KSCE Journal of Civil Engineering (2018) 22(11):4205-4214

DOI 10.1007/s12205-018-0439-2

Construction Management

pISSN 1226-7988, eISSN 1976-3808
www.springer.com/12205

Development of an Expert System Tool for the Selection of Procurement System in Large-Scale Construction Projects (ESCONPROCS)

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Received April 3, 2017/Revised December 6, 2017/Accepted March 11, 2018/Published Online June 30, 2018

Abstract

The human knowledge of a specific domain is dissipated either in books and journals or exists in the minds of few human experts. Expert system technology, which is of late becoming an important tool, uses the power of the human brain to store knowledge electronically so that information regarding decision-making can easily be accessed at anywhere and at any time. More often than not most decisions in the industry are based on just subjective decisions. But since each project is different from the other, there is the need to integrate heuristic approach in other to arrive at better decisions. Therefore the system, ESCONPROCS (Expert system for construction procurement selection) which is an expert system tool was developed based on extensive literature review of the available procurement systems as well as clients' priorities and other external factors that influence the selection of an appropriate procurement system. An expert survey was conducted and their responses were used to provide a recommendation for the rules. The system, ESCONPROCS is developed to assist decision-maker (client) reaches a more informed decision on procurement system selection and contracting.

Keywords: *procurement system, large-scale construction projects, expert system, client*

1. Introduction

The construction industry is one of the lynchpins that contribute to the economy of many countries. But the industry is becoming more challenging as the project type gets larger and complex. Large-scale construction projects (LSCP) are a feat of human multitasking. Projects of this kind are applied by complicated modalities and procedures that posses many different futures such as the enormous amount of financial investment, long project duration, and a lot of project participants, and wide construction scale. Studies on the performance of the construction industry like the one by (Latham, 1994) pointed to some key improvement areas, one of which is the use of a viable procurement system. Procurement system is a key factor in enabling successful implementation of a building project (Lahdenpera, 2015). The author continued to point out that the right delivery method chosen may help avoid problems and be key to the attainment of project-specific goals. It is also claimed that the correct choice of a project delivery system leads to the success of a building project (Chan, 2000). Because of its impact on project success, procurement system has gained much attention from the practitioners in the construction industry (Chang and Ive, 2002). Various models and fuzzy based models have been developed to assist decision making in the selection process (Alhazmi and McCaffer, 2000; Cheung *et al*., 2001; Chang and Ive, 2002; Chan, 2007).

Despite the tremendous work done by many researchers and the fact that these models provide some useful approach to improving the procurement system selection decision, they have failed to address the actual and practical need of clients. There is no useful mechanism in place to help clients to interact with computer systems which can assist them to gain some knowledge in the domain subject as they get physical interaction with the system and as such help them to make initial decisions on their own.

The purpose of this study is to develop an expert system tool for procurement system selection for large-scale construction projects (ESCONPROCS) to assist decision-maker (client) gain some knowledge and reaches a more informed decision on procurement system selection.

For this study, an extensive literature review was conducted to identify the factors affecting the selection of a procurement system. Factors identified by different studies were screened and compared. 23 factors were selected and base on these the authors then designed heuristic IF/AND/THEN decision rules and where an appropriate procurement system was recommended for each rule. These rules were used to develop an expert system tool. However, a survey was conducted to extract knowledge from human experts and the recommended procurement systems provided were compared with the recommendations provided by the developed system to find any mismatching rules. This knowledge from the human experts was then used to revise the

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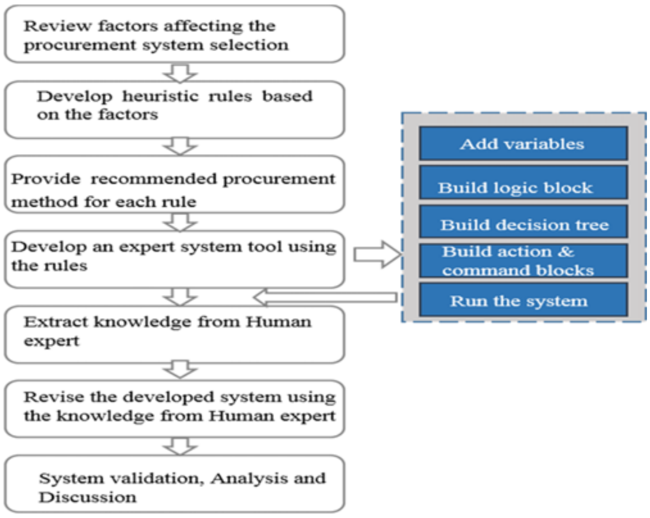

Fig. 1. The Research Process

system. A second survey was designed for the revised system and experts were required to confirm if the recommended procurement system assigned for each rule is Yes or No. The results were used to analyze and validate the system. Fig. 1 summarizes the research process. Variables were added to the inference engine of the system and logic blocks were used to build the statements in the form of simple rules.

With regard to selecting a viable procurement systems, several studies have been conducted extensively where different models and systems have been developed over the last decade. All these systems have attempted to identify clients' requirements and provide a mechanism to help choose an appropriate procurement system. Ratnasabapathy and Rameezdeen (2007) developed a decision support system for the selection of best procurement system in construction based on multi-attribute utility technique. However, the authors only considered 19 selected criteria in developing their model and a specific type of project for which the model was designed for was not explained. Cheung *et al.* (2001) developed a model for procurement selection method using analytical hierarchy process. Based on their findings, design-bid-build was identified as the best procurement path. Alhazmi and McCaffer (2000) developed a procurement selection system called the Project Procurement System Selection Model (PPSSM). This model consists of four screening levels in the selection process: (1) feasibility ranking; (2) evaluation by comparison; (3) weighted evaluation; and (4) Analytic Hierarchy Process (AHP). Through this approach, the most suitable procurement system could be selected. However, the authors failed to provide detail explanation on the criteria for selection. Chan (2007) on the other hand developed a mathematical rank model called the Fuzzy Procurement Selection Model (FAPSM). The author criticized previous models using criteria weights for decision making and therefore incorporated fuzzy approach to overcome the existing continental arguments on establishing a set of universal criteria on procurement selection.

In predicting an appropriate project delivery system for a target project, Chen *et al*. (2011) developed a Project Delivery System (PDS) selection model and compared with a developed ANN model. The results showed that the PDS model has a higher reliability than the ANN model in selecting a project delivery system for a particular project. Love *et al.* (1998) state that the use of multi-attribute decision analysis (MADA) in a procurement selection system has been seen as the foremost technique for examining client needs and for weighting the preferences from experts or each procurement system in the most objective way available. The MADA approach utilizes a score or utility factor,

Table 1. Review of Previous Studies on Procurement System Selection Approach

Author	Contents
Ratnasabapathy and Rameezdeen (2007)	A Decision Support System for the Selection of Best Procurement System in Construction based on Multi-attribute utility technique
Cheung *et al*., (2001)	A procurement selection model based on multi-attribute utility technology with the use of Analytical Hierarchy Process (AHP) to determine the importance weightings of the selection criteria based on client requirements.
Alhazmi and McCaffer (2000)	A project procurement system selection model which is an integration of Parker's judging alternative technique of value engineering and Analytical Hierarchy Process (AHP)
Chan (2007)	A mathematical rank model that incorporated fuzzy relations and researchers ideas on the assigning of weight of procurement selection criteria
Chen *et al*. (2011)	A project delivery system (PDS) selection model developed to predict an appropriate project delivery system for a target project
Love *et al*. (1998)	A procurement path decision chart, which allows clients to weight a simple set of criteria based on clients' requirements multiplied by set utility ratings for the various systems
Chan *et al,* (2001)	A multi-attribute model, which allows clients to weight a set of exclusive criteria multiplied by set utility ratings for limited number of procurement systems
Tucker and Ambrose (1999)	A three-dimensional interaction matrix that provides a procedure to evaluate the appropriateness of a procurement system for a particular project and the needs of the client.
Dell'Isola *et al*. (1998)	Decision matrix-based model that rates the performance of each procurement system for selected issues and its relative importance on a client/project profile.
Bennett and Grice (1990)	System based on the NEDO and Skitmore and Marsden models and allows clients to weight specific criteria multiplied by set utility ratings for the various systems

which is determined by industry experts for each criterion (client need, project characteristic, risk allocation, etc.) for each procurement system. However, Chan *et al*. (2001) seconded the view that there is no mutually exclusive set of criteria that uniquely and completely determine the appropriate procurement method for a specific project. The authors, therefore, conducted an improved study on multi-attribute approach by using an application of Delphi method to develop a multi-attribute model for selection of procurement systems for construction projects. The following Table 1, summarizes the review of previous studies on procurement system selection approach and their basic methodology developed over the last decade.

2. Procurement System in Construction

The term procurement system (also called delivery system) is defined in various ways by different scholars. It is huge in scope in that it postulates the gathering and assembling of countless separate individuals, firms and companies to design manage and construct construction projects such as office buildings, bridges, roads and railways, house etc. for clients (Rashid *et al*., 2006). Masterman (2002) defines procurement system as *an organizational structure adopted by the client for the implementation and at times the eventual operation of a project.* Alhazmi1 & McCaffer, (2000) were of the view that, the selection of an appropriate procurement method could cut down construction project costs by 5% approximately. Yet the selection of procurement systems has become more complex, mainly due to the introduction of new variations of procuring systems for delivering building projects (Ratnasabapathy and Rameezdeen, 2007).

2.1 Categorization of Procurement System

There are different methods of construction procurement. However, Masterman (2002); Bennett (2003) both put project procurement systems into categories depending on the contractual relationships between the various parties involved. They categorized various construction procurement systems into (1) Separated and Cooperative Systems (2) Integrated System (3) Management Orientated System. The separation of the design work from the construction is the main characteristic of this method (Masterman, 2002). This method is often referred to as the traditional approach or design-bid-build of procuring construction projects where tender documents are prepared first before contractors are invited to tender (Davis *et al.*, 2008). With the use of integrated procurement systems, design and build are said to be overlapped and this can improve the communication between the client and contractor (Masterman (2010). The management-oriented system is described as a *system that gives greater emphasis to the management and integration of the design and construction of projects. Under this system, the management of the design and construction a project is contracted out to a contractor who acts as a management consultant on behalf of the client* (Rashid *et al*., 2006). The construction management firm may also act as a complete contractor to take up the project. However, in their research report, Casey and Bamford (2014) identified 8 different project delivery routes that could be used to deliver projects as: (1) Construct only (2) D&C, plus variants (3) Managing contractor (4) Construction management (5) Direct managed (6) ECI (7) Alliance and (8) PPP. PPP is a partnership between the public (Government) and the private sector where private investors use private finances or resources to provide public infrastructures.

2.2 Review of the Factors Influencing the Selection of a Procurement System

Several studies have been conducted to identify the possible factors that influence the decision of selecting a viable procurement

Table 2. Review of Factors Influencing Procurement System Selection

Author	Factors influencing the selection of Procurement Systems
Husseini *et al.* (2016)	Flexibility, technology availability, risk allocation, owner want to be involved, contractor's capability, owner's available resources, political impact, life cycle cost
Qiang *et al*. (2015)	Project size, Client's management ability, Client's business culture, Contractors ability, Price competition, Quality performance, Flexible to changes, Schedule performance, Cost, Risk control, Financing ability, project location, policy regulation
Luu *et al*. (2005)	Owner's requirement for maintenance cost, owner's requirement for aesthetic building, risk allocation, owner's in-house technical capability, owner's type
Jimoh *et al.* (2011)	Cost certainty, Time certainty, Level of project quality, no casualties recorded to complete a project, Frequency of conflicts/disputes and arbitration
Liu *et al*. (2016)	Responsibility, The owner's willingness to be involved, The owner's in-house technical capability, Risk allocation, The owner's willingness to control overdesign
Davis *et al*. (2008)	Location of project, project size, project complexity, ability to make changes, client's knowledge, experience of the organization, time, cost, external factors, buildability
Sawalhi and Agha (2017)	Price competition, project complexity, time constraint, project size, client's experience in procurement methods, risk allocation, project type and nature, availability of procurement system in the locality, procurement staff, client's financial capability
Oyo and Gbadebo (2012)	Price certainty, number of competitors, client’s familiarity, political interference, government directive, risk allocation, controllable variables, funding structure, completion time, complexity of project
Mathonsi and Thwala (2012)	Client's level of knowledge, globalization, political influence, risk allocation, size & complexity of project, government policies, time constraint, funding arrangement, unemployment, lack of resources

system for a specific project. In their quest to identify the possible factors governing the construction project delivery selection, Qiang *et al*. (2015) conducted a study of content analysis on Chinese and developed countries' literature. In their study, about 25 factors were identified to be the factors governing project delivery. Jimoh *et al*. (2016) reviewed the existing procurement system practice in Nigeria and found out the factors affecting their selection. The results of their study showed that cost, quality, and duration of the projects are the most critical criteria considered. More studies conducted previously have all tried to identify the possible factors influencing the selection of a procurement system for a specific project. Table 2 summarizes the review of some of the factors influencing the selection of procurement systems.

2.3 Procurement System Selection Process

With regard to construction procurement systems, clients make decisions prior to choosing an appropriate procurement method for a construction project. Identifying, comparing alternatives and choosing a viable one among alternatives is an act of making a decision. With regard to procurement system selection, once the choice has been made and implemented, it is improbable to alter it practically as an attempt to effect change could be too pricey and will result in delays in the project. For this reason, Casey and Bamford (2014) provides the steps in the procurement method development process. Fig. 2 depicts the key steps involved in procurement method development process

3. Expert systems

3.1 Architecture of Expert System

An expert system is used in different fields in providing information to users. It is defined as an interactive computer-based tool that uses both facts and heuristics ("rules of thumb") based on knowledge acquired from an expert to provide advice or make decisions on problems falling within a specific domain. From the definition, it can be said that expert system operates as an interactive system that responds to questions, asks for clarification, makes recommendations and then generally helps to facilitate the decision-making process. The component of the

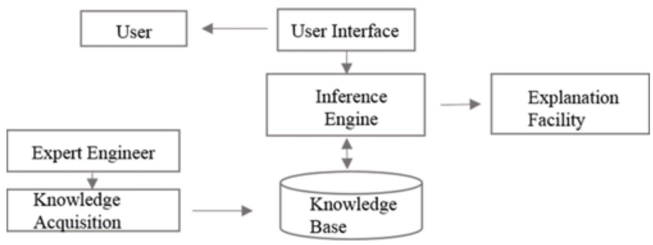

Fig. 3. Architecture of Expert System

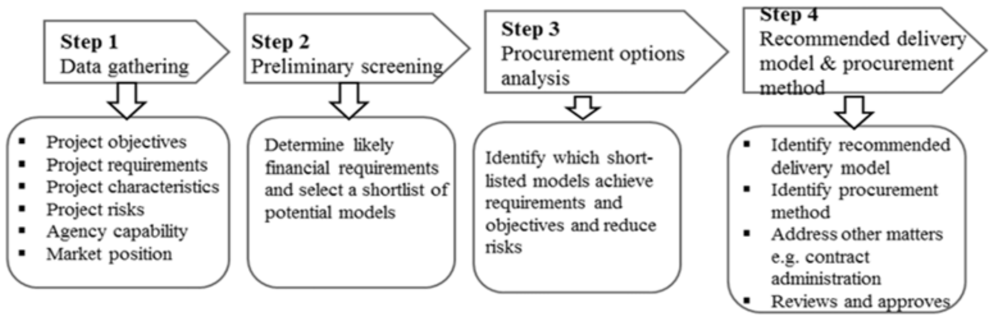

Fig. 2. Key steps in Procurement Method Development Process: Based on Infrastructure Casey and Bamford (2014)

Table 3. Review of Some Expert System Applications in the Construction Industry

Author	Application name	Content
Mosehi (1990)	*ESCHEDULER*	An expert system for planning and scheduling construction projects
Yates (1993)	*DAS*	A delay analysis system developed as a knowledge-based system for decision support in the process of construction delay analysis
Kaetzel and Clifton (1995)	*BETVAL*	A rule-based expert system developed to help the construction site staff to select the type of fresh concrete order from the ready-mix concrete plant
Abdullahi *et al*. (2008)	*COMIX*	A rule and framed based expert system which provides suggestions on the design of normal weight concrete mixes
Ireland (1990)	*PREDICTE*	An expert system that provides project duration estimates during the preliminary phases of project development
Diekmann and Gjertsen	*SEA*	A system developed for contract claims which help determine claim types that could flow from one unusual event occurring at a construction site
Ismail *et al*. (2009)	*ESPEAR*	A knowledge-based system developed for pavement evaluation and rehabilitation
Saoud (1996)	*BIDEX*	A rule-based expert system which gives suggestions on the design of bid decisions
Kartam *et al*. (1991)	*SIPE*	An expert system developed to generate project network information
Diekmann and Kim (1992)	*SUPERCHANGE*	A system for the analysis of change order claims for construction works

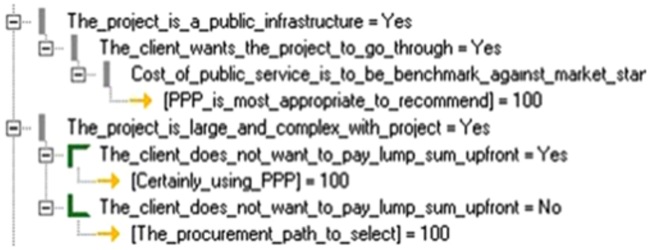

Fig. 4. Building the Decision Tree of the System

expert system consists of the user interface which takes the user through series of questions and could also query the system. The knowledge base consists of information on facts and rules which are stored. The inference engine, on the other hand, acts like a search engine which provides an output based on the query from the user. Fig. 3 summarizes the architecture of an expert system.

3.2 Review of Existing Expert System Applications in the Construction Industry

There are numerous existing expert system applications in the construction industry. Yates (1993) developed a knowledge-based system called DAS (Delay Analysis System) for decision support in the process of construction delay analysis. The system is capable of determining possible causes of project delays and suggests alternative causes of action to prevent further delays. Fig. 4. summarizes some of the existing expert system applications.

4. Developing the Expert System Tool

4.1 Methodology

Decisions are said to be continues but not in the case when it comes to selecting an appropriate procurement system for a particular project. Once the method is chosen and implemented it cannot be reversed. For this reason, decision-makers tend to seek the advice of human experts in a field domain in arriving at a better decision. However, due to the unavailability of human experts at all time and everywhere and considering how expensive to acquire them, the use of expert system becomes necessary. The development of the system, ESCONPROCS, involved 3 stages:

Stage1: Based on the reviewed factors governing the selection of procurement system and by comparing to sort out the most common ones among all, questions in the form of rules were designed and a viable procurement route was recommended for each rule and were used to develop a rule-based expert system tool.

Stage 2: Using the designed rules, the expert survey was conducted to extract human expert knowledge and the recommended procurement methods provided were used to revise the system.

Stage 3: A second expert survey was then conducted to validate the revised system. This was done by asking the experts to confirm if the recommended procurement methods provided for each rule as Yes or No.

In stage 3, the survey was conducted for the human experts in Korea only. However, in stage 2 the survey covered experts from 3 countries: Turkey, Ghana, and Korea. In designing the rules, reference was made to the study conducted by McGartland and Hendrickson (1985) on Expert System for Construction Project Monitoring developed as a knowledge-based expert system. For rule-based systems, the knowledge is represented in the form of IF [condition] THEN [action] rules. Rules may be in the form situation/action, premise/conclusion or antecedent/consequence relationships. Example:

IF: labor demand for the project week is less than 0.75 times the project's average labor demand

THEN: labor demand for that project week is low.

The system, ESCONPROCS was built using Exsys (an expert system shell) based on the designed rules. The procurement systems considered in the module include Public-Private Partnership (PPP), Design-Build (DB), Construction Management (CM) and Traditional method (Design-Bid-Build, DBB. The rules statements were added as variables with static values as *yes* and *no* in the knowledge base of the system and built as logic blocks. These variables were then built as decision trees to represent decision paths. In building the action blocks, the IF (condition) and THEN (action) parts were structurally represented before proceeding to build the command blocks. The system could then be run to see the recommended actions of appropriate procurement system for each rule in order appeared in the decision tree. Fig.4 depicts building the decision tree and the recommended procurement method assigned to each Rule.

4.2 Revising the System

In other to revise the system, a survey was conducted that included experts from Turkey, Ghana, and Korea. There were a total of 46 responses received of which 1 was invalid (45valid). However, to determine the consistency and the reliability of the rules, a reliability analysis was conducted using SPSS. From Table 4, the Cronbach's alpha value of 0.809 is greater than the acceptable alpha value of 0.7, suggesting that the Rules have a higher internal consistency and reliable to be used.

The KMO scale shown in Table 5 indicates the degree of explanation of the correlation between variable pairs. A small value would indicate that the selection of variables for factor analysis is not appropriate. The value of KMO is 0.496; less than

Table 4. Reliability Analysis

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.809	0.822	20

Table 5. Kaiser-Meyer-Olkin (KMO) and Bartlett's Test

KMO measure of sampling adequacy		0.496
Bartlett's forming sphere numerical	Chi-square approximation	338.616
	Bartlett's forming sphere numerical degrees of freedom	190
	Bartlett's forming sphere numerical heed probability	0.000

the average of 0.5. Therefore further analysis was not conducted. However, Bartlett's Test of Sphericity with a significance value of 0.000 which is less than the accepted 0.05 suggesting that this significance value is very small to reject the null hypothesis.

The relative frequency of the recommended procurement methods from the respondents was calculated for each Rule. Fig. 4 shows the relative frequency of the total outcome of the procurement choices from R10-R29. Out of the 20 questions, PPP accounted for 9 Rules (R11, R14, R16, R17, R18, R21, R23, R24, and R29). DB was preferable to 7 Rules (R10, R12, R13, R19, R26,

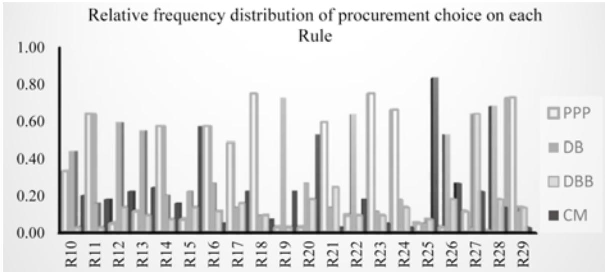

Fig. 5. Relative Frequency Distribution of Procurement Choice on Each Rule

Table 6. The Representative Rules for Procurement System Selection

Rule	Description
RULE010	IF: The client wants to achieve value for money through risk transfer and efficient allocation AND harnessing private sector expertise at the same time is what he/she wants THEN: Selecting DB is the most appropriate procurement path
RULE011	IF: To improve the sustainability of public services is a concern of the client AND the client wants to protect its fiscal position from unexpected shocks THEN: PPP is recommendable to use as the delivery method
RULE012	IF: The project to be built is an infrastructure project AND the client wants faster project completion at high quality and reduced delays THEN: DB is recommended
RULE013	IF: The project is large with duration of 3-5years AND the client wishes to finance the project without being involved in the project AND provide the end result meets the performance criteria is what he desires THEN: DB is recommended
RULE014	IF: The client Wishes to transfer operational & project execution risks totally to private sector AND achieving win-win situation is what he/she is looking for THEN: PPP is recommendable
RULE015	IF: The project is large and complex AND the client financing the project wishes to use experience construction knowledge to a successful project irrespective of the imminent high cost THEN: CM at risk is recommended
RULE016	IF: The project is technically advanced and highly complex AND the client has limited resources to start & complete the project but who desires to build & own the facility at the same time THEN: PPP is recommended to consider
RULE017	IF: The project is a public infrastructure project AND: The client wants the project to go through competitive pricing process AND: Cost of public service is to be benchmark against market standard THEN: PPP is recommended to consider
RULE018	IF: The project is large and complex with project cost over $500m AND the client does not want to pay lump sum upfront for the new project but wishes to pay annual fee to the private consortium THEN: PPP is recommended to consider
RULE019	IF: The project is large and complex in nature AND the client has the resources to fund the project AND the time constraint is tight THEN: DB is preferable to consider
RULE020	IF: The project is large and complex with many inherent risks AND the client wishes to procure the project with his own resources AND does not want to assume risk by not being involved in the day-to-day decision THEN: CM at risk is the recommended procurement route to consider
RULE021	IF: The client wishes to redirect limited funds to another important socio-economic sector AND while there is the need to provide and own an infrastructure project THEN: PPP is recommendable to use as the delivery method
RULE022	IF: Client who wishes to finance the project through its own resources AND who wishes to have a definite completion date & cost certainty before project starts THEN: DB is the most viable method to use
RULE023	IF: The client desires to improve public accountability through transferring service delivery risk to the private party AND has no or limited capital to finance the project but the need to provide necessary public infrastructure THEN: PPP is recommendable to use as the delivery method
RULE024	IF: The project is large and complex AND the cost is above $500m with over 2,500,000m2 AND the client wants the facility to be built with long-term benefits THEN: PPP is recommended to consider

Table 6. (continued)

Rule	Description
RULE025	IF: High-quality project at the expense of cost is what the client wishes to have AND want to be involved in the project's decision to apply construction management experience and knowledge and wants to assume risk THEN: CM at risk is the recommended procurement route to consider
RULE026	IF: The project to be built is large and complex AND the client wants to have the right for liquidated damages for delays and performance THEN: DB is the most viable method to use
RULE027	IF: The project under consideration is a public infrastructure project AND: The client has available budget to finance the project AND: The client wishes to be involved in the day-to-day running of the project and share project risk AND: Early completion is not much important to the client THEN: DBB with lump sum contract is the recommended procurement route to consider
RULE028	IF: The project is large and complex AND the client requires early completion of expected budget AND reducing claims and change order from contractor is what he/she wants THEN: DB is recommended
RULE029	IF: The project the project to be built by the client is large and complex AND client wants to increase and provide greater infrastructural solutions without any cost to the public purse THEN: PPP is recommended to consider

Table 7. Comparing the Recommended Procurement System Provided by the Proposed System and the Human Expert

Rules	Proposed system recommendation	Human Expert recommendation	Rules	Proposed system recommendation	Human Expert recommendation
R10	PPP ●	DB	R20	CM	CM
R11	PPP	PPP	R21	DBB ●	PPP
R12	PPP ●	DB	R22	DB	DB
R13	DB	DB	R23	PPP	PPP
R14	PPP	PPP	R24	PPP	PPP
R15	CM	CM	R25	CM	CM
R16	PPP	PPP	R26	DB	DB
R17	PPP	PPP	R27	DBB	DBB
R18	PPP	PPP	R28	DB	DB
R19	DB	DB	R29	PPP	PPP

and R28). DBB was the preferred choice for just Rule 27 while CM was accounted for 3 Rules (R15, R20, and R25) respectively. From the survey, 63% represents those who have been in the construction and engineering industry between 10-30 years, whereas 22% have been working over 30 years and just 15% of them with 10 years.

The Rules sent out as survey questionnaires for expert's recommendation are summarized below. Knowledge Base KB – RULES.

There are a total number of 20 knowledge-based rules considered by the system.

The recommendations provided by these human experts were tabulated and compared with what the authors had developed and recommended. By comparing, there were 3 wrong recommendations from the proposed expert system. Recommended procurement systems for Rules R10 (PPP), R12 (PPP) and R21 (DBB) did not match with the chosen procurement systems from these human experts (DB, DB, and PPP) respectively. However, the responses were further analyzed by calculating the selection weights of each procurement method chosen for the individual rules. Table 8 summarizes the comparison of the proposed system's recommendation and Human experts' recommendation.

Table 8. Selection Weights of the Procurement Methods

Selection weights									
Procurement paths					Procurement paths				
Rules	PPP	DB	CM	DBB	Rules	PPP	DB	CM	DBB
R10	1.33	**1.78**	0.8	0.09	R20	0.09	1.07	2.13	0.71
R11	**2.58**	0.62	0.71	0.09	R21	**2.4**	0.53	0.09	0.98
R12	0.18	**2.4**	0..89	0.53	R22	0.35	**2.58**	0.71	0.35
R13	0.44	**2.22**	0.98	0.35	R23	**3.02**	0.44	0.18	0.35
R14	**2.3**	0.8	0.62	0.27	R24	**2.7**	0.71	0.09	0.53
R15	0.27	0.89	**2.3**	0.53	R25	0.18	0.18	3.38	0.27
R16	2.31	1.07	0.18	0.44	R26	0.09	**2.13**	1.07	0.71
R17	**1.96**	0.53	0.89	0.62	R27	0.44	0.09	0.89	**2.58**
R18	**3.02**	0.35	0.27	0.35	R28	0.0	2.76	0.53	0.71
R19	0.09	**2.93**	0.89	0.09	R29	**2.9**	0.44	0.09	0.53

The calculation of the selection weights was done by dividing the number of responses of each procurement method under each rule by the total number of responses (45) and multiplied by the number of procurement options (4) available. Hence procurement paths with

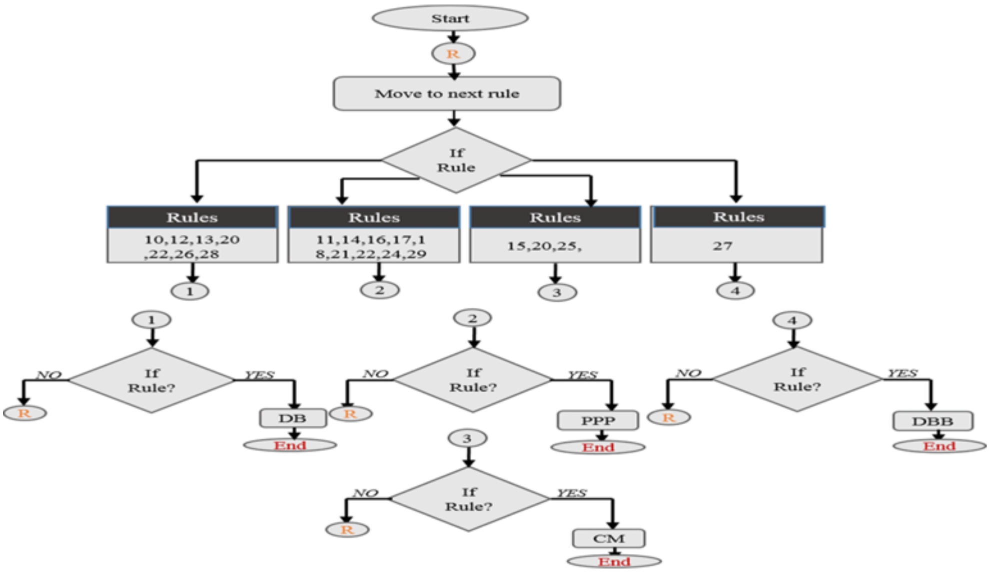

Fig. 6. Flowchart of Selecting a Viable Procurement System

highest weights were chosen as the ideal recommendations and were therefore used to revise the system. PPP appears to be the dominant procurement path recommended to be used on large-scale projects based on client's criteria specified in the designed Rules. Table 8 represents the weights of the procurement methods for each rule.

4.3 Grouping and Linking the Individual Rules

The problem of selecting a viable procurement system was broken down into simple and understandable IF/THEN rules in the logic block. The system on which ESCONPROCS was built provides THEN action (recommended procurement method) to each IF condition. However, a single IF condition rule cannot be used as a yardstick to select a viable procurement system. And since there are different individual rules in the system, each with its THEN action, it is appropriate to group and link the rules having the same THEN actions to form IF/AND/IF rules so that the type of procurement system that possesses the characteristics of these rules is selected. Fig. 8 represents the flowchart of how the individual rules in the system are grouped and linked. If all the rules in ports 1, 2, 3, and 4 are *yes* then DB, PPP, CM and DBB are selected respectively in order and the process ends. However, if the recommended procurement choice is *no* for each rule in the ports, then go back to R and move to the next rule

4.4 System Validation, Analysis, and Discussion

The proposed system was revised and built with the recommended procurement methods. However, these recommendations needed to be reconfirmed as appropriate or not appropriate. Therefore a second expert survey was conducted which targeted only experts with enough knowledge in construction projects and with experience over 7 years. The survey was designed for experts to confirm if the procurement methods used as recommended paths for each Rule was appropriate (yes) or inappropriate (no).

Total received responses = 36 and experience below 7 years = 5. Therefore 31 responses were used to analyze the data. The results of the survey were analyzed against the revised expert system's recommendation and summarized in Table 9.

The percentage weights were determined for each procurement method by dividing the outcome for that procurement path by the

Table 9. Confirmation of the Recommended Procurement Methods

Rules	Expert system's recommendation	Expert's confirmation	Outcome	% outcome	Rules	Expert system's recommendation	Expert's confirmation	Outcome	% outcome
R10	DB	Yes	27	87%	R20	CM	No	17	55%
R11	PPP	Yes	26	84%	R21	PPP	Yes	19	61%
R12	DB	Yes	28	90%	R22	DB	Yes	25	81%
R13	DB	Yes	26	84%	R23	PPP	Yes	20	65%
R14	PPP	Yes	20	65%	R24	PPP	Yes	24	77%
R15	CM	Yes	21	68%	R25	CM	Yes	24	77%
R16	PPP	No	19	61%	R26	DB	Yes	20	65%
R17	PPP	Yes	23	74%	R27	DBB	Yes	19	61%
R18	PPP	Yes	28	90%	R28	DB	Yes	29	94%
R19	DB	Yes	30	97%	R29	PPP	Yes	27	87%

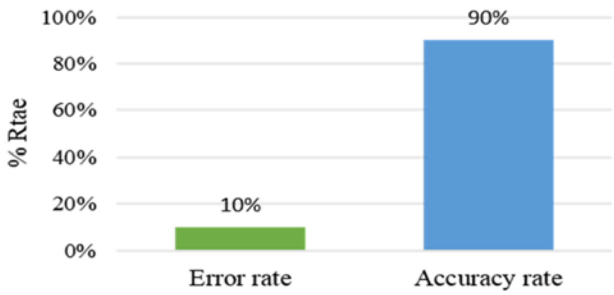

Fig. 7. Error and Accuracy Rate of the Developed System

total responses (31).

$$\%\text{Weight of each procurement method} = \frac{\text{the outcome of each procurement method}}{\text{Total responses}} \times 100$$

A higher percentage value indicates how strongly appropriate the recommended procurement method is. All the yes confirmation had a percentage value above the average with only 3 procurement paths receiving 61% confirmation. DB received a higher percentage weight on average with a minimum of 65% confirmation while PPP had a minimum percentage of 61%.

Out of the 20 Rules, 2 were confirmed as *no* with a percentage value a little above the 50% average. Recommended procurement paths for Rules R16 and R20 were confirmed as an error (not appropriate). Therefore percentage error rate of the revised system was determined as 10% (2/20*100) suggesting that the recommended procurement methods used to develop the system have a higher accuracy rate of 90%. This further suggests that 90% of these recommended procurement methods are appropriate for the designed Rules and are therefore reliable to a certain degree. Removing the 2 errors, PPP is still a preferable procurement choice on (8/18) as compared to (9/20) before the verification while DB also appears to be a strong preferable procurement option (7/18) with CM on (2/18) and DBB (1/18) being the least preferred procurement option. DB remained unchanged for all the corresponding Rules during the revision process and after the confirmation stage. While PPP seems to be the preferred procurement choice based on this study, DB is also highly recommended but depending on client's requirements and the project characteristics.

What accounted for the lower error rate is the fact that similar expert knowledge was extracted and used to revise the proposed expert system (ESCONPROCS). Fig. 6 summarizes the error rate and the accuracy rate of the developed expert system.

5. Conclusions

In other to assist a decision-maker (client) gain some knowledge and reaches a more informed decision on procurement systems selection, this study developed an expert system tool (ESCONPROCS). The study reviewed the current practices of procurement systems in the construction industry and considered the factors that influence the selection of these procurement methods. Using these identified factors as client's requirements coupled with project characteristics, knowledge-based rules (IF/AND/THEN) were designed and recommended procurement routes assigned to each rule were used to develop a proposed expert system tool. The authors conducted a survey questionnaire to extract human expert's knowledge. The result of the responses was compared with the proposed system developed and it was found out that 3 recommended actions of the Rules did not match with what the human experts provided. Hence the result of the survey was used to revise the proposed expert system tool. The analysis of the study shows that PPP and DB were recommended as the most preferred procurement methods to be used on large-scale projects, with the former recommended as the overall best procurement option. Unlike the other existing expert systems in the construction industry where expert opinions were not solicited and also the fact that detailed explanation of how the recommended actions are chosen had not been explicitly explained. This expert system developed is different in the sense that it used different human expert's knowledge to revise it and then further verified it through experts with enough experience on construction projects. The verification result showed a lower error rate of 10% (90% accuracy rate) suggesting that the procurement methods assigned could be used as appropriate recommended procurement systems. However, because the number of Rules was a little above average and the fact that the number of responses received was few and also the survey period was short, it is difficult to conclude that a satisfactory verification was certainly performed. For future study, it is necessary to include enough data to reduce the error rate and rightly prove the efficiency of this expert system.

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