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DETERMINING THE EFFECTIVENESS OF CONCURRENT ENGINEERING THROUGH THE ANALYTICAL HIERARCHY PROCESSING OF PROJECT SUCCESS CRITERIA

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Abstract
The emergence of Concurrent Engineering (CE) as the Project Procurement method of choice for effective integration and coordination into construction has been gaining grounds. However, this is based mainly on empirical data that were derived majorly from the implementation of CE within the manufacturing environment. Thus the theoretical foundations of CE has been more empirical that statistical. Although science is driven by data, strong theoretical foundations must exist in order to explain that data. This work seeks to confirm statistically, the prominence of concurrent engineering as the method which offers the most scope for effective attainment of construction objectives of Cost, Time, Quality and Clients Satisfaction. Using the Analytical Hierarchy Process (AHP) model, these project success criteria were used as the primary criteria, along with its sub-criteria, to calculate the Eigen-vectors, in order to synthesize a pair-wise comparison matrix of the criteria. Thus the priority weight vectors were obtained and used for the ranking of the four principal construction delivery methods: Traditional method, the Design and Build method, the Programme management method and the Concurrent Engineering method. The results of the data computations gave a ranking of the four (4) principal project delivery methods of; Traditional sequential delivery, Programme management, Design and build and CE, with the values 0.0001, 0.1027, 0.2062 and 0.6910 respectively. CE ranked highest in its effectiveness in attaining construction goals. The work thus confirm statistically, the prominence of concurrent engineering as the method which offers the most scope for effective attainment of construction objectives of Cost, Time, Quality and Clients Satisfaction.

Keywords: Project Success Criteria, Project Delivery Method, Analytical Hierarchy Process, Eigen-vectors.

INTRODUCTION

The principal aim of a client on initiating a construction project is to acquire a sound finished work at a minimum price, time, quality and utility. However, most clients do not have the desire or competence to undertake this on their own, hence they delegate the responsibility to the appropriate experts with the necessary competence for certain considerations. The construction procurement process is complex in its separation of functions into discrete sub-processes, in its structures and procedures, in its proliferation of actors and activities, in the diversity of the resources employed, their sources and their mobilization (Aouad et al, 1994). This fragmented nature of the construction process and the industry, evident in the large number of firms operating within it, the distinct separation of the professions and the resultant poor communication, lack of concurrency, institutional barriers, ad-hoc problem solving approach, lack of trust and collaborative spirit within the client/design/construction team amongst other factors have led to consistently low levels of performance (Banwell 1964, Aniekwu, 1986, Latham 1994).

To reduce the difficulties encountered with procuring projects, industry practitioners and researchers have turned to the manufacturing industry as a point of reference and a potential source of innovation. Accordingly, a method known as concurrent engineering which advocates for the use of a multi-disciplinary project team whereby participants are brought together during the design stage to determine how downstream issues may be affected by design decisions has become dominant. It refers to an approach used in product development in which functions of design engineering, manufacturing engineering and other functions are integrated to reduce the elapsed time required to bring a new product to the market. The portability of this method makes it possible to be relatively adaptable to other industries. Apart from these empirical data, no fundamental theoretical basis has been proffered for the advantage of concurrent engineering over other major construction delivery methods. This work tries to confirm statistically, the prominence of concurrent engineering as the method which offers the most scope for effective attainment of construction objectives of Cost, Time, Quality and Clients Satisfaction.

PROJECT DELIVERY METHODS

A project delivery method is a system used by a client for organizing and financing design, construction, operations, and maintenance services for a facility by entering into legal agreements with one or more entities or parties. There are four most common construction delivery methods, while the other methods are considered "hybrid" methods or some combination of the four (Construction Industry Institute (CII) (1997). They include:

1. The Traditional Construction Delivery Method;
2. The Construction (Programme) Management Method;
3. The Design and Build Method; and
4. Concurrent Engineering Method

The Traditional Construction Delivery Method

The Owner's architect and engineers (AE) carry out the design after the program of requirements and budget are set and the site is defined. The AE prepares the Contract Documents (i.e. construction documents, bid documents, working drawings and specifications) and Competitive bids are received from contractors, or a price is negotiated with a selected contractor. When a price is obtained, the construction contract is executed and the Owner authorizes construction to proceed (Elbeltagi, 2009).

The Programme Management Method

Program management or Construction management is the process of managing projects through a fee-based service in which the construction manager is responsible exclusively to the owner and acts in the owner's interests at every stage of the project. The construction manager offers advice, uncolored by any conflicting interest, on such crucial matters (Elbeltagi, 2009).

The Design and Build Method

The Design and Build method gives the client a single point of contact in which the contracting organization is responsible for design and construction. The client commits to the cost of construction, as well as the cost of design, much earlier than with the traditional approach.

THE CONCURRENT ENGINEERING METHOD

Concurrent engineering (CE) is the systematic approach to the integrated, concurrent design of products and related processes, including manufacturing and support. This approach is intended to cause the developers to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements. The primary goal of CE is to reduce the lead-time, or the total time from designing a product to releasing it into the market, while creating better designs as well (Elbeltagi, 2009).

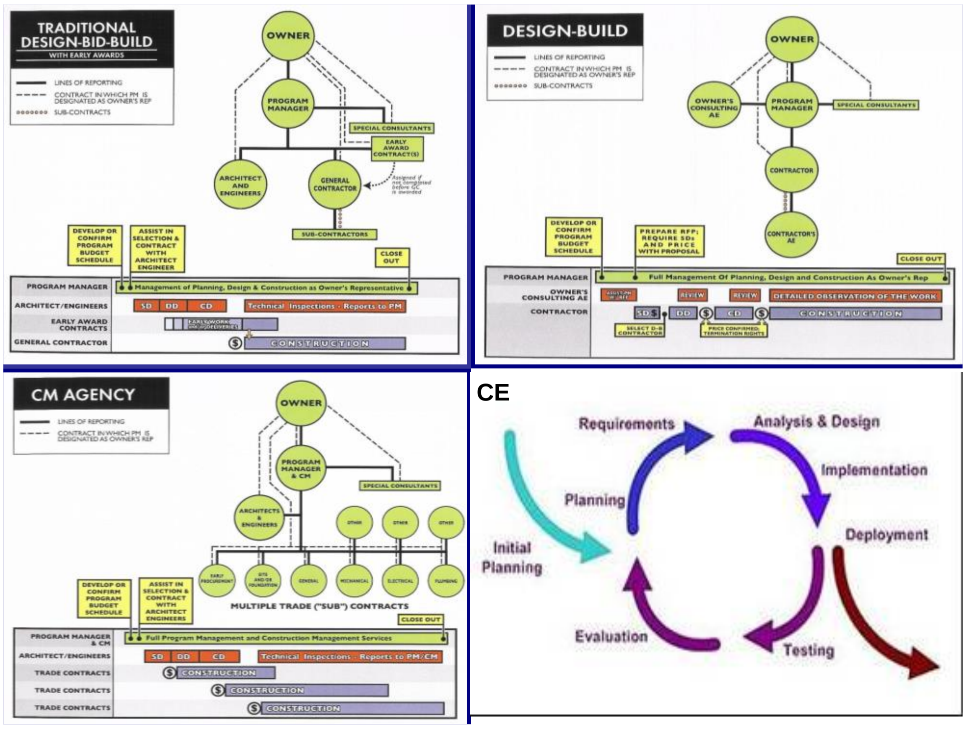

Fig. 1: Summary of Procurement Methods (After Construction Industry Institute, 1997)

PROJECT SUCCESS CRITERIA

Over 50 years ago, Oilsen, (1971) suggested cost, time and quality as the success criteria. Many other writers Turner, (1993), Morris and Hough, (1987) and Ballantine, (1996), all agree that cost, time and quality should be used as success criteria. Cost, time and quality became known as “The Iron Triangle” (Fig.2). In more recent times many research have proved that this is not a satisfactory success criteria and more is required beyond this. The reality is that the notion of success is a much more complex issue and often an illusory construct (Westerveld, 2002).

Thus Clients satisfaction was added to the criteria. Irrespective of the procurement methods adopted, the desire of the client is to acquire a good quality project at the lowest possible cost and on time, while satisfying the clients' needs.

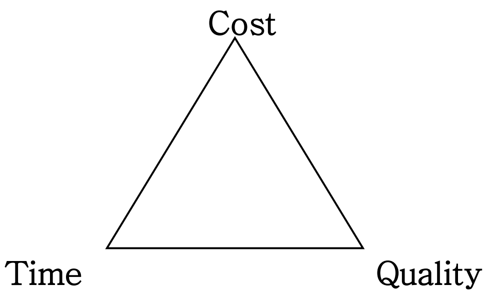

Fig 2: The Iron triangle.

Project success criteria is identified as the primary criteria clients use to assess the level of successful attainment of their primary objectives. Our approach therefore was to use the project success criteria of Cost, Time, Quality and Client's satisfaction as the primary criteria in an Analytical Hierarchical process and compute the eigen-values of the alternative construction delivery method and rank them. The various components of the individual success criteria were identified through literature and related to the delivery methods in terms of their inherent advantages and disadvantages and used to develop a diagram of the relationship between project success criteria and the delivery methods (Table. 1).

Table 1: Relationships of Project Delivery Methods to Project Success Criteria

Primary Criteria	**Secondary Criteria**	**Traditional Method**	**Program Management**	**Design/Build Method**	**Concurrent Engineering**
COST	Reworks/ Variations	✖	◕	◕	◕
	Cost Escalations	✖	✖	◕	◕
	Cost Over-Runs	✖	✖	◕	◕
TIME	Simultaneous Production	✖	◕	✖	◕
	Integration of Sub-Processes	✖	◕	✖	◕

	Material Supply Logistics	✖	✖	✖	✖
QUALITY	Lack of Testing Facilities	✖	✖	✖	✖
	Lack of Standardization	✖	✖	✖	✖
	Poor Workmanship	✖	✖	✖	✖
CLIENT SATIS FACTION	Cost Target	✖	✖	◕	◕
	Time Target	✖	◕	✖	◕
	Quality Target	✖	◕	✖	◕

◕ = *Favourable Relationship;* ✖ = *Unfavourable Relationship*

ANALYTICAL HIERARCHY PROCESS (AHP)

The Analytic Hierarchy Process (AHP) is a multi-criteria decision aiding method based on a solid axiomatic foundation. It involves a systematic procedure for dealing with complex decision making problems in which many competing alternatives (projects, actions, scenarios) exist [Forman and Selly (2002), Saaty and Vargas (1994), Saaty (1990), Saaty (1995), Vargas (1990)]. The alternatives are ranked using several quantitative and/or qualitative criteria, depending on how they contribute in achieving an overall goal.

AHP is based on a hierarchical structuring of the elements that are involved in a decision problem. The hierarchy incorporates the knowledge, the experience and the intuition of the decision-maker for the specific problem. The simplest hierarchy consists of three levels. On the top of the hierarchy lies the decision's goal. On the second level lie the criteria by which the alternatives (third level) will be evaluated. In more complex situations, the main goal can be broken down into sub-goals or/and a criterion (or property) can be broken down into sub-criteria. People who are involved in the problem, their goals and their policies can also be used as additional levels (Anagnostopoulos & Vavatsikos, 2006).

The hierarchy evaluation is based on pair-wise comparisons. The decision maker compares two alternatives Ai and Aj with respect to a criterion and assigns a numerical value to their relative weight.

The result of the comparison is expressed in a fundamental scale of values ranging from 1 (Ai, Aj contribute equally to the objective) to 9 (the evidence favoring Ai over Aj is of the highest possible order of affirmation) (Anagnostopoulos & Vavatsikos, 2006). Given that the "n" elements of a level are evaluated in pairs using an element of the immediately higher level, an n x n comparison matrix is obtained (Fig. 3). If the immediate higher level includes m criteria, m matrixes will be formed. In every comparison matrix all the main diagonal elements are equal to one (aii=1) and two symmetrical elements are reciprocals of each other (aij x aji = 1) (Anagnostopoulos & Vavatsikos, 2006).

K	P_1	P_2	$\cdots$	P_n
P_1	1	a_{12}	$\ldots$	a_{1n}
P_2	$1/a_{12}$	1	$\ldots$	a_{2n}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
P_n	$1/a_{1n}$	$1/a_{2n}$	$\ldots$	1

Fig. 3. Pair-wise comparison matrix A of alternatives P~ with respect to criterion K

Since n(n-1)/2 pair-wise comparisons are required to complete a comparison matrix, mn(n-1)/2 judgments must be made to complete the evaluation of the n elements of a level using as criterion the m elements of the immediately higher level. For large evaluations, the number of comparisons required by the AHP can be somewhat of a burden. For example, if 5 bids are to be evaluated, in a model containing 20 criteria, at least 10 x 20 = 200 judgments must be made. The decision-makers' judgments may not be consistent with one another. A comparison matrix is consistent if and only if aij x ajk = aik for all i, j, k. AHP measures the inconsistency of judgments by calculating the consistency index CI of the matrix

$$CI= \frac{\lambda_{\max} - n}{n-1} \quad \text{----------------------------------(1)}$$

Where: λmax is the principal eigenvalue of the matrix.

The consistency index CI is in turn divided by the average random consistency index RI to obtain the consistency ratio CR.

$$CR = \frac{CI}{RI} \quad \text{-------------------------------------} (2)$$

The RI index is a constant value for an n x n matrix, which has resulted from a computer simulation of n x n matrices with random values from the 1-9 scale and for which aij = 1/aji. If CR is less than 5% for a 3 x 3 matrix, 9% for a 4 x 4 matrix, and 10% for larger matrices, then the matrix is consistent (Anagnostopoulos & Vavatsikos, 2006).

Once the values are defined, a comparison matrix is normalized and the local priority (the relative dominance) of the matrix elements with respect to the higher level criterion is calculated. The overall priority of the current level elements is calculated by adding the products of their local priorities by the priority of the corresponding criterion of the immediately higher level. Next, the overall priority of a current level element is used to calculate the local priorities of the immediately lower level which use it as a criterion, and so on, till the lowest level of the hierarchy is reached. The priorities of the lowest level elements (alternatives) provide the relative contribution of the elements in achieving the overall goal. Hence, Saaty (1994) states that there are three basic principles in the AHP method, which are as follows:

1. Decomposition: After the problem has been defined, decomposition is necessary to be done, which is dividing a problem into smaller parts. The division process will resolve some levels of a problem. That is why this process of analysis is named hierarchy.
2. Comparative Judgment: This principle assesses the relative importance of two elements in a certain level related to those at higher level. This assessment is the main point of the AHP method because it influences the priority of the elements. This assessment result can be observed better if displayed in the form of Pairwise Comparison Matrix.
3. Synthesis of Priority: From each of Pairwise Comparison Matrix, the eigenvector value can be determined to acquire local priority. Because the Pairwise Comparison Matrix is available in each level, the global priority can be acquired by synthesizing between those local priorities.

The procedure of synthesizing is different according to each hierarchy. To rank the elements according to its relative importance through synthesizing procedure is called priority setting.

According to Saaty (1994), this AHP method is appropriate to be used in making decision that involves decision element comparison, which is difficult to be assessed quantitatively. This matter is based on the assumption that human beings' natural reaction when facing a complex decision making, is by grouping the decision elements according to its common characteristics. This grouping process includes rank the decision elements, and then comparing between each pair in each group in a form of matrix. Afterward, inconsistency ratio and weight for each element will be acquired. Thus, it will provide ease in testing the data consistency.

The ratio-scale form is used as an input in the AHP method, which states one's perception when facing the decision-making situation. The values in the ratio are then organized in a matrix, which is called the pairwise comparison matrix. Due to the limitation of human beings' brain capability, the ratio-scale is limited as well. In the AHP method, the scale range 1–9 is assumed sufficiently representing human beings' perception. The reason why te AHP method limits the ratio-scale 1–9, is acording to the research conducted by a psychologist (Miller, 1956), which shows that human beings cannot simultantly compare more than seven objects, either it increases or decreases two objects. In such condition, human beings will lose their consistency in making the comparison. The Standard Preference Scale used in the AHP method is provided in Table 2 as follows:

Table 2: Preference Scale for Pair-wise Comparisons

Preference Level	**Numerical Value**
Equally Preferred	1
Equally to Moderately Preferred	2
Moderately Preferred	3
Moderately to Strong Preferred	4
Strongly Preferred	5
Strongly to Very Strongly Preferred	6
Very Strongly Preferred	7
Very Strongly to Extremely Preferred	8
Extremely Preferred	9

Source:http://www.s.scribd.com/doc/2908406/Modul-6-Analytic-Hierarchy-Process/21 Juni 2009

THE APPLICATION OF AHP METHODOLOGY

Although science is driven by data, strong theoretical foundations must exist in order to explain that data. Otherwise, all we have is a collection of possibly related facts, and what good is that? Science isn't merely an attempt to collect data, but rather an effort to explain that data in an accurate, coherent, and useful manner. In order to assess the effectiveness of each procurement type in meeting client's objectives, several criteria must be taken into account and a consistent evaluation methodology must be applied. The model for the analysis is a multi-criteria decision making approach, based on the Analytic Hierarchy Process (AHP). The decision problem is decomposed into qualitative criteria and sub-criteria that are further analyzed in quantitative indicators on which the procurement types are evaluated.

The definition of project success changed over the years. In the 1960s, project success was measured entirely in technical terms: either the product worked or it did not. In the 1980s, [Kezner, 1998] defined project success in terms of meeting three objectives: 1) time, 2) Cost, and 3) quality. The quality of a project was commonly defined as meeting technical specifications. Client satisfaction was later included as a criteria. Thus the assessment of the viability of a project delivery method is basically an assessment of how well the method is able to attain the project success criteria of cost, Time, Quality and Client's satisfaction. These criteria are considered as the primary criteria in this particular study. The primary criteria were weighted as shown below using the preference scale for Pair-wise Comparism.

Table 3: Weighting of the Primary Criteria using the Preference Scale for Pair-wise Comparison

Primary Criteria	Preference Level	Numerical Value
COST	Equally Preferred	1
TIME	Strongly Preferred	5
QUALITY	Very Strongly Preferred	7
CLIENT SATISFACTION	Extremely Preferred	9

Four levels form the hierarchy whose goal, the optimal ranking of Construction Delivery Method, is placed on the first level. The secondary criteria which constitute the second level consist of the four principal criteria that describe construction success criteria; Cost Time, Quality and Clients' Satisfaction.

The next level which constitute the Secondary criteria of the hierarchy are the three elements (sub-criteria) that make up the success factors in the second level criteria.

The lowest level of the hierarchy consists of the construction delivery methods to be evaluated in order to rank them according to the selected criteria. The various elements that make up each criteria were weighted based on the experience, values and knowledge, using the Preference Scale for Pair-wise comparison as given in table 2.

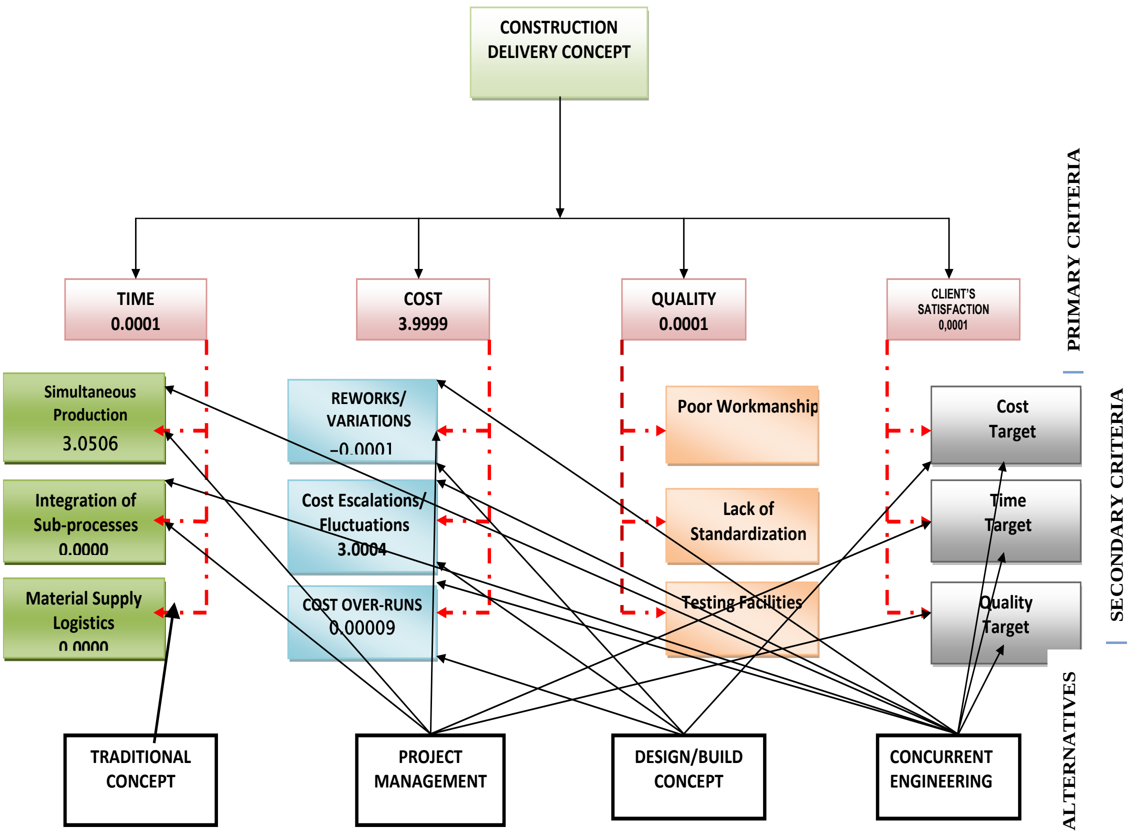

Fig. 4. The Affinity Diagram of Construction Success and Construction Delivery Methods

A Professional commercial software, "Expert Choice", developed by Expert Choice, Inc. [2011], was used to implement the AHP's steps, which automated many of its computations (Winston & Albright, 1997).

RESULTS

The analytical hierarchy process is used to confirm the preference of CE as the method of choice that has yielded itself to effective adaptation to the construction industry.

The Construction project success criteria of cost, time, quality and clients satisfaction are used as the primary criteria for assessing the well-suitedness of the various project delivery methods for construction. The Traditional sequential project delivery method; the Programme management method, the design and build method and concurrent engineering method, are the four (4) alternatives to be selected from. Each of the four (4) primary criteria were further broken down into three (3) secondary or sub criteria and decomposed into a hierarchy of criteria and alternatives as shown in Fig 4.

Basically, we decompose the decision problem into criteria and sub-criteria, then we establish the relative importance of each criteria over another based on experience and judgment, using the Preference Scale and then express it as a comparison matrix as shown in Table 4. We sum the values in each column of pairwise comparison matrix. We then divide each element by its column total (gives normalized pairwise comparison matrix) and then compute the average of elements in each row (gives estimate of relative priorities of elements being compared).

Table 4: Preference Matrix of Pairwise comparisons of the criteria with respect to goals

	Cost	**Time**	**Quality**	**Satisfaction**
Cost	1.00	5.00	7.00	9.00
Time	0.20	1.00	4.00	5.00
Quality	0.14	0.25	1.00	2.00
Satisfaction	0.11	0.20	0.50	1.00

The comparison matrix is synthesized to get the priorities of the alternatives, with respect to each criterion and the weights of each criterion with respect to the goal (Table 5). This was implemented on Microsoft Excel and computed weight and ranking of the various criteria. To determine the overall weight, each entry is divided by the sum of the column it appears in. And then each entry is expressed as a percentage of this sum. By averaging across each row, we correct for any small inconsistencies in the decision making process. The details of the manual computations are given in the appendix 1.

Table 5: Normalized matrix

	Weights	**Products**	**Ratio**
Cost	0.6381	2.821202	4.421291
Time	0.2267	0.94677	4.176721
Quality	0.0837	0.334616	3.999475
Satisfaction	0.0516	CI/RI should be less than 0.1 if consistent comparisons were ma	

The Consistency Index, Consistency ratio, were also computed) Table 6) and the Matlab Software was used to compute the principal Eigen-vector and eigenvalues λ.

Table 6: Consistency Index

n	1	2	3	4	5	6	7	8
CI	4.2	4.2	0.0256	0.1729	0.1440	0.2208	-0.1754	4.494
CR/RI	0.00	0.00	0.04	0.300	-0.25	0.24	-0.19	4917

The test result is inconsistent if CR ≥ 10%, The RI index is a constant value for an n x n matrix, which has resulted from a computer simulation of n x n matrices with random values from the 1-9 scale and for which aij = 1/aji. If CR is less than 5% for a 3x3 matrix, 9% for a 4x4 matrix, and 10% for larger matrices, then the matrix is consistent. The result of the analysis as shown above is consistent. The results in table 6, indicate that all the items compared were consistent.

The ranking is obtained by raising the pairwise matrix to powers that are successively squared each time. The row sums are then calculated and normalized. The Local priorities are then multiplied by the weights of the respective criterion. The results are summed up to produce the overall priority of each alternative. Multiplying together the entries in each row of the matrix and then taking the nth root of that product gives a very good approximation to the correct answer. The nth roots are summed and that sum is used to normalize the eigenvector elements to add to 1.00. The Table. 7 below gives the results for the four attributes of Cost, Time, Quality, and Satisfaction.

Table 7: Composite Relative Ranking

	Cost	Time	Quality	Satisfaction
Cost	0.6878	0.7752	0.5600	0.5294
Time	0.1376	0.1550	0.3200	0.2941
Quality	0.0983	0.0388	0.0800	0.1176
Satisfaction	0.0764	0.0310	0.0400	0.0588

The results in table 8 also indicate the Concurrent Engineering is by far the most preferred method with a ranking of 0.6910, while design and Build was ranked 0.2062, Programme management 0.1027 and the traditional method was ranked 0001.

Table 8: Final ranking of project delivery methods

CONSTRUCTION DELIVERY METHODS	FINAL RANKING
Concurrent Engineering	0.6910
Design & Build	0.2062
Programme Management	0.1027
Traditional Method	0.0001
	1.0000

This result confirms that CE is the most advantageous method to apply to construction in order to better achieve project success criteria. It is also consistent with the results of other empirical studies (Madan, 1993; Carter, 1994; Constable, 1994; Dowlatshahi, 1994; Evbuomwan et al., 1994; Frank, 1994; Nicholas, 1994; Thamhain, 1994; Smith et al., 1995; Prasad, 1996).

CONCLUSION

The research objective was to confirm statistically that CE is the most advantageous method to apply to construction in order to better achieve project success criteria. This work was motivated by the fact that the emergence of CE as the method of choice for effective integration and coordination into construction was based mainly on empirical data that were derived from the implementation of CE within the manufacturing environment.

The approach adopted the use the project success criteria of Cost, Time, Quality and Client's satisfaction as the primary criteria in an Analytical Hierarchical process and computed the Eigen-values of the alternative construction delivery method and ranked them. The AHP model was thus used to statistically select the best option out of the four principal construction delivery methods; the Traditional method, the Design and Build method, the Programme management method and the Concurrent engineering method as the alternatives. The results clearly determined statistically that concurrent engineering is the project delivery method which offers the most scope for effective co-ordination and integration into the industry with an eigenvector of 0.6910 and has advantages over other delivery methods.

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APPENDIX 1.0

Manual Implementation of the Analytical Hierarchy Process

Table 1.1: PAIRWISE MATRIX FOR COST

	Cost Escalations	**Rework/Variations**	**Cost Over-run**
Cost Escalations	1	7	3
Rework/Variations	1/7	1	3/7
Cost Over-run	1/3	7/3	1
pair-wise relative importance [1:Equal, 3:Moderate, 5:Strong, 7:Very strong, 9:Extreme]			
Table 1.1.1. CONVERT THE PAIRWISE MATRIX FOR COST TO DECIMALS			
Cost Escalations	1.0000	7.0000	3.0000
Rework/Variations	0.1429	1.0000	0.4286
Cost Over-run	0.3333	2.3333	1.0000
Iterate 1. Take successive squared powers of matrix 2. Normalize the row sums			
Table 1.1.2. EIGEN VECTORS FOR SECONDARY CRITERIA (COST)			
Cost Escalations	-0.940094510931664	-0.976223446860008	-0.690571816418779
Rework/Variations	-0.134315629728619	0.186689993991042	-0.199323247388269
Cost Over-run	-0.313339467872721	-0.110157287295892	0.695255930876295
Eigen Values	3.00004126165477	-0.00013792865767	0.000096667002

Table 1.2: PAIRWISE MATRIX FOR TIME

	Simultaneous Production	**Integration of Sub processes**	**Material Supply Logistics**
Simultaneous Production	1	5	7
Integration of Sub processes	1/5	1	5/7
Material Supply Logistics	1/7	7/5	1
Table 1.2.1. CONVERT THE PAIRWISE MATRIX TO DECIMALS			
Simultaneous Production	1.0000	5.0000	7.000
Integration of Sub processes	0.2000	1.0000	0.7143
Material Supply Logistics	0.1429	1.4000	1.0000
Iterate 1. Take successive squared powers of matrix			
Table 1.2.2. EIGEN VECTORS FOR SECONDARY CRITERIA (TIME)			
Simultaneous Production	0.972430087362219	.972437371246157	0.972437371246157
Integration of Sub processes	0.155405783767796	-0.077720913294414 - 0.134567747658694i	-0.077720913294414 + 0.134567747658694i
Material Supply Logistics	0.173864221633506	-0.086920305268690 + 0.150537040168224i	-0.086920305268690 - 0.150537040168224i
Eigen Values	3.050613711143587	-0.025306855571793 + 0.391717301440150i	-0.025306855571793 - 0.391717301440150i

Table 1.3: PAIRWISE MATRIX FOR QUALITY

	Poor Workmanship	**Lack of Standardization**	**Testing Facilities**
Poor Workmanship	1	3	7
Lack of Standardization	1/3	1	3/7
Testing Facilities	1/7	7/3	1
Table 1.3.1. CONVERT THE PAIRWISE MATRIX TO DECIMALS			
Poor Workmanship	1.0000	3.0000	7.0000
Lack of Standardization	0.3333	1.0000	0.4286
Testing Facilities	0.1429	2.3333	1.0000
Table 1.3.2. EIGEN VECTORS FOR SECONDARY CRITERIA (QUALITY)			
Poor Workmanship	-0.953895173370751	0.953919610688564	0.953919610688564
Lack of Standardization	-0.180648382173457	-0.090309953459839 - 0.156421622101547i	-0.090309953459839 + 0.156421622101547i
Testing Facilities	-0.239687630548800	-0.119853979027236 + 0.207482019703686i	0.119853979027236 - 0.207482019703686i
EIGEN VALUE	3.327046642366458	-0.163523321183227 + 1.030599707360593i	-0.163523321183227 - 1.030599707360593i

Table 1.4: PAIRWISE MATRIX FOR CLIENT'S SATISFACTION

	Cost Target	**Time Target**	**Quality Target**
Cost Target	1	7	9
Time Target	1/7	1	9/7
Quality Target	1/9	7/9	1
Table 1.4.1. PAIRWISE MATRIX FOR CLIENT'S SATISFACTION CONVERTED TO DECIMALS			
Cost Target	.000000000000000	.000000000000000	.000000000000000
Time Target	.142900000000000	.000000000000000	.285700000000000
Quality Target	0.111100000000000	0.777800000000000	1.000000000000000
Table 1.4.2. EIGEN VECTORS FOR SECONDARY CRITERIA (SATISFACTION)			
Cost Target	-0.940094510931664	-0.976223446860008	-0.690571816418779
Time Target	-0.134315629728619	0.186689993991042	0.199323247388269
Quality Target	-0.313339467872721	-0.110157287295892	0.695255930876295
EIGEVALUES	3.000041261654774	-0.000137928657672	0.000096667002897

Table 1.5: COMPUTATION OF EIGEN VALUES FOR THE ALTERNATIVES BASED ON SUCCES CRITERIA ©ST)

COST	Conc. Engineering	Programme Management	Design & Build	Traditional Method
Conc. Engineering	1	3	1	9
Programme Managt	1/3	1	1/3	3
Design & Build	1	1/3	1	9
Traditional Method	1/9	1/3	1/9	1
Table 1.5.1. CONVERT THE PAIRWISE MATRIX TO DECIMALS				
Conc. Engineering	1	3	1	9
Programme Managt	0.3333	1	o.3333	3
Design & Build	1	0.3333	1	9
Traditional Method	0.1111	0.3333	0.1111	1
Table 1.5.2. EIGEN VECTORS FOR ALTERNATIVES CRITERIA (COST)				
	Conc. Engineering	Programme Managt.	Design & Build	Traditional Method
Concurrent Engineering	0.765413394240525	0.336769136113986	0.456913301373799	-0.993197677534924
Programme Management	0.255079235122342	0.113516136723891	-0.000924492109134	-0.000019063361346
Design & Build	0.584675269915522	-0.933969792651174	-0.888207318711479	0.050967701388543
Traditional Method	0.085039687651186	0.037430763810615	0.048136673435152	0.104693201264410
EIGEN VALUE	3.763565649699764	0.238218468757986	-0.001832804486538	0.000048686028791

Table 1.6: COMPUTATION OF EIGEN VALUES FOR THE ALTERNATIVES BASED ON SUCCES CRITERIA (TIME)

TIME	Concurrent Engineering	Programme Management	Design & Build	Traditional Method
Concurrent Engineering	1	1	5	7
Programme Management	1	1	1/5	1/7
Design & Build	1/5	1/5	1	7/5
Traditional Method	1/7	1/7	5/7	1
Table 1.6.1. CONVERT THE PAIRWISE MATRIX TO DECIMALS				
Concurrent Engineering	1	1	5	7
Programme Management	1	1	0.2000	0.14229
Design & Build	0.2000	0.2000	1	1.4000
Traditional Method	0.1429	0.1429	0.7143	1
Table 1.6.2. EIGEN VECTORS FOR ALTERNATIVES CRITERIA (TIME)				
	Concurrent Engineering	Programme Managt.	Design & Build	Traditional Method
Concurrent Engineering	0.894433401441585	0.378272829320866	-0.707106781186712	-0.690069993971249
Programme Management	-0.389432157639848	-0.921015791093129	-0.707106781186383	- 0.703861983484055
Design & Build	-0.178886680288317	0.075654565864173	-0.000000000003284	0.138013998779344

Traditional Method	-0.127792959888388	0.075654565864173	0.000000000002298	-0.096611840720209
EIGEN VALUE	3.435526529744007	0.564480542955276	-0.000000000000001	-0.000007072699281

Table 1.7: COMPUTATION OF EIGEN VALUES FOR THE ALTERNATIVES BASED ON SUCCES CRITERIA (CLIENTS SATISFACTION)

CLIENTS SATISFACTION	**Concurrent Engineering**	**Programme Management**	**Design & Build**	**Traditional Method**
Concurrent Engineering	1	7	5	9
Programme Management	1/7	1	7/3	9/7
Design & Build	1/5	3/7	1	3
Traditional Method	1/9	7/9	1/3	1
Table 1.7.1. CONVERT THE PAIRWISE MATRIX TO DECIMALS				
Concurrent Engineering	1.0000000000	7.0000000000	5.0000000000	9,00000000000
Programme Management	0.1429000000	1.0000000000	2.3333000000	1.28570000000
Design & Build	0.2000000000	0.4286000000	1.0000000000	3.00000000000
Traditional Method	0.1111000000	0.7778000000	0.3333000000	1.0000000000
Table 1.7 2. EIGEN VECTORS FOR ALTERNATIVES CRITERIA (CLIENTS SATISFACTION)				
	Conc. Engineering	Programme Managt.	Design & Build	Traditional Method
Concurrent Engineering	0.958915965422118	-0.995970544188139	0.854423243971900	0.854423243971900
Programme Management	0.202303117006599	0.069702125844793	-0.151680094285592 + 0.358185520821917i	-0.151680094285592 - 0.358185520821917i
Design & Build	0.173296917415277	0.000031297034410	-0.222388076561240 - 0.221858785419826i	-0.222388076561240 + 0.221858785419826i
Traditional Method	0.097579703434394	0.056429493908717	0.132522581021958 - 0.049164927400453i	0.132522581021958 + 0.049164927400453i
EIGENVALUE	4.296246856877315	0.000033869399334	-0.148140363138324 + 1.118322071399122i	-0.148140363138324 - 1.118322071399122i

Table 1.8: WEIGHTING OF ALTERNATIVE

EIGEN VECTORS FOR ALTERNATIVES CRITERIA (CLIENTS SATISFACTION)				
	Conc. Engineering	**Programme Managt.**	**Design & Build**	**Traditional Method**
COST	3.763565649699764	0.238218468757986	-0.001832804486538	0.000048686028791
TIME	3.435526529744007	0.564480542955276	-0.000000000000001	-0.000007072699281
QUALITY	-0.000000000000001	-0.000007072699281	-0.000000000000001	-0.000007072699281
CLIENT SATISFACTION	4.296246856877315	0.000033869399334	-0.148140363138324 + 1.118322071399122i	-0.148140363138324 - 1.118322071399122i