DEVELOPMENT OF AN ICT-BASED LOGISTICS FRAMEWORK FOR THE CONSTRUCTION INDUSTRY

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Several information and communication technology (ICT) devices have been proposed and developed by researchers to improve logistics functions such as tracking and monitoring resources through the supply chain to the construction site. Such ICT devices include global positioning system (GPS), radio frequency identification devices (RFID), wireless sensors network system (WSN), geographical information system (GIS), management information system (MIS) and discrete-event simulation models (DES). While considerable research work has been carried out on the development of these devices and their adaptation to construction logistics process, limited work has so far been done on investment evaluation to justify their implementation financially. This paper presents a research work that seeks to develop a computer-aided framework for the evaluation of ICT-based logistics system in the construction industry. The work involves the identification and quantification of costs, benefits and risks involved in implementing ICT systems to solve, or mitigate problems that hinder the efficient operation of construction logistics. Furthermore, the paper presents a case study that demonstrates a comparative evaluation of the fitness of Cost-Benefit and Multi-Criteria analysis for underpinning the computational component of the proposed framework

Keywords: construction logistics, cost benefit analysis, information and communication technology, investment evaluation, multi-criteria analysis.

INTRODUCTION

Construction logistics management can be defined as the process of mobilizing the various resources required for construction process to the right place at the right time at the minimum cost and creating an enabling environment for construction activities i.e. ensuring safety/security, quality and efficiency (Guffond and Leconte 2005). Logistics practice in the construction industry is still trailing behind sectors like manufacturing and retail, where information and communication technologies are being applied at an advanced level to implement and improve their logistics system. Some of the factors responsible for inefficient logistics in the construction industry include: relative short-term nature of construction process, which makes it difficult to build optimized logistics system in a way that is possible in retail and manufacturing; the fragmentation of activities in construction process creates communication gaps, which may cause suppliers not to fully understand the implications of design, materials and components choices making them, sometimes, to supply wrong materials and/or wrong quantities of material to site (Rogers 2005); logistics is

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affected by the practice of the lower bidder getting the contract in which the rejection or acceptance of contract is based only on the conformance to technical specifications instead of other performance measures that relate to the process itself (Wegelius-Lehtonen 2001) and finally, most delivery and inventory data on construction sites are still recorded manually and these are prone to errors due to personal judgement and writing skills or lack of systemic understanding of communication protocols which often results in process delays. Therefore, it is very important to provide real-time methods of identifying, registering, collecting and communicating information about the status of construction materials (Jang and Skibniewski 2008).

Given the above short-comings of the current practice of logistics in the construction industry, especially regarding communication, information and communication technologies (ICT) can be regarded as an important tool for addressing these problems. ICT have the potential to enhance information flow, facilitate efficient delivery, mimize, or even prevent theft and damage risks, reduce delays in data retrieval, reduce waste and enhance the overall productivity of the construction process. Several ICT-based resources tracking systems have been developed and proposed for implementation in the construction industry. These include:

- Wireless sensors network system (WSN) for tracking and monitoring materials on construction site (Jang and Skibniewski 2008)
- Hybrid information and communication technology system for reducing vehicle/pedestrian collisions using wireless sensors network (Riaz *et al.* 2006)
- Positioning and tracking construction vehicles in highly dense urban areas and building construction sites using global positioning system (GPS) and vehicle position/location system called “dead reckoning” (DR) (Lu *et al.* 2007)
- Intelligent navigation for seamless inertial navigation system (INS)/GPS integrated land vehicle position/location applications (Chiang and Huang 2008)
- Application of integrated global positioning system (GPS) and geographical information system (GIS) technology for reducing construction waste and improving construction efficiency (Li *et al.* 2005).

Operations management at construction sites could particularly benefit from resources tracking with improved situation awareness applications, which will enable productivity assessment, waste reduction and accident prevention (Xuesong *et al.* 2008).

While ICT devices have been developed and proposed to improve construction logistics, limited work has so far been done for the systematic evaluation of such technologies prior to their implementation. This is particularly important because most of the devices are alternative systems with significant variations in their costs and benefits. Despite the importance of cost in the implementation of robust ICT systems in construction, the focus of major ICT research is on technical issues such as development of software applications and interoperability issues rather than managerial nature such as investment justification, strategy and strategic information planning (Love *et al.* 2004). Similarly, those responsible for ICT implementation in an organization often advocate optimistic estimate of benefits and cost savings. Thus, failing to identify the full cost implications may result in several years of use to achieve expected financial returns (Love and Irani 2001).

Having identified the need for investment evaluation, this paper presents an initial study carried out to develop a multi-criteria analysis model to analyse alternative ICT-based construction logistics systems and generate ranking values in which the alternative with the highest value is the most preferred one. This is part of an on-going research on the development of an ICT-based logistics framework for the construction industry. The study included the identification of the operational benefits of these ICT-based logistics systems including quantifiable benefits and intangibles. The inclusion of intangibles makes it impracticable to use monetary values as the common unit of costs and benefits. Hence, the need to adopt multi-criteria analysis approach in which the costs and benefits are classified as criteria or attributes and the relative importance of each criterion is weighted resulting in the qualitative comparison of possible alternative system configurations.

CASE STUDY

Logistics problem scenarios

Having established the need to improve construction logistics through the application information and communication technologies, a case study was developed to analyse two implementation scenarios of alternative ICT-based tracking systems. The case study was fashioned after the application scenario of a wireless sensors network material tracking and monitoring system proposed by Jang and Skibniewski (2008). For the purpose of this analysis, 40 units of precast concrete slabs and 40 units of steel frames are to be delivered by a standard delivery vehicle to a construction site. The two alternatives considered are radio frequency identification system (Alternative A) and wireless sensors network system (Alternative B).

Alternative A: radio frequency identification system (RFID)

Each construction material is tagged with RFID tags and RFID readers and antennas are installed at the inlet and exit of the storage. RFID readers at the storage inlet portal scan materials as they are being moved in and this automatically captures all the necessary data about the materials that are delivered to the storage. RFID readers at the storage exit portal automatically retrieve data related to the materials as they are moved out of the storage to the construction area. This gives real-time and continuous information about stock level in the storage reducing the chance of materials running out of stock.

Alternative B: wireless sensors network system (WSN)

Each construction material is tagged with sensor tags and wireless sensor routers are installed at strategic points around the circumference of a storage facility or laydown compound. The tagged materials are classified as nodes within the network and are able to communicate with one another and the routers. Information about the individual materials is communicated through the routers to the control station (management information system).

FRAMEWORK DEVELOPMENT

Conceptual framework

One of the various multi-criteria analysis methods is the family of multi-attributes utility theory. This theory allows compensation between criteria i.e. the gain on one criterion can compensate for the loss on another (Fulop 2005). A popular technique of these methods is called Simple Multi-Attributes Rating Technique (SMART). The ranking value x_j of alternative j is obtained simply as the weighted algebraic mean of the utility values associated with it, i.e.

$$x_j = \sum_{i=1}^{m} w_i u_{ij} / \sum_{i=1}^{m} w_i, \; j = 1,......,n \qquad .... (1)$$

where: m is the number of attributes,

n is the number of alternatives,

x_j is the ranking or multi-criteria index of alternative j,

w_i is the importance weight of attribute i and

u_{ij} is the utility value of attribute i for alternative j.

First, the criteria are ranked in their order of importance and points are assigned to them to reflect their relative importance. However, the comparison of the importance of attributes is meaningless if it does not reflect the range of utility values of the alternatives as well. Hence, Edwards and Baron (1994) proposed a variant of SMART named SMART using Swing that in the course of the comparison of the importance of the criteria also considers the amplitude of the utility values i.e. the changes from the worst utility value level to the best utility level among the alternatives. The conceptual model architecture of this framework in Figure 1 shows the model input (estimation of attributes values and measurement of importance weights), the model process (the calculation of the output using the input and the multi-criteria index formula in equation 1), and the model output (the multi-criteria index or alternative ranking value). An important criterion for measuring the performance of a multi-criteria analysis technique is decision maker's subjective evaluation in terms of accuracy, trustworthiness and ease of use. Only when the method is satisfactory to the decision makers will it be used frequently and regarded as important (Wang and Yang 1998). The SMART technique utility function that represents preferences reduces the amount of information in order to improve the comprehensibility of the technique. The trustworthiness of the output of SMART technique was demonstrated in the evaluation work carried out by Cho (2003) in which the best alternative predicted by SMART agreed with other techniques such as analytic hierarchy process (AHP), Bayesian Analysis and Outranking Method.

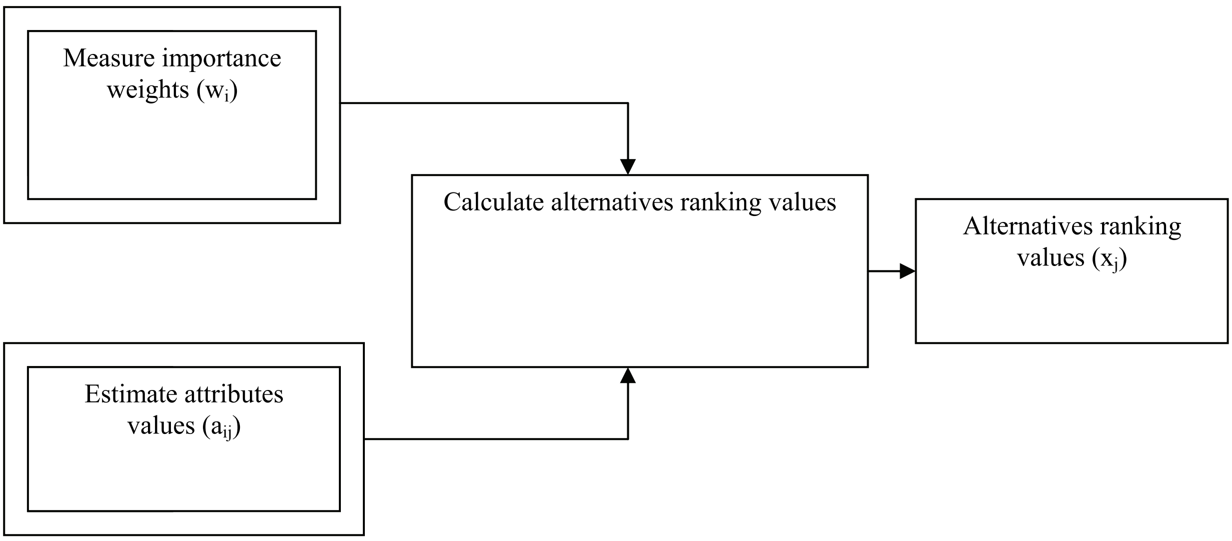

Figure 1: Conceptual framework architecture

Measurement of importance weights of attributes

For the purpose of the study presented in this paper, three attributes were considered; including cost, waste reduction and data accuracy. The analysis presented in this paper is a pilot study, as part of an on-going PhD research, to demonstrate the concept of multi-attribute utility theory and its applicability to analyse alternative systems. Hence, these three attributes were selected at random from a long list of attributes which represent the cost and benefits of implementing either of the two alternative systems described in section 2 of this paper. This was done to enable the demonstration of the proposed technique as part of the paper. Inclusion of additional attributes is possible by the expansion of the utility values in equation (1).

Scaling of attributes

This is a measure of the relative importance of the attributes in descending order, from the most important to the least important. In addition, the attributes are given weights according to their relative importance.

Cost: This might be the most important attribute to a contractor or supplier who may want to implement any of these systems given the short term nature of construction project. Due to the short time span of the usability of the solution that seek to increase inventory transparency in construction project supply chain, such solution should be speedy, easy to implement and not demand significant investment (Chang *et al.* 2001) Therefore, cost will be the top priority in this analysis.

Waste reduction: Waste reduction was considered next important attribute since waste contributes significantly to the overall cost of construction process. Real-time location of materials on construction sites will prevent material abandonment, enhances the storage of materials in appropriate places and hence, prevent waste generation. A cost reduction caused by preventing the generation of construction waste is of direct benefit for most of the participants that work on a construction project (Bossink and Brouwers 1996)

Data Accuracy: This is another important attribute because the exactness of the data retrieved by a real-time system will eliminate errors that are experienced in manual entry of data into the database. It has been identified that some of the problems encountered in warehouse operations are the entry of incorrect information on inventory level, warehouse capacity and storage location into warehouse management system (WMS) and the creation of inaccurate report by the WMS (Poon *et al.* 2009).

Weights measurement by swing method

The swing technique of measuring importance weight starts with the thought of a "worst conceivable alternative" i.e. the one that scores at the lowest on all the attributes; identify the attribute that gives you the greatest increase in satisfaction (utility) when you swing it from the lowest level to high level while leaving the other attributes at their lowest levels; choose another attribute and swing it to high level while leaving others at lowest level. The satisfaction from the second one will be at a percentage of the satisfaction from the first i.e. the first attribute has the greatest satisfaction. Continue the procedure until all attributes have been considered.

Imagining the worst conceivable alternative for this analysis, that will be an alternative with highest cost of implementation, lowest impact on waste reduction and lowest data accuracy. The attribute that will give me the highest increase in satisfaction, as described in section 3.2.1, if swung to high level is cost and hence, its improvement in satisfaction is 1 (maximum utility); swinging the second attribute (waste reduction), my increase in satisfaction is 60% of the maximum utility and swinging the last attribute (data accuracy) will give me 40% of the maximum utility. Swing percentages will be derived at a later stage of the research through elicitation from practitioners in the construction industry. The calculation of the importance weights of the attributes is described below:

Let w_1, w_2 and w_3 represent the weights of cost, waste reduction and data accuracy respectively.

$w_2 = 0.6\,w_1, \quad w_3 = 0.4\,w_1$

The weights must add up to 1 i.e.

$w_1 + w_2 + w_3 = 1$

$w_1 + 0.6\,w_1 + 0.4\,w_1 = 1$

$2\,w_1 = 1$

$w_1 = 0.5$

$w_2 = 0.6 \times 0.5 = 0.3$

$w_3 = 0.4 \times 0.5 = 0.2$

These weights were normalized by multiplying them with 100 to produce the values presented in Table 1 and they are independent of the alternatives.

Table 1: Weights of attributes

Attributes	Weights	Normalized weights
Cost	100	50
Waste reduction	60	30
Data accuracy	40	20

Estimation of the values of attributes

Cost estimation

The costs of the two alternative systems considered in this pilot study were calculated using Microsoft Excel spreadsheet. The cost is the life cycle (3 years) cost of the systems which is a combination of the initial capital cost and annual running cost. The capital cost is based on the market prices of the components that make up the systems and the annual running cost is annual cost of electric power consumption of the systems. The total cost of implementing the RFID-based logistics system (alternative A) was found to be £8471.40 while that of wireless sensors network (alternative B) was £7042.28.

Validity of 3-year life cycle

The shortest life span of any component of the RFID and WSN systems such as batteries has been found to be 3 years; the life span of an average construction project was considered to be 3 years and the ICT-based logistics system is expected to be designed and configured on project by project basis. Therefore, a life cycle of 3 years was chosen for this analysis and there was no need to include replacement cost in the life cycle cost.

Assumptions

- The discount rate used for the analysis is the interest rate of 4.3%, which was that of the banking industry at the time of carrying out the cost estimation.
- The flat rate of 15.19 pence per kWh was used to calculate the annual cost of electricity in running the systems. Assumed to run 24 hours per day.
- Consumer price indexes for consecutive 3 years were obtained from the National Office of Statistics to calculate inflation rates.

Evaluation of alternatives: proportional scoring method

This is the linear rescaling of each attribute to a common utility scale. The utility scale ranges from 0 to 100. The highest possible score for any alternative is 100 while the lowest possible score is 0. The most important thing is that the same utility scale is shared by each of the attributes that are assessed and eventually combined in a single ranking value (Levin and McEwan 2001). The proportional scoring utility function is shown in equation (2).

$$U(x) = \frac{x - Lowest\,Value}{Highest\,Value - Lowest\,Value} \times \frac{100}{1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where x is the measured quantity or assigned unit of the alternative for the attribute under consideration and U(x) is the utility score of the alternative for the attribute.

Cost
Alternative A is approximately £8500 while alternative B is approximately £7000 in terms of capital and annual running (3 years) costs. The upper limit of cost can be fixed at £10000 and it is the lowest value (most undesirable) while the lower limit will be fixed at £5000, which is the highest value (most desirable). Using equation (2):

The utility score for alternative A on cost attribute $\Rightarrow$

$$U(8500) = \frac{8500 - 10000}{5000 - 10000} \times \frac{100}{1}$$
$$= 30$$

The utility score for alternative B on cost attribute $\Rightarrow$

$$U(7000) = \frac{7000 - 10000}{5000 - 10000} \times \frac{100}{1}$$
$$= 60$$

Waste reduction
Logistics related sources of construction waste according to the studies carried out by Gavian and Bernold (1994) and Craven *et al.* (1994) along with the ICT-based solutions identified through this study are presented in Table 2.

Table 2: Logistics-related sources of construction waste

Sources	Causes	ICT-based solution
Procurement	Ordering error including overordering and under-ordering	RFID/WSN
	Supplier's error	RFID/WSN
Material handling	Damage during transportation to site or on site	
	Inappropriate storage leading to damage or deterioration	RFID/WSN
Operation	Damage due to weather condition such as temperature and humidity	WSN
	Damage due to accident	
Security	Damage due to vandalism	RFID/WSN

Assigning 1 unit to each of the causes of waste and applicable ICT solution, the alternatives were scored according to the information in Table 2 as follow: Total number of waste causes (Highest value) = 7; number of causes addressed by RFID (Alternative A) = 4; number of causes addressed by WSN (Alternative B) = 5 and the lowest value = 0. These values are substituted in equation (2) as follows:

The utility score for Alternative A on waste reduction $\Rightarrow$

$$U(4) = \frac{4-0}{7-0} \times \frac{100}{1}$$

$$= 57$$

The utility score for Alternativ e B on waste reduction $\Rightarrow$

$$U(5) = \frac{5-0}{7-0} \times \frac{100}{1}$$

$$= 71$$

Data accuracy

Accuracy of 'arm's length' (i.e. 1 – 2m) is considered appropriate for tracking resources effectively (Lu *et al.* 2007). According to the test carried out on an RFID logistics resource management system (R-LRMS) by Poon *et al.* (2009) (Alternative A), the accuracy of retrieved warehouse information is significantly improved. The test shows that the inventory level recorded by R-LRMS is exactly the same as the actual level and this implies 100% data accuracy. On the wireless sensor network system (Alternative B), the test carried out by Jang and Skibniewski (2008) showed the system produced relatively high accuracy with 58.6cm error in all range of clock frequencies. Expressing this error as a percentage of the maximum acceptable error (2m), the system (Alternative B) produced 71% data accuracy. These data 100% and 71% represent the utility scores for alternative A and alternative B respectively.

Ranking values of alternatives

The importance weights and the values of the alternative for each attribute were then transformed to ranking values of the alternatives using the weighted algebraic mean formula shown in equation 1. The outlay of the ranking values calculation is shown in Table 3. This result shows that Alternative B with the higher ranking value of 65.5 will be preferred to Alternative A with the lower ranking value of 52.1 (see Table 3). An example of the calculation for alternative A is shown below:

$$x_1 = \frac{w_1 u_{11} + w_2 u_{21} + w_3 u_{31}}{w_1 + w_2 + w_3}$$

$$= \frac{50 \times 30 + 30 \times 57 + 20 \times 100}{50 + 30 + 20}$$

$$= 52.1$$

Table 3: Ranking values of alternatives

Criterion	Cost	Waste Reduction	Data Accuracy	Ranking Values (xj)
Importance weight	50	30	20	
Alternative A	30	57	100	52.1
Alternative B	60	71	71	65.5

Model limitations

- The estimation of weights in this analysis is subjective and the importance weights may vary among different participants in construction logistics such as contractors and suppliers. Hence, there is need to carry out sensitivity analysis (Levin and McEwan 2001) which will prove the consistency of the model output when some key input parameters such as the importance weights are varied.

- The proportional scoring of the values implies risk neutrality and all of the unusual behaviour associated with that however the risk aspect of the alternatives can be ignored because the reliability of the alternative systems has been proved by previous experimentation and testing (Poon *et al.* 2009; Jang and Skibniewski 2008)

CONCLUSION

Various alternative ICT systems are available for the improvement of construction logistics but their cost and benefits vary significantly. Therefore, there is need to develop a model that can analyse various alternatives so as to guide decision in selecting a preferred alternative. This paper has presented the applications of multi-criteria analysis for the evaluation of alternative systems and the generation of ranking values, which are the measures of the viability of an alternative over the other based on a number of attributes. The study has demonstrated the applicability of multi-attribute utility theory in analysing alternative ICT-based logistics systems. Future research will aim to increase the number of attributes that will be used as part of the analysis with the view to incorporate a wider range of logistics problems that ICT systems can address. This will increase the robustness of the model and will be supported with sensitivity analysis that will be carried by varying key input parameters to prove the validity and reliability of the model output.

REFERENCES

Bossink, B A G and Brouwers, H J H (1996) Construction Waste: Quantification and Source Evaluation. *Journal of Construction Engineering and Management*, **122**, 55-60.

Cheng, E W L, Li, H, Love, P E D and Irani, Z (2001) An e-business model to support supply chain activities in construction. *Logistics Information Management*, **14**, 68-77.

Chiang, K and Huang, Y (2008) An intelligent navigator for seamless INS/GPS integrated land vehicle navigation applications. *Applied Soft Computing*, **8**, 722-733.

Cho, K T (2003) Multicriteria decision methods: an attempt to evaluate and unify. *Mathematical and Computer Modelling*, **37**, 1099-1119.

Craven, D J, Okraglik, H M and Eilenberg, I M (1994) Construction waste and a new design methodology. *In:* Kibert, C J (Ed.), *Sustainable Construction: Proceedings of the first international conference of CIB TG16*, 6-9 November 1994, Florida USA, 89-94.

Edwards, W and Barron, F H (1994) SMARTS and SMARTER: Improved simple methods for multi-attributes utility measurements. *Organization Behaviour and Human Decision Processes*, **60**, 306-325.

Fulop, J (2005) Introduction to decision making methods. Laboratory of Operations Research and Decision Systems, Computer and Automation Institute. Hungarian Academy of Sciences.

Gavilan, R M and Bernold, L E (1994) Source evaluation of solid waste in building construction. *Journal of Construction Engineering and Management*, **120**, 536-555

Guffond, J and Leconte, G (2005) Developing construction logistics management: the French experience. *Construction Management and Economics*, **18**, 679-687.

Jang, W and Skibniewski, M J (2008) Wireless network system for automated tracking of construction materials on project sites. *Journal of Civil Engineering and Management*, **14**(1), 11-19.

Levin, H M and McEwan, P J (2001) *Cost-Effectiveness Analysis.* 2ed. California: Sage Publications.

Li, H, Chen, Z, Yong, L and Kong, S C W (2005) Application of integrated GPS and GIS technology for reducing construction waste and improving construction efficiency. *Automation in Construction*, **14**, 323-331.

Lu, M, Chen, W, Shen, X, Lan, H C and Liu, J (2007) Positioning and tracking construction vehicles in highly dense urban areas and building construction sites. *Automation in Construction*, **16**, 647-656.

Love, P E D, Irani, Z and Edwards, D J (2004) Industry-centric benchmarking of information technology benefits, costs and risks for small-to-medium sized enterprises in construction. *Automation in Construction*, **13**, 507-524

Love, P E D and Irani, Z (2001) Evaluation of IT Costs in Construction. *Automation in Construction*, **10**, 649-658.

Office of National Statistics (2009) Consumer Price Index

Poon, T C, Choy K L, Chow, H K H, Chang, F T S and Ho, K C (2009) A RFID case-based logistics resource management system for managing order-picking operations in warehouses. *Expert Systems with Application*, **36**, 8277-8301.

Riaz, Z, Edwards, D J and Thorpe, A (2006) SightSafety: A hybrid information and communication technology system for reducing vehicle/pedestrian collision. *Automation in Construction*, **15**, 719-728.

Rogers, P (2005) Improving construction logistics. *Report of the Strategic Forum for Construction Logistics Group*.

Wang, M and Yang, J (1998) A multi-criterion experimental comparison of three multiattribute weight measurement methods. *Journal of Multi-Criteria Decision Analysis*, **7**, 340-350.

Wegelius-Lehtonen, T (2001) Performance measurement in construction logistics. *International Journal of Production Economics*, **69**, 107-116.

Xuesong, S, Wu C and Ming, L (2008) Wireless sensor networks for resources tracking at building construction sites *Tsinghua Science and Technology* **13**, 78-83.