i^2F Framework to Evaluate the Effectiveness of Field-Level *e*-Communication

Payam R. Zekavat and Leonhard E. Bernold

***Abstract*—The full-scale implementation of ICT in construction offers many of opportunities such as enhanced quality and reduction in wasted resources while drastically improving the collaboration between project participants. This paper introduces a novel ICT-based information network for the construction site designed to facilitate dynamic transactions among information "suppliers" and users at their point of activity. This proposed network is used to assess the potential impact of *e*-communication on the outcome of construction. This evaluation is based on i^2F framework unifying the procedure of evaluating the effectiveness of a piece of information considering its context. It combines information quality (InQ) and information value (InV) to calculate impact of a piece of information. Results of the performed analysis are summarized in a look-up table which models the importance of an information fragment for a process in different contexts.**

***Index Terms*—*e*CKiosk, ICT, Field-level communication, Information impact factor, Look-up table.**

I. Introduction

Many researchers have studied the use of IT in construction [1] describing the development of IT-technologies. However, "unclear benefits of use" is mentioned as one of the main barriers against the effective diffusion of information and communication technology (ICT) in construction [2], [3]. Also, there is no common agreement amongst scholars on how IT usage impacts the construction industry. Thomas [4] believes that integrating IT would improve productivity while [5] doubted the direct impact on productivity and claimed that the beneficial effects are gained via IT-imposed changes to the process procedure. Bernold and Salim [6] went ahead and measured the influence of effective communication resulting in both, change in work pattern and productivity increase. They showed that providing a detailed rebar placement plan to the fabricator alters the delivery pattern resulting in more efficient placement process. Because unproductive times were drastically reduced, the productivity of the placement crew was increased. This study is a one-of-a-case since we lack acceptable tools to measure the true effect of a piece of information communicated. This study will propose a framework to assess the impact of information on the outcome of an operation, such as rebar placement.

Following chapter will elaborate a novel ICT-based information network for the construction site. Then, the information impact factor (i^2F) framework will be described and the instruction of how to implement it will be provided.

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II. ICT-Based Work-Package

ICT application in the construction is still static and not fully integrated to the process level. ICT enables process automation and promises to offer extensive benefits in terms of enhanced process outcome quality, process resources saving, and improved coordination between project entities. ICTs provide many types of information which have never been tested in project management. One such example is the [7] introduced *e*CKiosk as an information hub to facilitate dynamic transaction among information "suppliers" and users at the point of activity. A key feature of the *e*CKiosk is that it extends *e*-communication to the field level. Unified electronic project network which covers construction site does not exist. Fig. 1 depicts the touch screen keyboard at the bottom enabling the user to type in any text. A visual representation of wireless sensor network is displayed at the left hand side. Also, the screen shows the current reading of several thermocouples data that is gathered via a wireless network and interpreted by a LabView code and then expressed in different ways like graph indicators or numerical indicators like bars, meters or gauges. An alarm LED will notify the user when each measurement is exceeding a specific threshold. The window of the GPS presents real time information informing the user about the current positions of delivery trucks. Several sorts of information like real time position, speed and direction are provided to the user. If the GPS receivers are used for equipment security -e.g. the concept of geo-fence- a warning will announce that the equipment is getting out of predefined area. The Skype windows on the right hand side let the user to communicate with every other project participants to ask for corresponding information. For example when a defect is detected, the problem can be described to the designer in real time while the designer can watch the problem. Then a decision will be made regarding how to solve the problem.

However a practical tool to measure the importance of a piece of information is not available yet. The following section proposes the concept of i^2F as a platform to evaluate effectiveness of communicated information.

III. Information Impact Factor

Proposed IT-based information exchange method not only supplies currently in practice information needs like drawings but also delivers new kinds of data to the point of activity which were not communicated before i^2F is defined to express the contribution of an information fragment to process performance. i^2F is a function of information quality (InQ) and value (InV). Quality is correlated with level of user satisfaction in working with information and value is the benefit of having that information. In summary high quality and valuable piece of information has a great impact on process outcome. Fig. 2 outlines the procedure of calculating i^2F by evaluating InQ and InV separately. The way the information from data-base is communicated to the user affects information quality. Some delivery methods like IT-based approaches may even act as part of information acquisition system. Zekavat and Bernold [8] explained how Bayesian Belief Network was applied to assess the InQ. In parallel, InV is evaluated based on some indicators (typically cost and time) in each specific process domain. The proposed matrix to find i^2F according to InQ and InV is presented in Fig. 3.

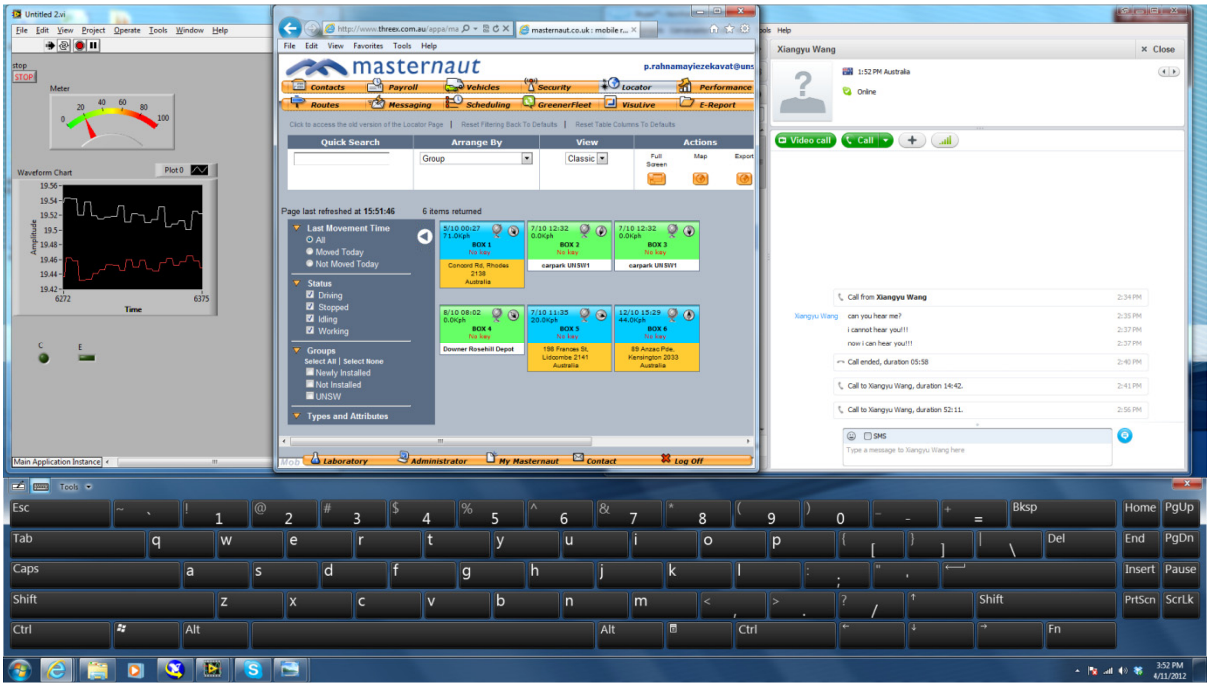
Fig. 1. A snapshot of touch screen of *e*CKiosk

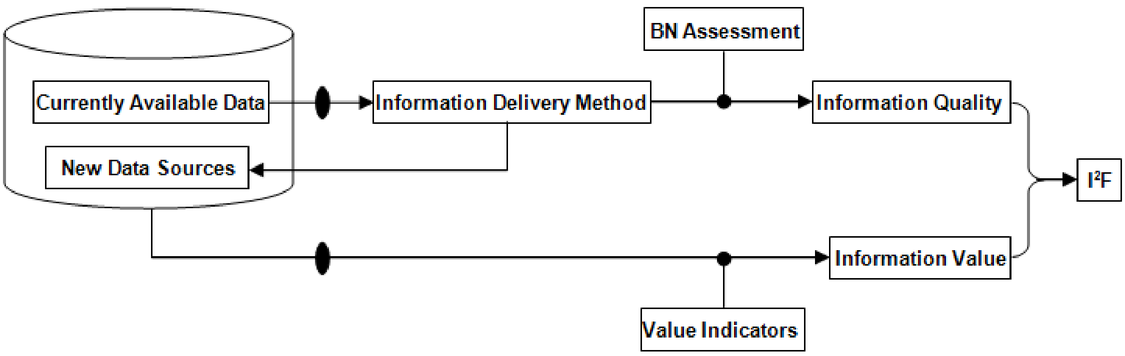

Fig. 2. i^2F framework, ⬮ = data processing

i^2F	Information Value 0%				50%					100%
Probability of High InQ 0%	0	5	10	20	30	40	50	60	70	75
	0	5	10	20	30	40	50	60	70	75
	0	5	15	25	35	45	55	65	75	80
	0	5	15	25	35	45	55	65	75	80
	0	5	20	30	40	50	60	70	80	85
50%	5	10	20	30	40	50	60	70	80	85
	5	10	25	35	45	55	65	75	85	90
	5	10	25	35	45	55	65	75	85	90
	5	10	30	40	50	60	70	80	90	95
100%	5	10	30	40	50	60	70	80	90	100

Fig. 3. Conjugated i^2F matrix

Such a matrix can be developed for each specific construction process. Result of survey of different construction processes may be reported in a practical way commonly called look-up table. An example of what resulted look-up table for a crane lifting looks like is demonstrated in Table I.

TABLE I: A TYPICAL i^2F LOOK-UP TABLE OF WIRELESS WIND SENSOR NETWORK FOR CRANE LIFTS OPERATION

		Data/Information Impact Factor		
		Wind Sensor Crane	Wind Sensor 1 km	Airport Weather Forecast
Crane Status	Crane Idle	0	0	0
	Crane Normal Work	5	5	0
	Crane Special Lift	5	50	100

IV. MEASURING INV IN PROCESS DOMAIN

In a construction process raw material, human resource and tools are integrated to build something. But information is what interlocks physical requirements to build a valuable outcome. The more a process and its outcome appreciated, the more valuable the used information is. Value of a piece of information is highly dependent on its application context. Value of the information about market price of cement is different from owner view point in design stage and supplier perspective in construction period.

Actually the non-deterministic flow of information reaching the work in progress (WIP) causes fluctuation in productivity. So the value of information needs to be assessed based on its process domain. Fig. 4 depicts how [9] has defined a construction process model resting on three origins of recourses namely pools, WIPs and supply chain. Pools represent resources that are in direct control of the project management while the other two rely on external systems not completely linked to the project organization. Following their suggestion a process domain is defined as a four dimensional space of (1).

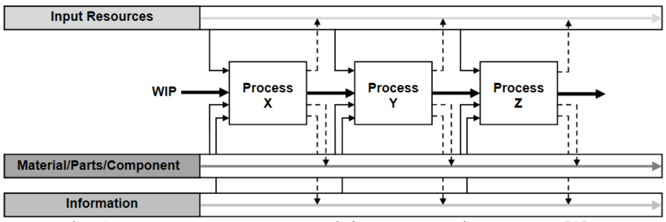

Fig. 4. DInVerse resources supplying construction process [9]

$$P = In\mathrm{Re}s \times WIP \times Information \times Conditions,$$
$$p_i = \{In\mathrm{Re}s_j, WIP_k, Information_s, Conditions_t\} \quad (1)$$

where $p_i \in P$ is a specific node in information value chain, and $In\mathrm{Re}s_j \in In\mathrm{Re}s$, $WIP_k \in WIP$, $Information_s \in Information$,and $Conditions_t \in Conditions$.

Indeed, because material doesn't sense any value of information, its supply stream is omitted from process value domain. Instead, conditions are added to define the domain. It will be explained how ambient conations like extreme climate events or work pressure may alter information value.

$In\mathrm{Re}s = \{Equipment, Tools, Labor, Foremen, Operators, ...\}$ refers to all sort of information consumers including human and machine. Identical pieces of information may be valued differently among various users. For example, GPS information about truck mixers' position is valued differently by batch plant planner and concrete pump operator at the site.

$WIP = \{Sub-\mathrm{Pr}ocess_1, Sub-\mathrm{Pr}ocess_2, ...\}$ includes process evolutional steps such as detailed design and construction sub-processes. Information about concrete strength is more invaluable during pouring in comparison to curing stage. Information value is not constant during process development and is subject to change as process progresses.

$Information = \{Raw\,Data, Structured, \mathrm{Pr}ocessed, Appli-\\ -cable\}$ regards how organized the information is. Different status of information means different value levels. Raw data from a wireless sensor (e.g. thermocouple) may mean to a software agent but not to a worker. Raw data is scattered and needs to rationally organized and sorted to be used. Time study raw data reported as average cycle time is an example of structured data. When cycle time of different machines in a fleet are processed the optimum combination of equipment is calculated. Based on processed information, decisions about production rate and efficiency of fleet are made.

$Conditions = \{Normal, Behind\ Scheduel, Infront\ of\ Plan,\\ HighTemerature, Wind, ...\}$ considers ambient conditions of process. Workforce is an essential element in evaluating the value of a piece of information. Timely information about traffic condition in rush hours prevents pouring crew idleness at site. There is not such a need about traffic details in normal working situations. Climate is another key player affecting work progress. Extreme climate events may cause catastrophic consequences if warning is not communicated to the site in time. So ambient condition was selected as the fourth dimension in defining a progress state.

A series of $p_i s$ elaborates process evolution from beginning to the end. Each p_i is referred to as a state or situational context. The value of a fragment of information fluctuates travelling the evolution path from one state to another.

Any opportunity to improve state-of-practice is referred to as value-adding changes. Assume that a set of value indicators $\{I_i\}$ with their corresponding weights $\{\omega_i\}$ are available to measure InV. Further consider that a specific p_i , Δ_j equals $|\hat{I}_j| - |I_j|$ where $|\hat{I}_j|$ represents the estimated value of $j's$ indicator intensity when a piece of information is missing and $|I_j|$ shows actual amount of it when that information is available. For instance if cost is selected as an indicator, the extra cost incurred because of missing a piece of information contributes to calculation of InV. The InV in each p_i equals the weighted sum of $\Delta_j s$. Note that the units of various indicators are not consistent (e.g. cost is measured in dollar while time is measured in hour). Utility theory is applied to transform quantitative criteria into a uniform scale of $(0,1)$. So it leads to:

$$IV = \frac{\sum_j \omega_j \cdot \left(e^{-\frac{\Delta_j}{R_j}} \right)}{\sum_j \omega_j} \quad (2)$$

where R_j is the coefficient of risk attitude determined by the project headquarter for each p_i . A new piece of information that did not exist before, may lead to negative values of Δ which cause InV greater than unity. As an example assume an unloading process using a crane in a blind area where the crane driver cannot see the unloading spot. If only cost and time are selected as indicators, the value of steering information provided to the crane driver through the radio by the watchman in normal climate condition can be calculated based on unloading cycle time and cost. Now assume that a wireless camera attached to the crane hook, shows the unloading area on a screen in the crane cabin. The extra saving in cycle time and cost of involved laborers and machines will lead to an InV greater than one. Now think about unloading process in a windy condition, when the information from wind sensor postpones the process. Although the process duration is extended (negative value) but the amount of monetary saving because of preventing undesirable event like crane collapse is such tremendous that will evaluate wind sensor InV as high.

In construction industry value can be measured by several indicators like cost and time saving, quality, and safety. Bowden et al. [10] summarized potential improvement areas in construction to be a) Reduction in construction time and capital cost, b) reduction in operation and maintenance costs, c) reduction in defects, d) reduction in number of accidents, e) reduction in physical waste, and f) increase in predictability of real-time progress and cost information. Based on this taxonomy, the value of a piece of information can be assessed based on its capability to cause any of mentioned improvements. It is assumed that all of above improvement potentials can be converted into money and/or time except predictability. As a matter of fact, the evaluation model only considers cost and time as value indicators while the predictability effect is utilized as a modification factor. Value of enhanced predictability can be considered indirectly by modifying $\Delta_j s$. In summary the value of a piece of information `in a state p_i , is calculated as below:

$$IV = \frac{\omega_{\cos t} \cdot \left(e^{-\frac{1}{\phi} \cdot \frac{\Delta_{\cos t}}{R_{\cos t}}} \right) + \omega_{time} \cdot \left(e^{-\frac{1}{\phi} \cdot \frac{\Delta_{time}}{R_{time}}} \right)}{\omega_{csot} + \omega_{time}} \tag{3}$$

where ϕ is the predictability modification factor obtained from a comparative analysis. Predictability includes risk of inconsistent realization of planning. This may happen because of misunderstanding, inefficacy in implementation, lack of interoperability, miscalculation and/or etc. To calculate ϕ in each state, considering project completion percentage m, the information user is asked to rate his/her confidence level about process completion time within the planning constraints (CL_o). After that the new information is provided to the user the receiver is asked to estimate s the confidence level (CL) in percent. Finally, we are able to calculate ϕ as:

$$\phi = \frac{CL}{CL_o} - m.(\frac{CL}{CL_o} - 1) \tag{4}$$

For example, a foreman's confidence in being able to accurately forecast concrete pouring duration for an 80 m^2 slab is enhanced when supplied with complementary information about traffic condition received from a GPS transmitter embedded in the concrete truck.

V. Summary and Conclusion

Wireless tools are a part of daily life in 21st century and ubiquitous communication creates an *e*-world. Construction industry is not an exception and is embracing the internet. However, its application is centred at the management level while the field is still disconnected from project network. But wireless technologies promise to improve communication at the field-level. Following this hypothesis, the article introduced an information hub, the *e*CKiosk, to facilitate a seamless project network responding to information exchange needs at the work-front. The danger of overloading associates the question about what information should be communicated. To provide an answer the i^2F framework was developed as a base structure to assess value of a piece of information. Effective information must be transferred and useless information be restricted from occupying space on the network. i^2F measures effective worth based on information quality and value. Information quality is a conceptual model that has to be extracted from its end-user. In fact, the end-user's judgment has to be the basic metric to quantify quality. Information value, on the other hand, is calculated by considering the consequence of not having a piece of information. The more "negative" the consequences, the more valuable an information fragment is. It was explained in the paper that information value needed to be calculated in the usage context. A four dimensional space was defined to model construction process. The key to calculate information value is the change in value indicators through the information evolution path. Cost, time and predictability were selected as value indicators in this paper.

i^2F is a promising tool to quantify usefulness of information in construction . Look-up tables are the core of i^2F framework because they provide the semantic base on top of that the intelligent agents control the information flow through the *e*CKiosk.

References

[1] O. Samuelson, "IT-Barometer 2000, "The use of IT in the Nordic construction industry," *Electronic Journal of Information Technology in Construction*, vol.7, no. 3, pp. 1-26, 2002.

[2] V. Peansupap and D. Walker, "Factors affecting ICT diffusion: A case study of three large Australian construction contractors," *Engineering, Construction and Architectural Management*, vol. 12, no. 1, pp. 21-37, 2005.

[3] P. E. D. Love, Z. Irani, H. Li, E. W. L. Cheng, and R. Y. C. Tse, "An empirical analysis of the barriers to implementing e-commerce in small-medium-sized construction contractors in the state of Victoria, Australia," *Construction Innovation*, vol. 1, no.1, pp. 31-41, 2001.

[4] S. R. Thomas, "Impacts of Design/information technology on project outcomes," *National Institute of Standards and Technology, Gaithersburg, Md., USA*, pp. 99-786, 1999.

[5] L. Koskela and S. Kazi, "Information technology in construction: How to realise the benefits," Working Paper, Technical Research Centre of Finland, 2001.

[6] L. E. Bernold and M. Salim, "Placement-oriented design and delInVery of concrete reinforcement," *Journal of Construction Engineering and Management*, vol. 119, no. 2, pp. 323-335, 1993.

[7] P. R. Zekavat and L. E. Bernold, "Mobile electronic site kiosk for construction," in *Proc. the 37th AUBEA. Conf.,* Sydney, 2012, pp. 575-583.

[8] P. R. Zekavat and L. E. Bernold, "Assessing the quality of electronically communicated information at construction field level," in *Proc. the 2ndICCEM. Conf.,* Hong Kong, 2013, unpublished.

[9] L. E. Bernold and S. AbouRizk, *Managing Performance in Construction*, 1st ed. Hoboken, New Jersey., USA.: Wiley, 2010, ch. 3, pp. 82.

[10] S. Bowden, A. Dorr, T. Thrope, and Ch. Anumba, "Mobile ICT support for construction process improvement," *Automation in Construction*, vol. 15, no. 5, pp. 664-676, 2006.

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