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Performance Assessment Modelling for the Integrated Management System in Construction Projects

Amiruddin Ismail
Sustainable Urban Transport Research Centre
Department of Civil and Structural Engineering
Faculty of Engineering and Built Environment
Universiti Kebangsaan Malaysia (UKM)
43600 UKM Bangi, Selangor
Darul Ehsan, Malaysia
E-mail: abimismail@gmail.com
Tel: +603-89216203; Fax: +603-89216147

Abbas M Abd
Department of Civil and Structural Engineering
Faculty of Engineering and Built Environment
Universiti Kebangsaan Malaysia

Zamri Chik
Department of Civil and Structural Engineering
Faculty of Engineering and Built Environment
Universiti Kebangsaan Malaysia

Muhammad Fauzi Mohd. Zain
Department of Architecture, Faculty of Engineering and Built Environment
Universiti Kebangsaan Malaysia

Abstract

The most appropriate tools to manage the uncertainty and vagueness of the quality performance in construction projects are the Quality Management and Environmental Management systems. Because of the benefits of their interaction, the two systems were integrated to formulate the Integrated Management System (IMS). Quality performance has been assessed to monitor the construction processes and activities status. The developed Evaluating System has been utilized different assessment criteria, sub-criteria, and their combinations. The concepts of fuzzy set theory have been introduced to represent the uncertainty and vagueness of each quality requirements. The study context is limited to construction projects to point out the using of these concepts for analyzing and improving the quality culture in this sector. The findings reflect the relative significance and the probability of fail for each article of the system components, the ability of integration for two systems or more, and some recommendations were suggested for further development.

Keywords: Environmental System, Integration Management, Quality System, Construction Management

1. Introduction

One of the most significant issues facing today's construction industry is the achieving of customer satisfaction. This perspective reflected from the important role played by customer as the core of the construction industry and the driving force for improvement. The satisfaction process is defined as the process running throughout the construction project by which means the project requirements are progressively captured and translated into effect. Because of its pivotal role in eliciting and communicating customer requirements to the design and construction teams, the satisfaction process is a cornerstone for achieving goals. Hence, it has to be flexible, well organise and responsive to the customer requirements (Othman et al., 2004).

Formal observations, literature review, experience analysis of 97 construction related experts, documentary data, questionnaire and unstructured interviews with projects' team undertaken by the author showed that very few buildings are finished on time, or at the right cost and customer (clients) often blame the construction industry of providing products that do not achieve their requirements and meet their expectations. Furthermore, customers articulated that they used change orders to achieve their expected requirements and to adapt to the influence of the internal and external risks. This is attributed to the limitations of the current project management approaches, which confine the development of the project processes to a certain stage. This perspective hinders the interaction between the project parties and processes, and impedes exploiting value opportunities and managing risk threats in all project's processes. In order to overcome the limitations of the current briefing approaches, the Integrated Management System's concept was developed. This concept supports and encourages the development of decision making process throughout the project life cycle as an approach to achieve customer satisfaction and respond in an innovative manner to the performance improvement, and to manage change orders effectively (Othman et al., 2004).

Developing such system without establishing the procedures that control its processes development leaves the project management uncontrolled and jeopardise achieving client's satisfaction. Because such system development can add value or risk to the project or could add both, the well-established methodologies of Quality Management (QM) and Environmental Management (EM) are the most appropriate tools to manage project performance.

This paper aims to establish the basis and set the rules for this approach, and develop the tool that will manage and control quality performance in construction projects. Two objectives were developed to achieve this aim. The first one is theoretical, which focused on utilizing the role of QM and EM in managing quality performance. The second objective is practical which presents an innovative decision making tool, developed by the author that will be used in the process of making an appropriate decision, assessment and as training tool for the project staff.

2. Integration of Management Systems

Traditionally, an organization would implement its management systems one at a time, with their boundaries remaining clear-cut after the implementation process to highlight their importance to employees. As a result, however, isolation among management systems and with the overall business management is most likely to happen, hindering the chances to achieve some of the expected benefits and creating new problems of its own. Waste of resources, conflicts of interest, sub-optimization of local goals in opposition of overall goals, repetition of activities, increasing paperwork, confusion on priorities and objectives and a general lack in achieving the organization's objectives may be some of the problems created by this lack of connectivity among functional management systems that have been implemented using standards.

This lack of integration between management systems has been recognized by researchers, practitioners and standards developers, mostly from the quality field, resulting in different initiatives to counteract it (Karapetrovic et al., 1998; Wilkinson et al., 1999). For instance, MS standards for quality (ISO 9001:2000), and environment (ISO 14001:2004) have been made more compatible with each other.

Although some work has been done for the integration of management systems, further work is still required, both conceptual and empirical. The most pressing need, identified by Jonker et al., 2004, is to develop a model for the integration of management systems along with a supporting methodology for its implementation. Additional considerations to be included in both the model and the methodology are:

- Different starting points to build upon, e.g. an ISO 9001 QMS or an ISO 14001 EMS or none at all.
- Different sequences of integration, e.g. an IMS covering quality and environmental requirements may be implemented by integrating QMS first and EMS later or an EMS first followed by a QMS.
- Different finishing points according to organization's own needs, e.g. an IMS including quality, environmental and occupational health and safety requirements.
- The need for engaging stakeholders into the systems to optimize the organization's performance;
- Level of integration of functional standardized requirements within the IMS, e.g. alignment or harmonization (Karapetrovic et al., 2002).
- Auditing, evaluation, control and improvement of an IMS (Dale, 2004).

These considerations are missing in the existing models developed to integrate management systems, thus motivate to create the approach of this research.

Having two or more Management Systems implemented in a single organization could increase the risk an organization has of actually having these problems. Furthermore, certain problems have been identified as the result of isolation between MS's built based on standards. Throughout the literature, a list of problems derived from such isolation has been identified mostly referred to isolation between QMS and EMS (Corcoran, 1996; Karapetrovic et al., 2002; Wilkinson et al., 2002):

- Waste of resources.
- Conflicts of interest and confusion in priorities and goals.
- Repetition of activities and processes.
- Increasing paperwork.
- Lack of commitment towards the MS from top management.
- Ending up with dissatisfy stakeholders nonetheless for lack of performance.

An alternative to overcome isolation among standardized management systems and its corresponding problematic is the integration of standardized management systems.

3. Fuzzy Approach to IMS Representation

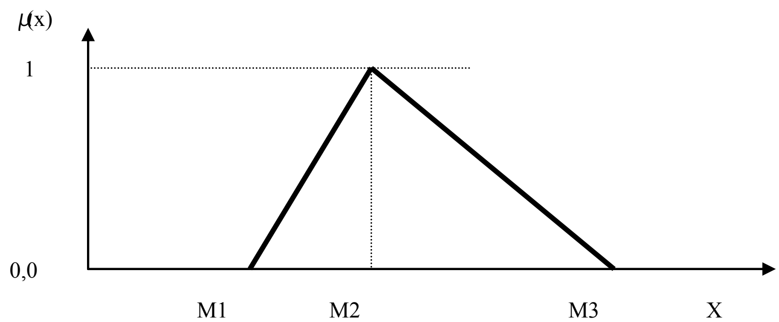
To deal with vagueness of human thought, Zadeh (1965) first introduced the fuzzy set theory, which was oriented to the rationality of uncertainty due to imprecision or vagueness. A major contribution of fuzzy set theory is its capability of representing vague data. The theory also allows mathematical operators and programming to apply to the fuzzy domain. A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership (characteristic) function, which assigns to each object a grade of membership ranging between zero and one. The parameters m1, m2 and m3 respectively denote the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event.

Each Triangular Fuzzy Number has linear representations on its left and right side such that its membership function $\mu(x)$ can be defined as:

$$\mu(x) = \begin{cases} 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots & x \langle m1 \\ (x - m1)/(m2 - m1) \ldots\ldots\ldots\ldots & m1 \le x \le m2 \\ (m3 - x)/(m3 - m2) \ldots\ldots\ldots\ldots & m2 \le x \le m3 \\ 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots & x \rangle m3 \end{cases} \quad (1)$$

A fuzzy number can always be given by its corresponding left and right representation of each degree of membership as explained in Figure 1.

Figure 1: Fuzzy triangular number representation



Fuzzy sets were first introduced to elucidate the concept of fuzziness. Fuzzy sets represent linguistic variables whose values are not numbers, as for numerical variables, but are words or sentences in a natural or artificial language (Zadeh 1965). The mix design involves a complex and nonlinear procedure that is influenced by the material interaction and culture of construction quality. Hence, it is difficult to develop a comprehensive analytical model by considering all design variables. Typically, concrete mix companies have extensive records of their past mix proportions, which can be used to develop a model for the design procedure.

As shown in Figure 1. A fuzzy set A can be defined mathematically by assigning to each possible element in the universe of discourse a value representing its degree of membership in the fuzzy set. This means that, contrary to the classical sets theory in which an element either belongs to or does not belong to a set (i.e. its membership to that set is crisp), in fuzzy sets theory the belonging of an element x to a set A is defined by a degree of membership indicated by a number in the interval [0,1]. Hence, the fuzzy set A can be defined by a set of ordered pairs, a binary relation, as follows (Bojadziev et al., 1997):

$$A = \{(x, \quad _A(x) \quad x \in A \quad _A A(x \quad \in [0,1] \quad (2)$$

where $\mu_A(x)$ is the membership function that specifies the degree to which any element x in A belongs to the fuzzy set A. Definition (2) associates with each element in A a real number $\mu_A(x)$ in the interval [0,1] which is assigned to x. Larger values of $\mu_A(x)$ indicate higher degrees of membership. In general, the fuzzy set A can be expressed by m discrete values, $\mu_A(x)$ as follows:

$$A = [x_1 \mid \mu_A(x_1), x_2 \mid (x_2), x_3 \mid \mu_A(x_3), \ldots\ldots x_m \mid \mu_A(x_m)] \quad (3)$$

Properties of fuzzy sets are briefly introduced as follows:

A normalized fuzzy set is one that includes at least one element x0 in the universe of discourse that attains the maximum degree of membership, that is $\mu_A(x_0) = 1$; otherwise the fuzzy set is called non-normalized. For example, all fuzzy sets in Figure 1 are normal as they have at least one element x with a degree of membership equal to l.

α -level interval or α -cut, denoted by A_α, is defined as the crisp set of elements x which belong to A at least to the degree α. It gives a threshold that provides a level of confidence α in a decision or concept modelled by a fuzzy set. The threshold may be used to discard from consideration those element x in A with degrees of membership $\mu_A(x_0) < \alpha$. This can be expressed as:

$$A_\alpha = \{x \mid x \in R, \mu_A(x) \geq \alpha\}, x \in [0,1] \quad (4)$$

Operations on fuzzy sets, which are relevant to this research work, include the intersection and union of two or more fuzzy sets. The operations with fuzzy sets A and B in the universe U are introduced via operations on their membership functions $\mu_A(x)$ and $\mu_B(x)$, as follows:

a) Intersection of fuzzy sets A and B denoted as A∩B is defined by

$$\mu_{A \cap B}(x) = \min(\mu_A(x), \mu_B(x)), x \in \mu \quad (5)$$

The intersection of two fuzzy sets is related to the conjunction (logical operator AND) in fuzzy logic. For instance, if a1< a2, min (a1, a2) = a1; this is, min (0.5, 0.7) = 0.5.

b) Union of A and B denoted as $A \cup B$ is defined by:

$$\mu_{A \cap B}(x) = \max(\mu_A(x), \mu_B(x)), x \in \mu \quad (6)$$

The union of two fuzzy sets is related to the logical operation of disjunction (OR) in fuzzy logic. For instance, if a1< a2, max (a1, a2) = a2; that is, max (0.5, 0.7) = 0.7

c) Complementation of the fuzzy set A is $\overline{A}$ if the following condition is true:

$$\mu_{\overline{A}}(x) = 1 - \mu_A(x) \text{ or } \mu_A(x) + \mu_{\overline{A}}(x) = 1 \quad (7)$$

The complement of a fuzzy set is related to the logical operator NOT in fuzzy logic and its membership function $\mu_{\overline{A}}(x)$ is symmetrical $\mu_A(x)$ with respect to $\mu = 0.5$

4. Modelling the Evaluating System

The main features of ISO 9001: 2000 are; process approach to system; process measurement and management; customer satisfaction monitoring; and continual improvement, ISO 9001: 2000 also places a stronger emphasis on the quality management function of the organization as distinct from quality assurance and quality control activities and thus is very clear for the five requirements. The ISO 14000 series consist of five standards: Environmental management systems, environmental auditing, environmental labelling, environmental performance evaluation and life cycle assessment. ISO 14001: 1996, an environmental management standard against which an organization can be audited on a voluntary basis, is applicable to different organizations in diverse geographical, cultural and social conditions. The other standards in the ISO 14000 series provide guidelines which either support the implementation of an EMS or the analysis of product characteristics. None of these other standards need to be implemented. ISO 14001: 1996 provides a structured management system to enable construction firms to achieve benefits that would enhance the organization's image and credibility (Tan et al., 1998). The major elements and requirements of ISO 9001: 2000 are:

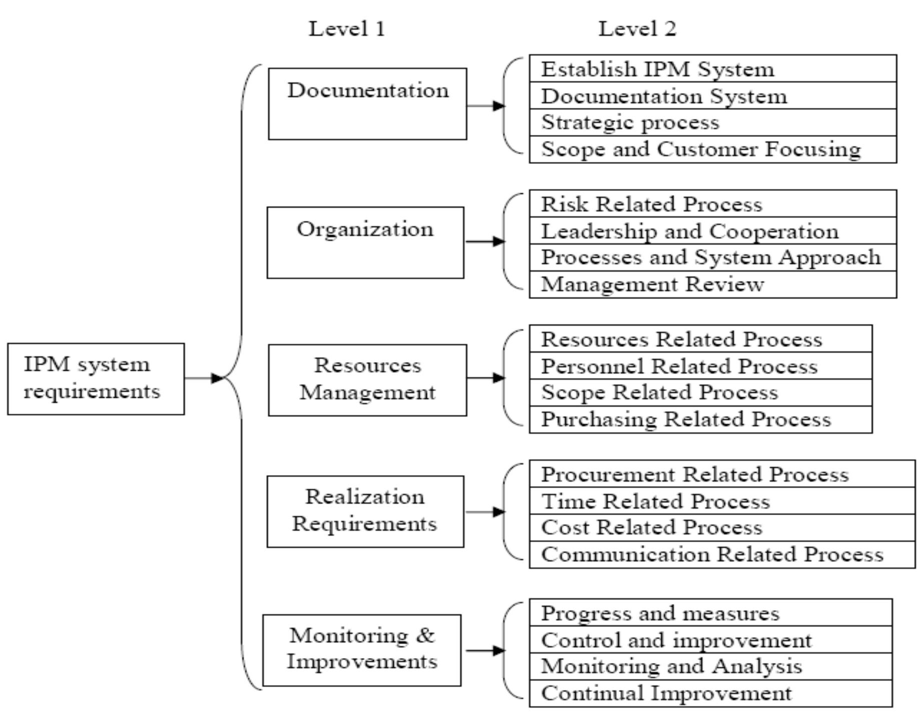
- Quality management system: General requirements and documentation requirements;
- Management responsibility: Management commitment, customer focus, quality policy, planning, responsibility, authority and communication, and management review;
- Resource management: Provision of resources, human resources, infrastructure, and work environment;
- Product realization: Planning of product realization, customer related processes, design and development, purchasing, production and service provision, control of monitoring and measuring devices; and
- Measurement, analysis and improvement: General, monitoring and measurement, control of nonconforming product, analysis of data, and improvement.

The major elements and requirements of ISO 14001: 1996 are:

- Environmental policy.
- Planning.
- Environmental aspects: Legal and other requirements, objectives and targets, and environmental management programs.
- Implementation and operation: Structure and responsibility, training, awareness and competence, communication, EMS documentation, document control, operational control, and emergency preparedness and response; and Checking and corrective action: Monitoring and measurement, non-conformance and corrective and preventive action, records, audit, and management review.

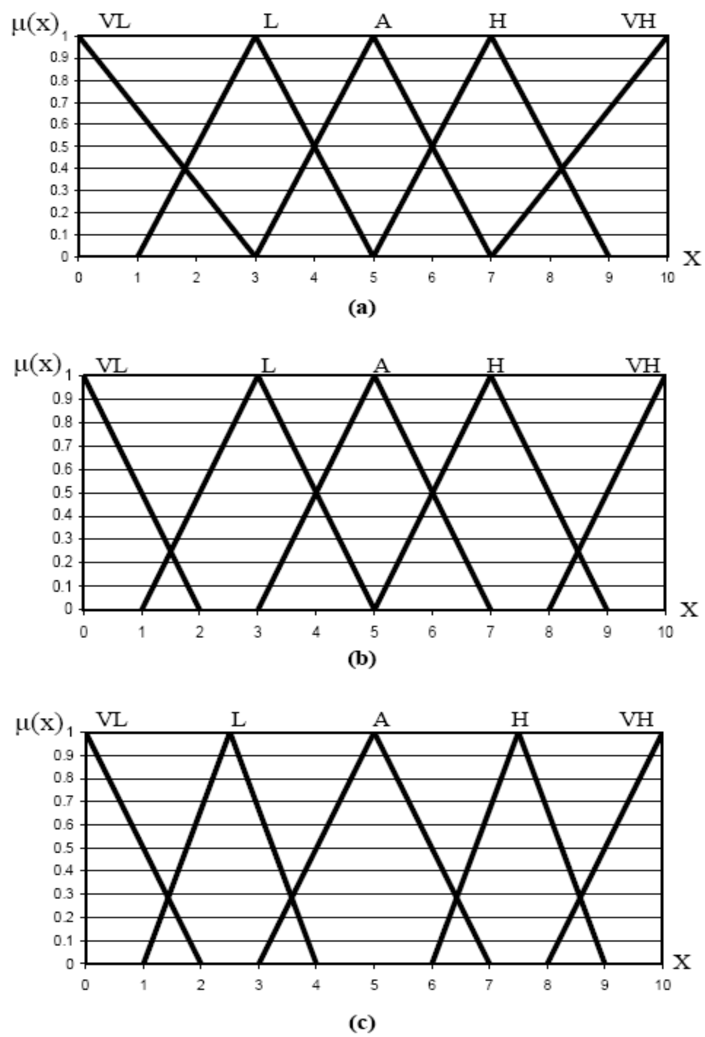
Arising from the five main quality management system requirements, ISO 9001:2000 and the four main requirements of environmental system ISO 14000:1996; the integrated management system have been established to provide a unique document that can be applied for the different goals. The different levels of system articles are shown in Figure 2.

Figure 2: Main and sub-items of IPM system



In order to accommodate the diverse range of expressions and human differences in interpreting the degree to which any system component is available, significance, probability, the availability universe (A), defined as a fuzzy set, has values ranging from zero to one, corresponding to eleven possible values. These values are (very low, low, average, high, and very high). These functions are represented by the translational/triangular models where every linguistic term is represented by isosceles triangles as shown in Figure 3-a, 3-b and 3-c respectively. The first requirement (System setup and documentation) and second one (System management) have been represented by the model in Figure 3-a, which reflect high vagueness degree. The interaction between levels is high due to the high degree of uncertainty for the articles under these two items. Meanwhile; third Items (Resources management) and fourth (Requirement realization), are represented by the second model which have least degree of vagueness, it can seen from the small area of interaction between the five levels of assessment, Figure 3-b. The fifth requirement (monitoring and improvement) has been represented by intermediate scale as shown in Figure 3-c. The three scales of representation (3-a, 3-b, and 3-c) reflect the degree of confidence of the experts with the assessment that can be provided by the project staff or quality assessors.

Figure 3: The three models for represent the IMS system



One of the features of this representation is that the fuzzy set can be simply represented by a numerical interval. For example the fuzzy set ***average (A)*** in Figure (3-a) can be written as:

available = {0.0|0.0, 0.0|1.0, 0.0|2.0, 0.0|3.0, 0.5|4.0, 1.0|5.0, 0.5|6.0, 1.0|7.0, 0.0|8.0, 0.0|9.0, 0.0|10}

Following Equation (3), or simply as available = [3.0, 7.0], which is the base of the isosceles triangle. This feature is a result of the form of the fuzzy set. Since isosceles triangles are used, identifying the location of the triangle's base through a numerical interval is sufficient to draw the complete fuzzy set.

The second variable, significance (S), is also represented by a triangular fuzzy set, and can take values ranging from 0 to 1 (Kashiwagi, 1995). These values are determined by a system expert as discussed earlier. The expert's knowledge and experience linguistically evaluate the importance or significance of every system component to the overall Integrated Management System Performance (IMS). The objective of this representation is to combine the different system components. This combination is necessary to obtain the overall system performance. The overall System performance (QSP) is found using equation (8):

$$Significance \quad of \quad IMS = \frac{\sum(A_i \times S_i)}{\sum S_i} \tag{8}$$

In which IMS = Total Integrated Management System Performance, Ai = individual availability of each system component, and Si = significance of a particular system component. This equation, which is normally referred to as the fuzzy average function, is an aggregation function in which different components are combined to produce a final single result. According to Zadeh's extension principle, the mathematical operations on fuzzy sets should follow a special procedure. The extension principle extends the binary operation (X) of real numbers to fuzzy sets (Caballero et al., 1999). Accordingly, the arithmetic of fuzzy sets can be derived in the following manner:

$$\mu_{(A*B)}(x) = \vee\left[\mu_A(x) \wedge \mu_B(x)\right] \tag{9}$$

Where {*=(+,-,x,/); $\wedge$=minimum, and $\vee$=maximum}.

Thus the multiplying and division operators used in Equation (8) are replaced by their counterparts listed in Equation (9). Note that the fuzzy sets will present by numerical intervals as shown earlier. This representation, although shortened, does in fact carry all the information in the extended form of the fuzzy set representation. The next section illustrates the evaluation method of the different components of the Integrated Management System Performance (IMS) using the different arithmetic of fuzzy sets discussed in this section.

To calculate the component "Establish IPM system", an element of IPM system, one needs to evaluate all the units comprising it (Eq. 10).

$$A_{11\,performance} = \sum(A_{11i} \times S_{11i}) / \sum S_{11i} \tag{10}$$

What should be noted here is that the above equation is a fuzzy composition equation that corresponds to Equation (10).

$$A_{11\,performance} = \frac{\sum\left[\wedge(A_{11i} \times S_{11i}), \vee(A11i \times S_{11i})\right]}{\sum S_{11i}} \tag{11}$$

Where $\wedge$= the minimum, and $\vee$ = the maximum. For Equation (11) A11i corresponds to the different units of the (Establish IPM system) performance (Table 2). Each A11i is a linguistic term that corresponds to the degree to which every unit of the Establish IPM system is available, and S11i corresponds to the significance of the unit to the total Establish IPM system performance. As mentioned earlier, both fuzzy sets are presented by isosceles triangles that are better described using numerical intervals. The database collected from the experience of participants for the significance of requirements and the probability of fail for both the quality and environmental system are presented in Table 1 and 2 respectively.

Table 1: Organization quality system: significance and probability of fail

No.	Sub-Item	Significance			Probability of fail		
		From	To	Avg.	From	To	Avg.
1	Establish IPM System	1.91	5.53	3.72	1.97	5.49	3.73
2	Documentation System	1.01	4.58	2.79	2.80	6.43	4.62
3	Strategic process	3.66	7.39	5.53	3.62	7.30	5.46
4	Scope & Customer Focusing	4.66	8.27	6.46	4.65	8.24	6.44
5	Risk Related Process	1.87	5.47	3.67	4.69	8.30	6.49
6	Leadership and Cooperation	4.63	8.25	6.44	4.53	8.14	6.34
7	Process & System Approach	3.63	7.36	5.49	3.64	7.39	5.52
8	Management Review	1.20	4.79	2.99	1.23	4.75	2.99
9	Resources Related Process	6.99	9.47	8.23	6.26	8.89	7.57
10	Personnel Related Process	6.20	8.86	7.53	7.15	9.54	8.35
11	Scope Related Process	1.64	4.30	2.97	1.43	4.08	2.76
12	Purchasing Related Process	4.66	7.80	6.23	4.77	7.81	6.29
13	Procurement Related Process	6.33	9.05	7.69	4.90	7.88	6.39
14	Time Related Process	4.71	7.63	6.17	6.23	8.88	7.55
15	Cost Related Process	7.59	9.79	8.69	7.24	9.59	8.41
16	Communication Related Process	2.97	5.85	4.41	3.32	6.19	4.75
17	Progress and measures	5.27	8.11	6.69	4.59	7.76	6.18
18	Control and improvement	4.47	7.67	6.07	4.13	7.39	5.76
19	Monitoring and Analysis	4.78	8.31	6.55	5.32	8.39	6.86
20	Continual Improvement	3.93	7.10	5.52	3.78	7.00	5.39

Table 2: Environmental system: significance and probability of fail

No.	Sub-Item	significance			Probability of fail		
		From	To	Avg.	From	To	Avg.
1	Establish IPM System	1.21	4.84	3.02	1.16	4.71	2.94
2	Documentation System	1.34	4.98	3.16	1.89	5.44	3.66
3	Strategic process	2.85	6.69	4.77	2.96	6.61	4.78
4	Scope & Customer Focusing	2.35	6.05	4.20	1.46	5.06	3.26
5	Risk Related Process	4.31	8.00	6.15	1.64	5.33	3.48
6	Leadership and Cooperation	4.47	8.11	6.29	1.16	4.71	2.94
7	Process & System Approach	1.76	5.42	3.59	1.02	4.55	2.78
8	Management Review	1.16	4.88	3.02	0.68	4.05	2.37
9	Resources Related Process	6.03	8.78	7.41	6.65	9.27	7.96
10	Personnel Related Process	6.08	8.87	7.47	5.66	8.34	7.00
11	Scope Related Process	3.49	6.62	5.06	2.34	5.55	3.94
12	Purchasing Related Process	6.44	9.07	7.76	5.29	7.94	6.61
13	Procurement Related Process	6.38	9.02	7.70	7.75	9.88	8.81
14	Time Related Process	7.22	9.60	8.41	7.42	9.67	8.55
15	Cost Related Process	7.42	9.71	8.57	7.57	9.78	8.68
16	Communication Related Process	5.72	8.65	7.19	5.37	8.00	6.69
17	Progress and measures	4.91	8.27	6.59	2.73	6.32	4.53
18	Control and improvement	6.04	9.20	7.62	5.87	8.96	7.41
19	Monitoring and Analysis	4.33	7.48	5.91	1.91	5.21	3.56
20	Continual Improvement	4.00	7.32	5.66	2.05	5.39	3.72

An example for the calculations of the quality performance assessment for resources management article was presented in Table 3. The fourth column of the table lists the values of multiplying Availability (Ai) by Related Significance (Si), which represents the numerical interval that corresponds to the minimum and maximum.

Table 3: The integrated management system: resources management calculation

Resources Management	**Significance Si**		**Availability Ai**		**Ai×Si**	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**
Resources Related Process	6.03	8.78	3.21	5.30	19.36	46.53
Personnel Related Process	6.08	8.87	2.44	4.65	14.84	41.25
Scope Related Process	3.49	6.62	5.45	8.24	19.02	54.55
Purchasing Related Process	6.44	9.07	6.22	8.86	40.06	80.36
Σ Si	22.04	33.34	Σ (Ai×Si)		93.27	222.69

The overall performance for this element is calculated using Equation (10):

$$A_{11\,performance} = \sum \frac{(A_{11i} \times S_{11i})}{\sum S_{11i}} = \frac{(93.27,222.69)}{(22.04,33.34)} = (4.23,6.68)$$

The interpretation of this numerical interval can easily be done by imposing the isosceles triangle, whose base corresponds to it on the membership values graph in Figure 4. This process yields one component performance between Average and High but it near to Average.

Figure 4: Membership graph for resources management

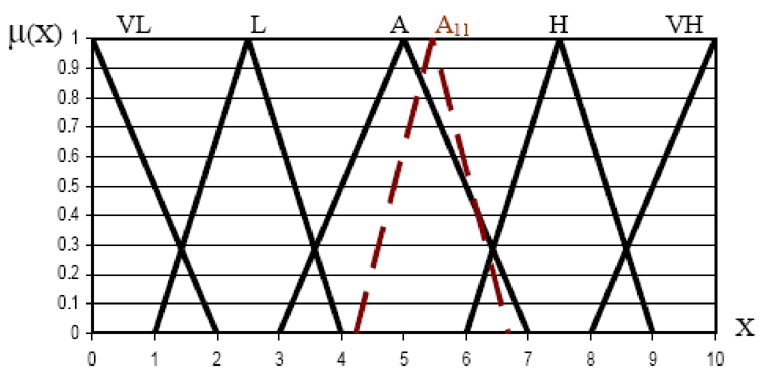
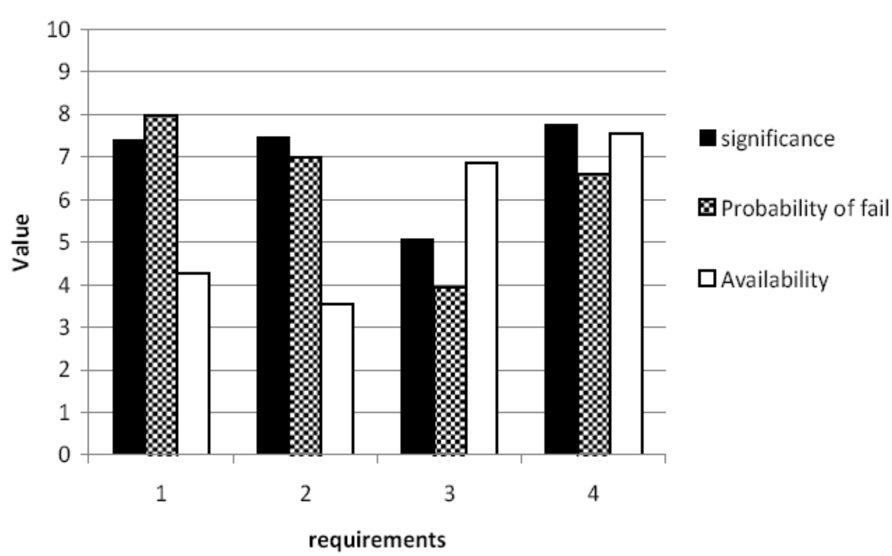


Figure 5: Significance, availability and probability of fail for resources management elements



From Figure 5 the correlation between the probability of risk setup by the experts and the shortage of availability of the IMS requirements can conclude. On the other hand, the relation between the degree of significance and the availability of the requirements can be examined for each article and for the whole system.

5. Summary, Concluding Remarks and Recommendations

The outcome of this research provides contributions in several areas. At a global level, this research work has developed a unique methodology for modelling project quality performance integrating with the environmental requirements in construction projects. The knowledge and experiences have been modelled using fuzzy set theory for a powerful analysis technique. The following are significant aspects of the contributions of the integration process achieved in this research:

- Identifying the significance and fail probability for all items within the IMS system, and explain the most significance and the critical fail probability are for the system.
- Provide a mathematical approach; using fuzzy logic, to model the system and to create a numerical assessment approach that reduce the vagueness of using the linguistic term in the qualitative assessment up today.
- Mitigate waste of resources, duplication of documentation and confusion of priorities due to having two or more isolated management systems within an organization while still satisfying the stakeholders' needs.
- Possible reduction in audit fees as well as administrative costs of implementation and maintenance compared with isolated systems.
- Potential to be modified to address new requirements within the same system.
- A way to achieve "world class" status or to build into the success of organizations' current systems.
- Improvement of understanding and use of the system by everyone within the organization
- Provides direction and structures for the business to achieve standards in optimum costs.
- Provides a strong foundation towards a learning organization through the implementation of two or more management systems and their integration, regardless of the final level or extent of the resulting integrated system.

It is recommended, for further development, to study the potential risks resulting from the integration process itself, also, how to counterbalance the effect of these risks on the final performance. However, an organization should decide what is the best for them before embarking in such an endeavour. The IMS Scope, level of integration, use of resources and timeframe for implementation are aspects an organization should decide based on its particular conditions of size, type, market, technology required and management experience. Expert system Utilizing the mathematical approach of this research is also recommended to ease the application of such system in the site.

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