Arizona State University has spent over $3M to test the concepts of IMT with a process called the Performance Information Procurement System (PIPS). PIPS awards a construction project based on differential of past performance, capability to identify and minimize risk on a unique project, and price. The process minimizes subjectivity, and allows the contractor to take control of the project. Using the Type A environment they have run over 300 tests on $167M of construction in public and private construction. Preliminary results include the following (Kashiwagi and Mayo 2001, Kashiwagi, 2002):

1. 99% customer satisfaction and performance (on-time, on-budget, meeting quality expectations).
2. Minimized inspection.
3. Quality control by contractors.
4. Performing contractors minimizing risk.
5. No contractor cost change orders.

CONCLUSIONS

The principles of IMT identify a performance information environment that is different from the traditional specification low bid environment. IMT stresses the movement from the low bid environment to the information environment using performance characteristics, which have been used in the manufacturing sector with great success. The successful parties in the current construction industry require change to become successful in the information based or performance based environment. These parties may attempt to maintain the current practices of the industry, which are incompatible with the new environment. The authors recommend that other researchers perform research with IMT concepts to further verify the validity of the information concepts.

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