Utility Assessment Model for Wireless Technology in Construction

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Construction projects are information intensive in nature and involve many activities that are related to each other. Wireless technologies can be used to improve the accuracy and timeliness of data collected from construction sites and shares it with appropriate parties. Nonetheless, the construction industry tends to be conservative and shows hesitation to adopt new technologies. A main concern for owners, contractors or any person in charge on a job site is the cost of the technology in question. Wireless technologies are not cheap. There are a lot of expenses to be taken into consideration, and a study should be completed to make sure that the importance and savings resulting from the usage of this technology is worth the expenses. This research attempts to assess the effectiveness of using the appropriate wireless technologies based on criteria such as performance, reliability, risk. The assessment is based on a utility function model that breaks down the selection issue into alternatives attribute. Then the attributes are assigned weights and single attributes are measured. Finally, single attribute are combined to develop one single aggregate utility index for each alternative.

Keywords: Analytic Hierarchy Process, Decision Theory, Utility Function, Wireless Technologies

Introduction

During the construction phase of a project it is essential that the information flow is smooth and continuous throughout the life of the project. Actual presence of information in the field working environment is still predominantly paper-based. The paper-based jobsite documentation process is ineffective as it is unable to deliver the information on time (De la Garza et al. 1998). Thus, the problem for the construction industry is that the information supplied and required at the field has multiplied but traditional manual processes are still in effect.

Wireless technologies have the potential to solve this communication problem, increase collaboration, and provide new capabilities through evolving technologies. The basic premise of wireless construction is to network previously stand alone islands of communication on a construction site to allow for the network between different parties involved in the construction project (Nuntasunti et al. 2006). But the construction industry has been slower than other industries in adopting new technologies into its business processes due to many reasons (Mitropoulos et al. 2000). Unlike the structured environment and highly repetitive processes in manufacturing, construction poses many barriers to the implementation of advanced technologies. Lack of collaboration, high cost, and insufficient technical support and training are among the primary reasons given for reluctance to implement information technologies (Bernold 2006). Moreover, there is lack of metrics to assess value and quantify benefits of applying these technologies. Each technology has its own technical, economic, and risk considerations that make the selection process a difficult one. The selection decision involves many tradeoffs among technology attributes.

This paper proposes a utility assessment model for wireless technologies. This model will help decision makers in construction companies to select the appropriate equipment to be utilized in tracking construction site work progress. The rest of the paper is organized as follows; background is presented to provide the need for such methodology. Then the Utility assessment model is presented by providing theoretical background for the model. An example is implemented to illustrate the use of the proposed utility assessment model in a construction project followed by the conclusion. Finally, the limitations of the research are highlighted.

Background

Field supervisory personnel's on construction sites spend between 30-50% of their time recording and analyzing field data (McCullouch 1997) and 2% of the work on construction sites is devoted to manual tracking and recording of progress data (Cheok et al. 2000). In addition, since most data items are not captured digitally, data transfer from a site to a field office requires additional time. When the required data is not captured accurately or completely, extra communication is needed between the site office and field personnel (Thorpe and Mead 2001). These extra efforts are inefficient in terms of cost and time. These inefficiencies are embedded and distributed among many different activities and project participants, and hence, the project team is generally not aware of the implications and aggregate time and money waste associated with them. Wireless technologies can be used to improve the accuracy and timeliness of the data collected from construction sites. Previous research on such technologies mainly discussed the technological feasibility of using a particular technology to support various construction project tasks (Akinci et al. 2005, Jaselskis et al. 1995). But still there is a need for a methodology to assess the effectiveness of using such technologies.

Assessment Model

The utility assessment model is divided in two parts. The first part consists of developing the utility function model that will help evaluators assess available wireless technologies for project progress tracking. This part includes presenting the main objective and identifying the attributes that will help the evaluators in their decisions, and the alternatives to be assessed. The second part consists of analyzing and identifying the best alternative.

Basic Theories

Multiple criteria decision making methods were developed to help individual decision-makers facing a choice involving uncertainty about outcomes. Construction management involves numerous multiple criteria decision making problems. When the evaluation problem has multiple dimensions, intuitive judgments may become exceedingly difficult (Hastak 1998). The basic idea of this theory is that the main objective is simplified into smaller alternative attributes. After users conduct assessment of these attributes, importance weights are assigned and single-attribute utilities are calculated. Based on the risk attitude of the decision maker three types of utility curves exist: Risk aversion, risk neutral, and risk seeking as shown in figure 1. The straight line function used for risk neutral attitude, is commonly employed in practical application (Georgy et al. 2005).

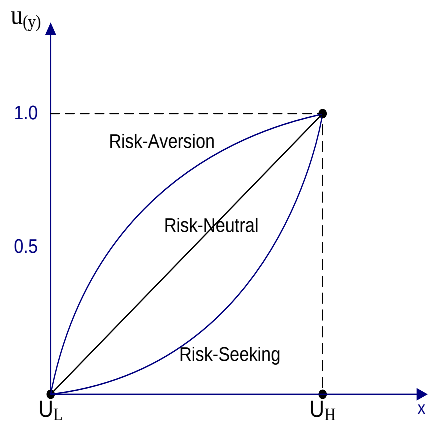

Figure 1 Type of utility curves

The last step is to combine the single-attribute to develop one single aggregate utility index for each alternative. For utility independent attributes, the additive multiple attribute utility takes the form:

$$U(x_1, x_2, \ldots\ldots x_n) = f\,[w_1u_1(x_1), w_2u_2(x_2), \ldots\ldots w_nu_n(x_n)]$$ **Equation 1**

Where $u_n(x_n)$ = single attribute utility function for attribute i, and w_n the weight corresponding to the relative importance of attribute i.

This study chose analytic hierarchy process (AHP) for developing the preference structure. AHP has recently become popular in different areas of construction management like contractor selection, procurement, facility location determination, construction safety management, and green building evaluation. (Lin et al. 2008).

Eigenvector Prioritization Method

The eigenvector prioritization method represents the core of AHP. It is based on three principles: decomposition, comparative judgment, and synthesis of priorities (Saaty 1988).

The decomposition principle requires the attributes to be presented in a hierarchy form to establish their interdependencies and facilitate their analysis through the AHP. Figure 2 illustrates an example of hierarchy of influence. The proposed decision support model takes into account three important criteria and also the various subcriteria associated with them. The three criteria are technological criteria, economic criteria, and risk criteria. Subcriteria include the most likely factors that will govern the decision between different alternatives. These factors have been grouped under these three criteria. The list of criteria and subcriteria is not an all inclusive list, but a representative sample of factors that have importance in the selection process.

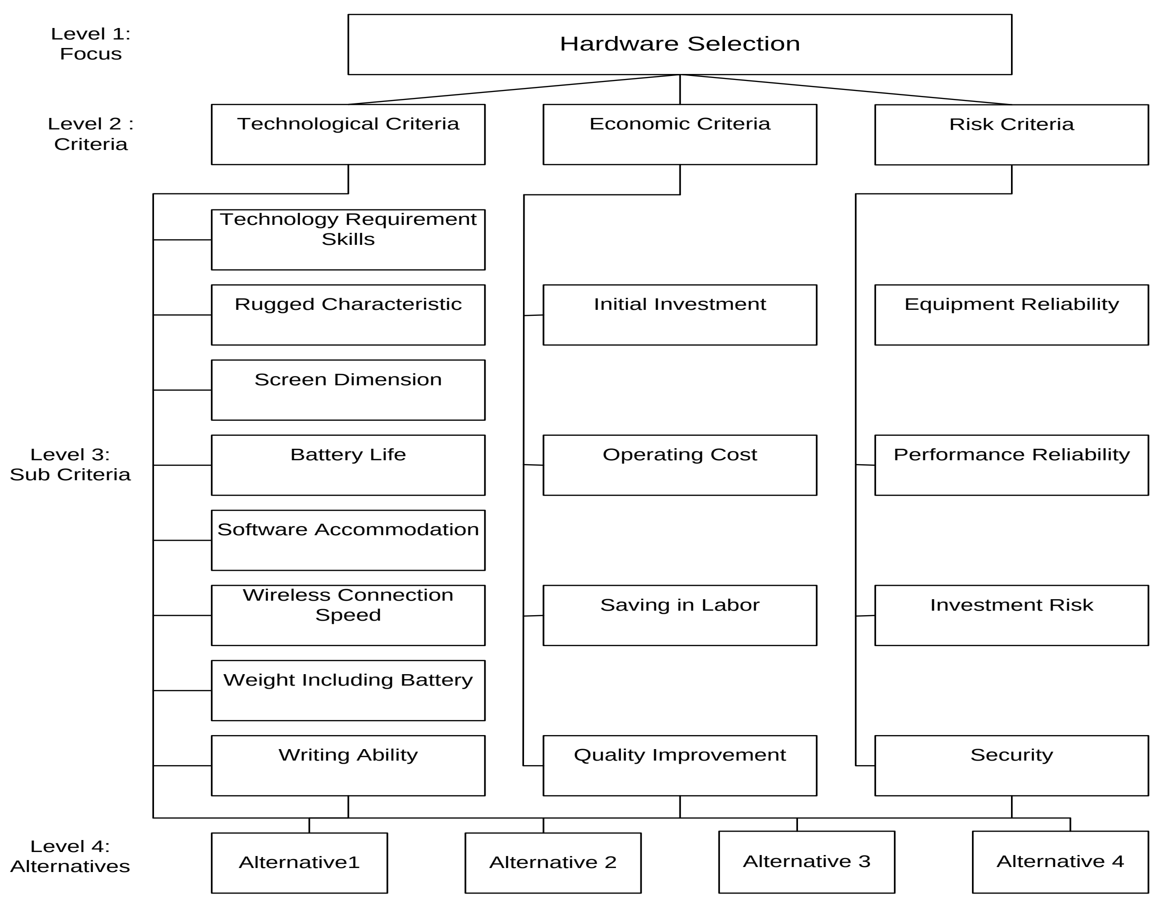

Figure 2 Hierarchy of Influence

The comparative judgment uses pairwise comparisons of the elements within the same level of the hierarchy with respect to the next higher level. The assessments are collected into comparison matrices $[A]_{n*n}$, and then those matrices are used to generate a ratio scale that reflects the local priorities of elements in the level by calculating the normalized principal eigenvector $[W_{n*1}]$, corresponding to the dominant eigenvalue λ_{max} for the matrix $[A]_{n*n}$ as shown in equation 2 and 3.

$[AW]_{n*1} = [A]_{n*n} . [W_{n*1}]$ **Equation 2**

$\lambda_{max} = (1/n) \sum (AW_i / W_i)$ **Equation 3**

Then AHP measures the consistency of the evaluator's judgment by using the consistency ratio (CR) which is the ratio of consistency index over random index (RI) as shown in equations 4 and 5. The RI for various matrix n has been approximated by Saaty as shown in table 1.

Table 1
Approximated random indices RI

n	1	2	3	4	5	6	7	8	9	10	…
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	…

Empirical studies conducted by Saaty have indicated that a deviation in consistency ratio of less than 10% is acceptable without adversely affecting the results (Saaty 1980).

Consistency Ratio (CR) = CI / RI **Equation 4**

Consistency Index (CI) = (λmax –n) / (n-1) **Equation 5**

Syntheses of priorities takes each of the derived ratio scale local priorities in the various levels of the hierarchy and construct a composite (global) set of priorities for the element in the lowest level of the hierarchy.

Example

In order to show the functionality of the model, four alternatives were identified. The four alternatives are a combination of mobile devices with wireless communication capabilities as shown in table 2.

Table 2
Technology alternatives

Alternative 1	**Alternative 2**	**Alternative 3**	**Alternative 4**
Rugged Tablet Computer & WLAN 802.11b	Rugged Tablet Computer & Wireless Subscription	Rugged Personal Digital Assistant (PDA & WLAN 802.11b	Rugged Personal Digital Assistant (PDA & Wireless Subscription

After the attributes are identified and presented in a hierarchical layout as shown in figure 1, the next step is to assign measurement scale for these attributes as shown in table 3. The measures scale is based on literature review, reviewing manufacturers and associations' websites, and exchanging email with experts (Elmisalami et. al.2006, Abduh and Skibniewski 2002).

Table 3
Attributes measures

Attributes	Measures
Technical Requirement Skills	Very Low/ Low/Moderate/High
Rugged Characteristic	IP # #
Screen dimension	2/3/4/5/6/7/8/9/10 (inches)
Battery life	1/2/3/4/5/6/7/8/9/10 (Hours)
Weight including Battery	0.5/1/2/3/4/5/6/7/8/9/10 (Lb)
Writing Ability	Typing/Touching
Software Accommodation	CAD/Project Management/Both
Wireless Connection Speed	kbps- Mbps
Initial Investment	% of Project Total Cost
Operating Cost	% of Project Total Cost
Saving in Labor	Unsatisfactory/Moderate/Satisfactory /Very Satisfactory
Quality Improvement	Unsatisfactory/Moderate/Satisfactory /Very Satisfactory
Equipment Reliability	Low/Moderate/High
Performance Reliability	Low/Moderate/High
Investment Risk	Low/Moderate/High
Security	Yes/No

Step 3 is to apply the eigenvector prioritization method. For that a survey was conducted to determine the preferences between the attributes and to construct the attribute utility curves. The survey was conducted by asking experts from the industry. The pairwise comparison scale (table 4) presented by Saaty was used to represent the relative importance of one element over another with respect to the criteria.

The survey was divided into two sections. The first section was to set priorities between the attributes. The responses to the pairwise comparisons at each level of the hierarchy were placed into a comparison matrix as shown in figure 3. Only half of the matrices needed to be filled by the evaluators because the other half is reciprocal. The numbers (on a scale 1 to 9) in the matrices corresponds to ratio scales. That is, a value of 3 in first matrix (first column third row) means that rugged characteristic is 3 times more preferred to technology requirements skills with respect to the technology criteria. At every level in the hierarchy, a similar pairwise analysis is conducted for each critera/subcriteria of that level. Based on the hierarchy of influence established earlier, four pairwise matrices needed to be developed. The comparison matrices are evaluated to establish the priority vectors. These vectors are weighted by multiplying them with the weight of the corresponding criteria from the preceding level. Similar procedure is employed at each level of the hierarchy.

Table 4
Pairwise comparison scale presented by Saaty

Degree of Importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values between adjacent degrees of importance

Using equation 5 and 6, the consistency of the pairwise for each matrix was checked (less than 10%). In case the consistency ratio for a matrix was greater than 10% then either the values of the matrix were rejected or additional steps were taken to modify pairwise comparisons till acceptable consistency ratio was obtained.

Tech.	Skills	Rugged	Scr. Dimen.	Batt. Lif.	Soft Accom.	Wir. Speed	Weight	Writing Abil.
Skills	1	1/3	1/4	1/5	1/4	1/4	3	1/5
Rugged	3	1	3	3	2	1/5	4	2
Scr. Dimen.	4	1/3	1	1/3	1/2	1/3	3	4
Batt. Lif.	5	1/3	3	1	2	3	5	2
Soft Accom.	4	1/2	2	1/2	1	1/3	5	2
Wirel. Speed	4	5	3	1/3	3	1	4	3
Weight	1/3	1/4	1/3	1/5	1/5	1/4	1	1/3
Writing Abil.	5	1/2	1/4	1/2	1/2	1/3	3	1

Econ.	Init.	Oper.	Sav.Lab.	Qual. Imp.
Init.	1	2	4	3
Oper.	1/2	1	2	3
Sav. Lab.	1/3	1/2	1	4
Qual. Imp.	1/3	1/5	1/4	1

Risk	Equ. Reli.	Perf. Reli	Inv. Risk	Secur.
Equ. Reli.	1	1/2	1/7	1/6
Perf. Reli	2	1	1/2	1/4
Inv. Risk	7	2	1	1/3
Secur.	6	4	3	1

Hardware Select.	Tech.	Econ	Risk
Tech	1	1/5	1/6
Econ.	5	1	1/3
Risk	6	3	1

Figure 3 Pairwise Comparisons

The second section of the survey was to determine the utility of each attribute. The responses of the evaluators (table 5) were used to construct the utility function for each attribute by substituting the value of U_L and U_H in equation 1. Typically U_L represents the value where the degree of liking reaches zero, while U_H represents the value where the degree of liking reaches its ultimate level of 1.0.

Table 5

Utility preferences

Attributes	U_L	U_H
Technical Requirement Skills	High	Low
Rugged Characteristic	IP13	IP33
Screen dimension	2	8
Battery life	2	6
Weight including Battery	0.5	4
Writing Ability	Typing	Touching
Software Accommodation	CAD	Both
Wireless Connection Speed	256 Kb	11 Mb
Initial Investment	0.5%	2%
Operating Cost	0.25%	1%
Saving in Labor	Moderate	Satisfactory
Quality Improvement	Moderate	Satisfactory
Equipment Reliability	Low	High
Performance Reliability	Low	High
Investment Risk	Low	High
Security	No	Yes

Finally the attribute utility function U_T can be constructed through integrating the single attribute utility functions and using the preference structure calculated based on figure 3. The average weights vector would be used as it depicts the most likely values for the sought preference structure.

Equation 6 presents the multiple attributes utility function to provide a collective assessment of the assessed technologies for real time construction project progress tracking. Values of U_T can vary between 0 and 1. The larger the U_T value for an alternative the more favorable it is to be used in the real time model. As shown in table 6, the utility function of the four alternatives varied between 0.46 and 0.76, which suggest that neither if the four alternatives are perfect enough to obtain aggregate utility close to 1. Although alternative 3 had the highest utility of value 0.76 corresponding to the most favorable choice.

$$U_T = 0.0032U_1(x_1)+0.0136U_2(x_2)+0.008U_3(x_3)+0.0152U_4(x_4)+0.0096U_5(x_5) +0.168U_6(x_6)+0.0024U_7(x_7)+0.0064U_8(x_8)+0.004U_9(x_9)+0.128U_{10}(x_{10}) +0.075U_{11}(x_{11})+0.058U_{12}(x_{12})+0.024U_{13}(x_{13})+0.04U_{14}(x_{14})+0.11U_{15}(x_{15}) +0.18U_{16}(x_{16})+0.33U_{17}(x_{17})$$

Equation 6

Table 6
Utility of alternatives

U_T(Alt1)	U_T(Alt2)	U_T(Alt3)	U_T(Alt4)
0.52	0.46	0.76	0.64

Conclusion

This paper presented a utility function model to help in choosing an appropriate technology to fulfill the initial goal. Companies interested in implementing technology within their organizations must recognize the nature of the new technologies involved, their lifecycles, and most importantly how to integrate their work processes with these technologies. Undeniably, new systems come with uncertainties, risks, costs, problems and implementation resistance. Based on the utility model developed, alternative 3 gave the highest utility value corresponding to the most favorable choice for the decision makers. This is an ongoing research and more example project implementation results are expected in the near future.

Limitations

The utility function model developed in this study provides a comprehensive approach to assess technologies that will be used in real time project progress tracking. However there are some limitations in the presented implementation. The authors included only risk neutral evaluators for the utility function development process. Future research should include more diversified risk attitude such as risk-seeking and risk-adverse attitude. The survey results used in this paper were based on a small sample. A larger survey is underway. In addition to that, a cost/benefit analysis should be incorporated to quantify the monetary value of this model.

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