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A VALUE MAP FOR COMMUNICATION SYSTEMS IN CONSTRUCTION

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SUMMARY: *The use of ICT in construction has progressed over the last two decades. This paper summarizes the results of a survey that aimed at testing the usability of major communication tools and future mobile communication systems in the construction industry. In addition to documenting industry utility regarding the communication tools, the survey also tried to address the main issues that could hinder the use of communication systems in the industry. Three fundamental issues limit the usability of more advanced ICT tools. First, Software: the fundamental problem facing more use of ICT is not the devices themselves. Rather, it is the in-suitability of software systems. This is mainly due to the lack of interoperability between software systems and the low relevance to industry needs. Second, weak process structures: communication takes place in an ad hoc nature in many cases. The weak formalization of work processes is the main reason for this problem. For it to be coherent and relevant, communication has to be blended in a consistent stream conducive for information flow that matches the progress of work process. Finally, culture: construction personnel tend to favor oral and face-to-face communication. However, new entrants to the industry are more perceptive to ICT tools. Three values-generating components are key to overcoming such barriers. First, content: making the content being communicated more meaningful to industry. Second, access: assuring ability to access such information at different contexts. Finally, usability: ease of use and interoperability.*

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1. INTRODUCTION

Over the past two decades, investments in information communication technologies (ICT) have intensified in most industries with significant returns. A study by the Federal Reserve Bank of New York (Stiroh, 2001) found that capital deepening (increasing the amount of capital employed by each worker), not total factor productivity (the efficiency with which both capital and labor are used) nor cyclical gains, was the major contributor to the impressive boost of USA productivity in the last decade. The study traced this to the massive IT investments in the early 1990. At the same period, constant reports by Statistics Canada show that the construction industry has one of the lowest levels of ICT use in Canada.

Recently, there has been an increased awareness by construction companies regarding the benefits of better utilization of ICT. This paper attempts to develop a "value" map of communication tools in construction (what makes value to the industry). What communication tools achieve the best value at which situation? What are the most valuable aspects of communication systems? Why? The proposed amp was structured to identify the Information Needs and Requirements of the individuals in the industry by determining the types of information communicated in a Construction Project, determining the types of situations in which the information is communicated, Communication Tools currently on the market and/or on the cusp of being introduced to the market. The research identified a value for each type of information communicated on a Construction Project based on the input obtained from industry experts through the use of a survey from 43 Canadian Construction firms specializing in the ICI/Residential and Heavy Civil sectors.

The nature of communication patterns in the industry has a direct correlation to the nature of the construction Site environment. The Construction site can be best described as a reactive environment, where unplanned changes to work regularly occur, and unanticipated events as well as temporary critical problems are inevitable. The large number of unanticipated events occurring at a construction site is due to the inherent complexity, dynamics, and number of activities involved in the project. This creates an information intensive environment and requires the site staff to have on-demand access to construction project plans, drawings, schedules, and budgets. The research tends to indicate that Information Communication Technologies can enable more efficient use of site knowledge and experience on a real time basis, effectively handling on site problems that are caused by unanticipated events.

2. RATIONALE AND RELATED WORK

Since the .com boom, the AEC industry has been investing in communication hardware—mostly, mobile phones and wireless networks. However, the mismatches between such investments and the daily business processes of these organizations have been blamed for a reduced level of efficiency and returns on investments (Sun et al. 2003; Lofgren 2004).

However, recent studies point out clear buy-in and awareness at industry not only of communication tools but also its benefits. Williams et al. (2007) compared the adoption of information technology systems by USA and Korean companies. They found that while companies showed strong interest in information technology systems (especially Web-based document and content management applications). "It appears that, although Web portal software or services are commercially available today, they are not being used by a significant number of U.S. construction companies, small and large … interest in electronic approval of submittals and exchange of CAD files is strong. Yet again, either a lack of familiarity about available IT tools or a reluctance to invest time and money to adopt them makes contractors stay away. Again, the company size does not have an impact". Leskinen (2006) found similar results in Finland and reported that, while the construction industry supports further implementations of ICT, it does not see full/intensive deployment as a major priority. These two studies, among many others,

A properly structured and integrated approach for the delivery of information to the right person at the right time and in the right format is seen as a means for overcoming the typically *ad hoc* (almost sporadic) nature of project communication (De la Garza and Howitt 1998). Even the typical dependence of construction personnel on inter-person communication can be supported or formalized (and subsequently enhanced) through new technologies such as e-mail, and instant messages (Magdic et al. 2004). However, this has to be done in a value-adding manner to overcome the traditional face-to-face or oral conversations that may waste much of the tacit knowledge generated and reduce efficiency.

In the search for reasons for such low levels of ICT implementation, Stephan et al. (1998) argued that hardware is not the problem. Rather it is "human issues" such as organization problems and poor leadership. The challenges are more related to cultural, operational and organizational issues. For example (Menzel et al. 2002): the different expectation and needs of stakeholders; software heterogeneities; limited IT budgets; cultural reliance on paper-based or oral communication means. Some researchers (such as Aziz et al. 2005; Rebolj et al. 2004) have developed means to support context awareness to help boost the ease of use of ICT tools for site personnel. Others have addressed the human aspects of construction communication (Magdic and Rebolj 2005).

To address the disconnection between ICT and business processes, Brewer et al. (2006) looked into the integration of IT in construction supply chains. Eisenblatter et al. (2005) developed an implementation strategy to enable companies (especially, SMEs) to analyze and reengineer their business processes to support easier implementation of mobile technologies.

To bridge the gap between site and office personnel, researchers investigated the types of information needs at the site level. For example, De la Garza and Howitt (1998) classified the job site needs into a matrix. At one dimension, this classification lists the typical requests for information (such as design intent, contract specification, implementation problems, means and methods). On the second dimension, the classification lists the project issue to which these requests are made (material management, cost management, scheduling, safety, submittals, etc.). This classification will be used as the basis for our value map.

3. METHODOLOGY

In order to develop this map, the research developed a basic model for communication in construction projects. The model development included the following elements:

1. Contexts: clustering construction projects into coherent situations through identification of project conditions that could have an impact on the needs for information and the relative value of ICT tools. In other words, are the values of each ICT tool sensitive to certain project conditions? If so, what project condition that may have bearing on the map?
2. Information needs: the identification of the types of information that are communicated during construction projects (within each context). A preliminary list of the types of Information Needs and Requirements communicated in a Construction Project were determined through a literature review, personal experience, and professional input from three industry experts.

3. Communication tools: these are the tools that can be used to communicate information needs within each context. Five conventional communication tools were included: Face to Face, Phone (Land line or Mobile), Fax Machine, Hard Copy (Courier/Delivery/Pick-Up) and e-mail. In addition, three advanced mobile computing tools were included: PDA, tablet PC, and Wearable computers.

The initial model was used as the basis of a survey of Canadian construction firms to define the utility/value of several communication tools to the industry. The survey included thirty one firms in the ICI/Residential Category and twelve in the Heavy Civil Category, the respondents all varied in age and background.

The individuals operating in the ICI/Residential Sector identified themselves as follows, thirteen were categorized as General Contractors, five were categorized as ICI Developers and thirteen were categorized as Residential Developers or Home Builders. Within each category, the Construction sectors were further categorized as either, Industrial Commercial Institutional (ICI), Residential Low Rise, and Residential - Multi/High-rise. Of the General Contractor respondents, 23% were small firms, 46% were medium firms, and the balance was large firms. All of these Contractors manage ICI (100%) projects. In addition, 30% of those also manage Residential (multi/high rise) projects. Of the respondents who were ICI Developers**,** 40% were small firms, 40% were medium firms and 20% were large firms. Of the respondents who were Residential Developers/Home Builders**,** 77% specialized in Multi High Rise Construction, 54% specialized in Low Rise Construction and 8% overlapped into the ICI Sector. Lastly of the residential companies surveyed, 38% were small companies, and 62% were large companies.

Similarly the Heavy Civil Sector of Contractors surveyed was categorized into two separate sections; Heavy Civil, which included bridges, sewer, water main and roads, and Heavy Civil specializing in Emergency Repair

of Sewers, water mains, roads and bridges. The census indicates that 50% of the firms were classified as small (total sales of less than $50 million/year), 33.33% of the firms were classified as medium (total sales of $50 million to $200 million/year), and 16.67% of the firms were classified as large (total sales of greater than $200 million/year). Through conversations with these two contractors, it was determined that the most important information required for emergency contracts were site instructions and the ability to obtain locates for existing utilities within 30 minutes of response time. In order to get to the root of an emergency and/or commence any remedial work the firms must have the locations of all existing utilities. Therefore, the model for the heavy civil contractors will be the same for both sections since existing utility locates are required in all cases of construction and the only difference is the response time in receiving the locates.

The surveys were conducted via a one on one personal interview; the average length of the survey was approximately thirty-five to forty minutes. Often the interview led into discussions regarding the downfall of IT in the Construction Industry or rater the ideologies of ICT are not geared for the Construction mentality. The insights obtained from the interviews as well as the survey analysis are further discussed

The survey was broken down in three parts. The first part was to develop a background on the companies participating in the survey, such as the firm's "IT" structure and knowledge as well as their familiarity with the concepts of mobile computing, before performing the survey. The second part was designed to quantify the needs of the individuals based on an importance rating associated to the needs, and to determine the ways in which the information is currently being communicated. Also to be quantified was the type of mobile device, in their opinion, would be best suited to communicate their specific type of information. The last portion of the survey was to determine the firm's beliefs on the downfalls of IT in the construction Industry, and determine the stage of the entire construction process that needed improvement assuming there were no boundaries.

4. THE INITIAL MODEL

The initial model is a three-dimensional matrix that includes identification of the contexts of communication, the information needed/exchanged, and the tools of communication.

Contexts for Communication: The first component in the model is an identification of the various situations/ context in which the industry exchanges information. Information needs vary based on the project nature. In order to better capture the exact needs for various types of projects, this research project developed a set of typical contexts or types of construction projects that could have impacts on the needs for information. The nature of the project, its scope and the stakeholders involved has a bearing on the types of information exchanged and the relative importance of each ICT tool in such situation. To an extent, the proposed contexts are a sort of taxonomy of projects based on four dimensions:

Construction Sector: possible modalities (types) in this dimension include: Residential (Single and Multi Unit), Industrial Commercial Institutional (ICI), Heavy Civil (Infrastructure & Roads). It was determined that since the Residential and ICI sectors involve the same type of construction activities, they can be combined and considered as one context (or project type) in the model. On the other hand, The Heavy Civil sector involves the construction of infrastructure and roads. The information requirements and needs on projects of this nature are specific and unique to the type of construction.

Communication Stakeholders: the subtypes of this dimension include the following possibilities:

- Contractor: General contractor, Design Builder, Construction Manager
- Developer
- Sub-Contractor
- Owner/Client: Public (Government), Private
- Labour: Unionized, Non-unionized

When analyzing the various contractor types, it was determined that the General Contractor, Design-Builder and Construction Manager all have similar characteristics and information requirements. Working for a Public owner does not change the information requirements or needs of contractors, rather it increases the amount of documents exchanged to create a thorough paper trail. The basic needs, quality, productivity and price, are equal for both the Private and Public owners. The type of labour involved on a project does not change the information

requirements and needs of the contractor. Rather, it changes the hours of operation, productivity, and at times, the quality. Since this dimension does not relate to the information requirements it is determined to be insignificant and thus will not be included in the model.

Scenario of Work Performed: It was decided that there are two conditions in which a contract could be awarded; they are "Non-Emergency" and "Emergency". In a "Non-Emergency" model, circumstances in which a normal contract is awarded will be considered, whereas an "Emergency" scenario, immediate response and repair will be considered. "Emergency" circumstance projects require immediate and efficient communication of the known information, therefore neglecting some red tape. "Non-Emergency" projects are more formal and require specific tasks to be completed before a project can be continued. Since the most common type of "Emergency" scenario occurs in the Heavy Civil sector, it was decided that the Heavy Civil context will be the only type in which "Emergency" and "Non-Emergency" information requirements and needs will be considered.

Location of Work: the sub types of this dimension include: Urban (Metropolitan Areas), and Rural (Remote Areas). Since the basic requirements of a project does not change based on the location, it was determined that this tier could be neglected in the model. It is important to note however, that although the basic requirements do not change on the location of a project, the modes and methods of communication information change. Therefore, the preferred methods of communicating information will be differentiated in the model based on project location. It was shown throughout this paper that the information communicated on a project is independent to the location of the project and stakeholders involved. However, as the distance between site and office increases the mode in which the information is communicated has a tendency to change.

Table 1 shows the initial set of contexts considered in the survey. It should be noted that after conducting the survey, it was found that the differences between most contexts are insignificant. The contexts were then reduced to two only: residential and ICI, and Heavy civil.

TABLE 1: Main Contexts in the Initial Model

	Stakeholder				Scenario		Location	
	Contractor	Developer	Owner	Labour	Emergency	Non-emergency	Rural	Urban
Residential/ICI	No significant difference (the categorizing dimensions are important but not discriminating)							
Heavy Civil	No significant difference				Sub Context A	Sub Context B	No difference	

Information Needs/Requirements: Identifying the information needs and requirements of the Construction Industry is the second task that is required to develop a model for the value of ICT tools in the construction industry. In the Pre-Project phase, information exchanged is generally communicated between the Owner, Contractor's Project Manager and the Design team. This is different from the Construction and Turnover phase, where the bulk of the information is predominantly communicated to the Project Manager, Site Superintendent / Foreman and Design Consultants. The research of de la Garza and Howitt (1998) was used as the starting point of developing a complete list of information needs and requirements. It must be stated that the list of information needs and requirements is not a complete or exhausted list of all information communicated between site and office, but rather the most important information communicated to complete a project successfully. The following is a brief description of the categories used for information needs and requirements of the construction industry.

- Request for Information: This category pertains to all information exchanged regarding pre-project, correspondence, design, and construction startup. This category contains such items as documents pertaining to contract specifications, contract drawings, change orders, shop drawings, and design intent clarifications. These are the most frequently exchanged information throughout a construction project cycle.
- Material Management: This category refers to all documents of material required in a construction project. These documents consist of placing requests and ordering material, determining the status

and location of material ordered, as well as any special handling or delivery of material. Ordering construction materials and maintaining an inventory log are imperative to the organization of material management.

- Equipment Management: This category pertains to all documents and information exchanged with regards to the equipment required on site. This generally includes equipment rentals and allocation. It is important to have the proper equipment on site to perform the work efficiently.
- Cost Management: This category pertains to any information and documents exchanged relating to cost and accounting of a project. Some of the items include budget pricing, material and equipment cost accounting and purchase orders and/or extras.
- Site, Schedule and Construction Information: This category relates to all information exchanged between construction site and office. This includes scheduling updates, productivity information, updating drawings, progress reports, visitor logs, and daily site diaries. This information is usually exchanged on a daily basis between project managers, site super and coordinator.
- QC/QA Management: This category relates to all quality control and quality assurance documentation. Some of the documentation that is frequently exchanged are soil reports, inspection and test results, deficiency lists, and quality reports. This documentation generally insures that the work performed on site is according to specifications and drawings.
- Safety: This category pertains to all safety documentation exchanged between site, office, and sub-contractors. Some of the reports include accident reports, safety violations and labour force contracts. These documents are usually government required on any construction project.

Communication Modes/Tools

Five modes of communication are listed; Face to Face, Phone (Land line or Mobile), Fax Machine, Hard Copy (Courier/Delivery/Pick-Up) and e-mail. Based on their professional opinion and the advantages and disadvantages listed, the second part of the survey table asked the respondents to select the mobile device that they believed would be the best device to communicate information. Three mobile devices were listed; Tablet PC, Personal Digital Assistant (PDA), and Wearable Computer.

5. THE SURVEY

The fundamental piece of the survey is the table indicating the Various Information Needs and Requirements. There are two primary tables for each survey (see Tables 2 for a sample). The first table is developed for the participants to associate a value of 1 to 5 to the listed Information Needs and Requirements for the seven categories, where 1 indicates that the Information Need or Requirement is the of the least importance and 5 indicates that the information need and requirement is the of greatest importance. The next portion of the table is developed to determine the current preferred method(s) of communicating and/or receiving the listed information need and requirement.

Each respondent was asked to indicate their preferred type of conventional communication tool for each of the listed information needs and requirements in the survey table. The purpose of this section is to see what the trends are when communicating the various listed information. The participants were instructed to indicate their preference(s) with a check mark, and these check marks would then be tabulated in the final model. The third section of the survey was to indicate, based on the given advantages and disadvantages of the mobile devices listed, what they believe is the best option for communicating the various types of information needs and requirements. Once again, more than one device could be selected based on the individual's preference; these selections were then tabulated as well in the final model to determine if one single device could be used to facilitate a more efficient communication channel between site and office or if a combination of devices is best suited.

The second table of the survey was designed to determine if the channels of communicating the information needs and requirements change between site and office if the site was situated in a remote location or rural site. It is important to understand that the value of the information does not change. Rather, the way in which the information is communicated, as well as the perceived Mobile device used to communicate the information may change.

Each participant was requested to evaluate the importance of the listed Information needs and requirements with a value of one to five, as shown in Table 2. The corresponding values were then tabulated and averaged. These values are the foundation in determining the value of the information communicated as well as the corresponding importance based on the averaged score.

In order to create the value map for an effective ICT platform, each participant was asked to indicate a percentage of the Information needs and Requirements that had to be efficiently and adequately addressed through the use of the listed mobile computing devices before it became a communication tool of choice in the industry. The percentages collected were tabulated, and an overall average was calculated. The overall average was then used to determine the minimum number of Information Needs and Requirements that had to be adequately addressed through the use of ICT. The top items were then selected with an "X".

TABLE 2: Sample of the ICI/Residential Urban Survey Table

Information Needs & Requirements	Indicate the level of Importance of the corresponding Information Needs & Requirements *(1 - Least Important, 5 - Very Important)*	Preferred Method(s) of Communicating / Receiving the listed Information (Check Columns)					Perceived Effective Mobile Communicating Device you would use for Communicating / Receiving the listed Information (Check Columns based on Best Judgment)		
		Urban Project (Metropolitan Areas)					Urban Project (Metropolitan Areas)		
		Face to Face	Phone (Land Line or Mobile)	Fax Machine	Hard Copy (Courier/Deliver/ Pick-up)	E-Mail	Tablet PC (Larger Device)	PDA (Small Hand held)	Wearable Computer (Hands Free)
Design Intent & Clarification									
Change Orders / Contemplated CO									
Sub-Contractor Information / Contract									

6. SURVEY RESULTS

There are eight categories created for both types of survey. Tables 3 and 4 show the final list of information needs for the categories of ICI/Residential and Heavy Civil as identified by the experts along with their relative importance. It is shown that several of the items or sub-categories were ranked as being more important to communicate efficiently than others; the following is a list and brief description of some of the highest ranked needs.

Design Intent and Clarification: The design intent and clarification is one of the most important items in a construction project. This is the concept of the finished product, from Request for Proposal to building operation. It is imperative to design and return a product according to the users design and intent.
Change Orders / Contemplated Change Orders: This is a contractual item, the purpose for change orders (CO) and contemplated change orders (CCO) is to add/or subtract requirements from building design and contract. Although the concept is simple, it often tends to be a legal issue. It is important to clarify and understand the CO and/or CCO prior to commencing the work in question.

TABLE 3: Relative Importance of Information Needed (Residential/ICI)

CATEGORY:	Information Need and Requirement	Score
Request for Information	Design Intent and Clarification	4.48
	Change Orders / Contemplated Change	4.55
	Sub-Contractor Information / Contract	4.06
	Contract Specifications	4.52
	Contract Drawings	4.71
	Means and Methods	1.55
	Specialty Work Package Information	3.58
	Implementation Problems	4.06
	Site Instructions	4.50
	Shop Drawings Submittals and Approvals	3.27
Material Management	Place Request/Order Material	4.15
	Material Order Status	3.60
	Material Location	3.08
	Special Material Handling/Delivery	3.11
Equipment Management	Equipment Rentals	3.21
	Equipment Allocation	2.85
	Equipment Location	2.92
Cost Management	Budget Pricing	4.03
	Material Cost Accounting	3.84
	Equipment Cost Accounting	3.45
	Purchase Orders and Extras	4.42
Site, Schedule and Construction Information	Schedule Updates	4.35
	Productivity Information	3.68
	Updated Drawings and As-Builds	4.13
	Time Sheets	3.81
	Progress Reports	3.97
	Visitor Log	2.84
	Daily Site Diary	3.65
QC / QA Management	Soil Reports / Inspection & Test Results	3.84
	Deficiency Lists (PDI's)	4.16
	Quality Assurance / Control Reports	3.77
Safety	Accident Reports	4.48
	Reporting Safety Violations	4.35
	Labour Force Contracts	3.16

TABLE 4: Relative Importance of Information Needed (Heavy Civil)

CATEGORY:	Information Need and Requirement	Score
Request for Information	Estimating / Quantities Clarification	4.42
	Contract Specifications	4.67
	Contract Drawings	4.75
	Consulting Engineer Co-Ordination	4.33
	Specialty Item Work Package Information	3.67
	Means & Methods	3.17
	Change Orders / Contemplated Change	4.75
	Sub-Contractor Information / Contract	3.83
	Implementation Problems	3.92
	Site Instructions	4.33
	Existing Utilities Locates	4.50
Material Management	Place Request/Order Material	4.42
	Material Order Status	4.00
	Material Location	3.67
	Special Material Handling/Delivery	4.00
Equipment Management	Equipment Allocation	4.00
	Equipment Location	3.67
	Equipment Rentals	3.67
	Sub-Contractor Equipment	2.75
Cost Management	Budget Pricing	3.50
	Material Cost Accounting	3.50
	Equipment Cost Accounting	3.50
	Sub-Contractor Costs	3.33
	Purchase Orders and Extras	4.25
	Labour Costs	3.75
	Progress Draws	3.75
Site, Schedule and Construction Information	Schedule Updates	4.25
	Productivity Information	4.50
	Updated Drawings and As-Builds	4.25
	Time Sheets	4.00
	Progress Reports	4.17
	Daily Site Diary	3.92
	Staff Scheduling	4.08
QC / QA Management	Soil Reports	3.58
	Deficiency Lists	3.50
	Quality Assurance / Control Reports	3.33
Safety	Accident Reports	4.42
	Reporting Safety Violations	4.33
	Labour Relations / Collective Agreement Info	3.58
	Sub-Contractor Health and Safety Packages	3.75
	Safety Meetings – General Issue Specific	3.92

Contract Specifications: This is the document that lists all specifications of building materials, methods of installing the materials and quality of the workmanship. The contract specifications are a legal document and must be understood thoroughly.
Contract Drawings: These are the drawings that pertain to the original design and contract; they generally only include several addenda's and then are updated periodically according to the conditions of the project. It is important to remain up to date on the changes and understand all details of the project.
Site Instructions: These are instructions and/or changes that are based on site conditions. The site instruction is usually issued due to a change in site conditions or details that do not work; therefore a site instruction is issued to correct the problem.
Purchase Orders and Extras: These are directions of purchasing materials, labour or extras to contract. Depending on the conditions of the order they can be arranged as time and material basis or contract, either way it means extra to the cost of the project.
Schedule Updates: It is important to maintain an updated schedule; if the schedule is updated, then one can see whether or not more resources are required if delayed or how many float days are still available for the next item on the critical path, hence reducing the chances of incurring extra costs on a project.
Accident Reports/Reporting Safety Violations/Safety Regulations: These items have recently become a government mandate, there is a fear that there are too many lost working days and lives to injured employees due to simple safety negligence. It is important to protect the point of production workers for a successful project completion.
Locates: This item refers to locating all utilities prior to excavating any area in question. Locating all utilities is a government mandated item designed to help protect the general public and point of production workers.

Utility of Communication Tools
The Industry Utility pertains to rating the relative importance of various ICT tools when attempting to meet the industry needs in various contexts. It was clear that all conventional channels of communication such as Face to Face communication, Land line or mobile phone communication, the Fax Machine, Hard Copy communication, and E-Mail are currently being used by all respondents. Their preferences differed, however, based on the information being exchanged.

In the residential/ICI, The results indicate that sixteen of the selected information needs and requirements are predominantly communicated between site and office via a hard copy document whether it is couriered, delivered or picked-up. The preferred methods for the remainder of the information needs and requirements were as follows; seven via e-mail, six via phone line, and four through the fax machine. The communication of information by e-mail is increasingly becoming a preferred choice of communication versus the use of a phone line between the various stake holders in a project because it creates a paper trailed dialogue, whereas phone conversations can be forgotten or manipulated. It must be understood however, that the telephone can never be replaced in the construction industry because it is relied upon heavily for peer to peer relationships and immediate responses; hence the mobile phone will always be imperative in the construction industry.

In heavy civil and in the case of urban projects it was determined that twenty two of the information needs and requirements are communicated primarily by hard copy, whether it be couriered, delivered or picked-up. Several of these items such as Equipment Cost Accounting, soil reports, reporting safety violations, and safety meetings (general or issue specific) were tied with other methods of communicating such as fax machine, phone conversations or face to face communication. This secondary communication channel indicates that there may be follow up communication to the hard copies exchanged. It also indicates that communication within the heavy civil industry is still extremely paper based, particularly due to the legal requirements of the contract or the simplicity and security of sending and reading paper documentation.

Ten of the selected information needs and requirements are currently communicated via the telephone (land or mobile), making it the second highest form of communication. The telephone is one channel of communication that can never be replaced in the construction industry because it is heavily relied upon for peer to peer communication and immediate responses. It was noticed that the phone is primarily used to communicate simple and straight forward information, such as material management, equipment management, and staff scheduling.

The final methods of communication were e-mail, fax machine, and face to face communication. These items seemed to be the least used by the heavy civil industry. This trend seems to indicate that the majority of the work

in the heavy civil sector is performed before a site office is established; therefore making other channels of communication less feasible.

In the case of rural projects, Once again, the majority of the information needs and requirements were communicated via hard copy, telephone, and fax. Very minimal face to face communication occurs in this setting. There was a slight increase in the amount of information exchanged via fax machine likely due to the fact that the sites are not close enough to have a hard copy delivered or picked up as they are in urban sites

When determining the perceived effective mobile device for communicating the pre-defined information needs and requirements in the ICI/Residential model selected two devices, the Tablet PC and the PDA. It is apparent that the mobile device that was by far the most popular in all of the categories was the Tablet PC. It was selected to potentially communicate twenty five of the information needs and requirements effectively versus six for the PDA.

When interviewing the respondents, the consensus was that although the Tablet PC was a larger device and less convenient, they felt that the larger screen would enable the mobile worker to read documents that were large in nature with relative ease. High resolution to view the documents effectively is needed, such as Design Intent and Clarifications, Updated Drawings, Contract Specifications, As Build Drawings, Site Instructions, Specialty Work Packages, Purchase Orders, Deficiency Lists and Soil Reports.

The Industry agreed that the PDA would be useful for items that are less verbose such as implementation problems, Material Management, and equipment rentals. This is an indication that the PDA is considered as more of an extended mobile phone, whereby only simple e-mail can be exchanged. As far as the Wearable hands free computer, a maximum of 6 of the 31 respondents thought that it would be an effective way to communicate during a construction project of any kind.

The respondents surveyed in the Heavy Civil Industry indicated that they perceived the Tablet PC and PDA as the two most effective mobile devices for communicating the pre-defined information needs and requirements of the model for an urban project. It was found that the tablet PC was preferred for communicating sixteen items, the PDA was preferred for fifteen items and the two devices were tied for the preference of six items.

The trend established that the Tablet PC was the preferred device for communicating documents that were large in nature such as Updated Drawings, Contract Specifications, As Build Drawings, Estimating, Specialty Work Packages, etc. and needed high resolution in order to be viewed effectively. The items best suited for conventional communication via Hard Copy or Fax were deemed as possible items that could be communicated efficiently with a Tablet PC.

The PDA on the other hand was selected to communicate items that are smaller in nature, such as Consultant Co-Ordination, Site Instructions, Utility Locates, Material Management, and Equipment Management. These items tend to be conventionally communicated via telephone, e-mail, or face to face. This is a good indication that the PDA is perceived in the same manner as a telephone rather than a computer.

The industry indicated that they were more comfortable implementing the PDA within their organization, however, the Tablet PC is perceived as a more effective mobile computing device because it enables users to view large documents. It can therefore be assumed that although the industry prefers the PDA which is a device that is less complex and similar to a mobile phone, a communication tool that the industry is very familiar with, the Tablet PC has several advantages that the PDA cannot offer to the heavy civil industry.

7. ANALYSIS

It clear that, currently, there is not one single device that can be considered as the most effective communication tool. It is obvious that the respondents to the survey unanimously agreed that ICT is a premature and underdeveloped solution for the Construction Industry. They also affirmed the long-term belief that ICT could have positive impacts on project success. This coincides with similar studies that looked into the use patterns of information technology.

It seems that neither the hardware nor the human-ware are now the causes (or at least the main causes) of low ICT implementation in the industry. To this end, post survey analysis and discussions with experts were

conducted to identify a map of the issues that reduces the value generated by ICT investments. What are the factors that has bearing on the value of ICT investments in construction industry? What are the current barriers? What benefits are anticipated when investing in ICT? What elements of ICT generate value to industry.

The following sections summarize the elements of the proposed map (see also Figure 1).

Salient Industry Factors: It is important to understand construction industry culture and needs; it is in this that one can observe whether or not the needs of the industry can be satisfied and/or addressed by ICT.

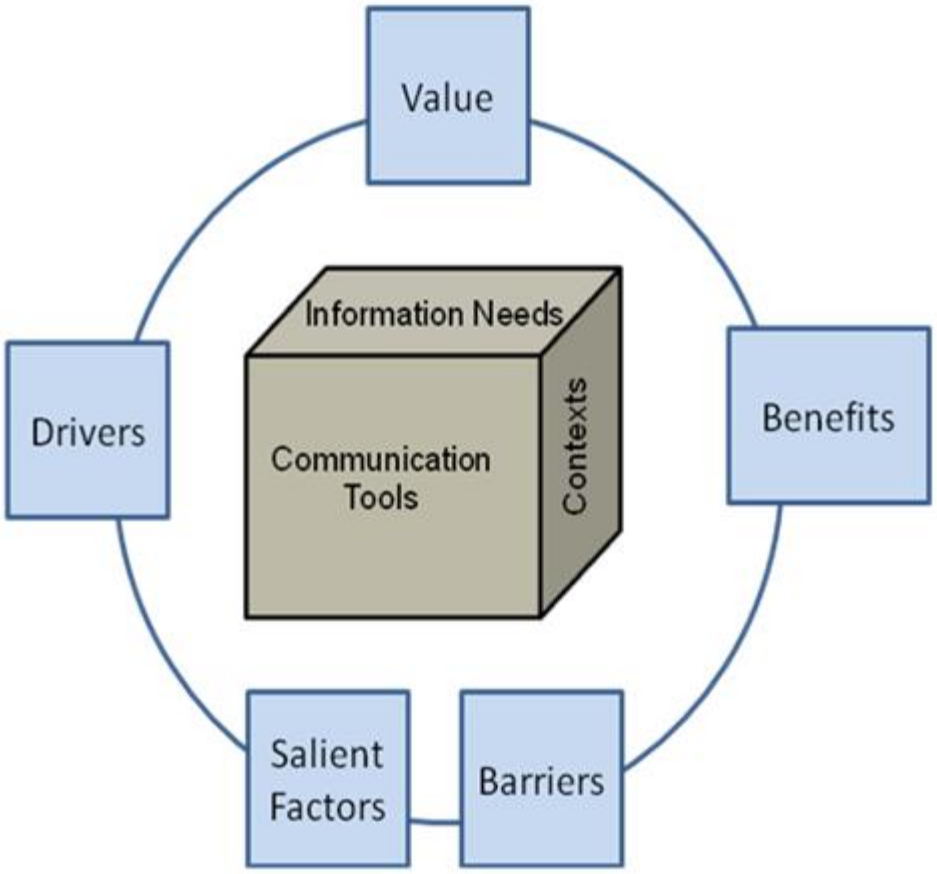

FIG 1: Value Map of Communication Tools

Fragmentation: The first Characteristic of the Construction Industry is that it is a complex network of specialized trades and individuals interacting on a daily basis, therefore the day to day operations are primarily based on interpersonal communications that are either formal or informal. Interpersonal Communication is often used in order to solve a problem on site. It is not only important to know who is informed about the problem but also to communicate with others about the problem at hand. This type of communication can be accomplished in many ways, such as short notifications, face to face communication, e-mail, Instant Messaging, or telephone calls. The channel chosen for interpersonal communication depends primarily on the people involved in the construction project as well as the nature of the problem.

Competitiveness: The second characteristic is that the Construction Industry operates in a highly competitive environment. Due to this competitiveness, the speed at which information travels from one person to another is fundamental in maintaining efficiency and keeping costs at a minimum. The Construction site can be best described as a reactive environment, this means that unplanned changes to work and design regularly occur, and unanticipated events as well as temporary critical problems are inevitable due to unknown or unforeseeable site conditions and/or details. This creates an information intensive environment and requires the site staff to have

on-demand access to construction project plans, drawings, schedules, and budgets to reduce costs associated to delays.

Legal Requirements: The third characteristic of the industry is that document exchange is still primarily paper based. This is due to the contractual nature of the industry as well as the types of documents that are exchanged on a weekly basis, such as drawings, plans and/or details.

Although the nature of communication overall has gradually changed over to electronic information documentation, the administrative tasks at a Construction site remain paper based due to the types of documents exchanged. Over the past decade or so, tender drawings have been exchanged via electronic document sharing databases and/or e-mail. This trend has had some success primarily because it is driven by the general contractors who are trying to reduce reproduction and shipping cost of tender documents prior to being awarded a project. This method of document exchange has now imposed the burden of drawing reproduction onto the shoulders of the subcontractors as oppose to the owners and general contractors.

ICT Drivers in the Construction Industry: Before a new communication tool is implemented, one must investigate the drivers, and barriers of the potential tool to determine the forecasted value to the individuals utilizing the device. There are several communication drivers that are influencing the implementation and industry's decision to select an ICT tool, they are as follows:
Volume/Size of information: As discussed in the previous section, the information exchanged on a construction project is generally large in nature and tends to favor hard copy document exchange via hand delivery, regular or express mail. This does not suggest that all information can not be exchanged electronically, but rather a characteristic that must be identified by the individuals designing and developing the ICT.

Nature of information: Since a construction project involves several entities and stakeholders, the nature of the information exchanged is primarily legal information and there is a need for a proper paper trail to prevent ambiguity and litigations. Since the bulk of the information exchanged are legal in nature, it has been suggested that by exchanging documents via ICT, the stakeholders on a project can have a detailed and easily accessible databases of all documents (legal or non-legal) exchanged throughout the life cycle of the project.

Timeliness: It has been suggested throughout the research that the construction industry operates in a highly volatile and dynamic environment. These conditions are due to the reactive nature of a project, this means that unplanned changes to work and design regularly occur, and unanticipated events as well as temporary critical problems are inevitable due to unknown or unforeseeable site conditions and/or details. These conditions encourage immediate and efficient response time for requested information from the pertinent individuals involved.

Visualization: Since a construction project involves the physical nature of constructing a product, much of the information exchanged is visual in the form of drawings, details and sketches. This driver demands the importance of all communication devices to have adequate communication media quality for all information exchanged.

Barriers: The drivers are the key features of the construction industry that drive the pursuit of alternative and more efficient modes of communication. As with any new ideologies, there are barriers of the industry and suggested technologies that must be identified. The following is a list of the drawback and/or barriers that must be addressed by both the construction industry and ICT prior to evaluating the potential value of a new communication channel.

- Ageing work force with an unfamiliarity and opposition to changing their mind-set with regards to the use of computers and new technologies
- Initial capital cost and training are high to implement ICT
- Generally a low level of sophistication among various sub-trades
- Reluctance of point of production workers to accept and use advanced ICT
- Culture of the industry has always been based on "personal relationships" and oral communication
- Construction industry remains a physical and visual industry, where it is common to make site visits and physically see, review and solve problems

- An increase in information exchange can lead to more time consuming paper work, therefore reducing the physical time required on site
- Construction industry is dynamic and sporadic, not one project is identical
- Reliability issues with new technologies that are unproven
- Durability of the devices in the harsh conditions of a construction environment
- Lack of infrastructure for networks to operate efficiently outside of the urban locations

These limitations and drawbacks listed are an indication that the construction industry and ICT must adapt and change with one another if it is to be selected as the communication tool of the future. The drivers and drawbacks listed are not designed as a deterrent to implementing ICT in the construction industry, but rather an indication as to the potential value and design requirements, due to the inherent nature of the target market.

ICT Benefits The main benefits as reported by industry experts for the use of ICT include the following items:
Time savings*:* Efficient use of ICT enhances co-ordination and provides access to relevant information in a timely manner, which can lead to the enhancement of productivity and hence cost savings.
Mobility*:* Mobile characteristics of ICT can enable more efficient use of site knowledge and experience on a real time basis, with the possibilities of effectively handling on-site problems caused by unanticipated events.
Information tracking & Security*:* The ability of streamlining the communication process via integrated data management, on-site data collection and immediate availability of information to all project participants. This helps the industry keep a trail of information progress between all stakeholders and site office; it presents an efficient solution for maintaining a secure correspondence trail, especially with the legal nature of the documents exchanged on a daily basis.
Customer relations*:* ICT can enable improved support for informal communications as well as real time data exchange on the construction sites. This can lead to improved project collaboration through video conferencing and constant mobile connectivity, therefore, increasing the efficiencies and abilities to respond and communicate the pertinent information with the clients.

ICT Value: Although ICT present several benefits, it still may be a lackluster solution to the communication needs of the construction industry. It is not only essential to identify the benefits and barriers of a device, but rater but it is necessary to identify the value that the industry is looking for in a new communicating tool. Consequently, the value function of ICT to the industry is based on the following values according to the industry experts:

Content:

- *Integration of information:* In essence, the low levels of ICT adoption in construction is just a reflection to the problems related to the lack of adequate software in the industry. The ability to link pertinent and relevant information in an integrated view. There is a need for a program that can distribute updated drawings at all times as well as integrating scheduling, budgeting and accounting to allow for more efficient project management, site management and close out processes.
- *Relevance:* It has been suggested that more communication is optimal; however, it is important to filter the information transferred between site and office so that only the pertinent information is sent to the individuals to whom it regards. This indicates that the information communicated must be quality information and relevant to the individuals who receive the information.

Access:

- *Reach:* The ideology is that all stakeholders have the access to and ability to use the ICT tools. The construction industry is not one entity but rather a vast array of separate and specialized entities, some of whom are considered small and others large, it is important that all entities have the capabilities of affording and utilizing the tools, similar to that of the cell phone. Once this paradigm is accomplished then the information can be communicated and reach all relevant stakeholders.
- *Spread:* It is important not only to be able to communicate the information, but the industry is looking at the speed in which the information can be communicated. The ideology of the industry is that the quicker the information is communicated, the quicker the problems and ambiguities are resolved, resulting in time and cost savings. The other issues are the spread of the network, is the infrastructure proven to enable access in all locations. Since the industry is sporadic and projects

are constantly moving, will there be capabilities outside the urban core which are acceptable to the expected industry standards.

Usability:

- *Ease of use:* As mentioned throughout this research, ICT must develop a device which will accommodate the growing concerns with regards to the harsh working environments, the existing culture of personal and informal day to day communications, and the barriers of an ageing workforce who are uncomfortable with new technologies and change. These challenges are one of the primary drivers as to the lack lustrous acceptance of ICT in the construction industry.
- *Interoperability:* As discussed prior, the industry is an array of enterprises who work together towards a common project goal, completion. The problem proposed by this is one that not every enterprise utilizes the same software and programs, therefore, there is a need for the ability to link and navigate through different software systems regardless of the original nature of the document. The ideology to interoperability is similar to that of a cell phone carrier, there are several networks and regardless of the network every individual is capable of making and/or receiving a call. Once the idea of interoperability is achieved, then the processes and communication channels can be streamlined to produce one large communicating network.

8. DISCUSSION

The value functions discussed are the primary features of ICT that must be identified and attained prior to the acceptance of ICT in the construction industry. The idea is to link all of the values as seen by the industry into one device or several devices that can be utilized throughout the industry. These values were not investigated as a deterrent to the ideas of using ICT, but rather as an indication as to what the industry is expecting from a new tool to rectify the current communication conditions.

Based on the above analysis, it can be argued that the following are the three most important issues/actions needed to foster ICT use in the next period.

1) Software vs. hardware: The fundamental problem in construction communication lies in the inadequacy of software systems not in the ICT hardware. The industry has been relatively perceptive to all new trends, however, after initial trials the hype faded down. This is due to disappointment with the value generated by such devices. This is due to many reasons that encompass cultural, usability and cost issues. However, the inherent stumbling block is the lack of genuine value (ROI) due to the limited capabilities of software systems. Hence, personal and paper-based communications are still more valuable to the industry
2) Process structures. Another major weakness in construction communication is the proper (or lack of) integration of communication and information exchange in work process. The concepts that are being misconceived by the ICT industry are that the Construction Industry is relatively content with the way regular business operations are handled. Companies that have started using e-mail and PDA's have mentioned that the increased ability to send and receive information has actually slowed down the physical construction process because much of the information communicated is either redundant or requires too much time to filter and comprehend.
3) Culture: at the labour-level in particular, the Industry still remains a predominantly primitive industry in terms of IT solutions, and mobile computing hardware does not seem to be the answer to their needs. The trend, however, could be turning to the positive given the increasing penetration of ICT hardware in society (especially amongst younger generations), the increasing competitiveness in the industry which supports fast and reliable communication (especially in global projects), and the promising trends in the development of human-friendly interoperable software systems.

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