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Project Delivery Systems for Capital Projects: a Multi-attributed Decision Support System

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Abstract: This paper describes a method for selection of most suitable project delivery systems for capital projects. It expands upon the method advanced by the Construction Industry Institute (CII) - Owner's Tool for Project Delivery and Contract Strategy Selection, (2003). The extensions included in this paper alleviate the inherent subjectivity associated with the assignment of relative weights to the selection factors, used in the CII method. To set the relative weights in an objective manner, several types of pair wise comparisons and their respective calculation methods were analyzed. Two types of binary methods and the Analytical Hierarchy Process (AHP) method, using the relative importance scale of 1 to 9, were considered. The results were compared to those obtained using the Super Decisions software, which is based on the mathematical theory of AHP. The results obtained through the methods AHP-3 and AHP-4 were found reasonably close to those obtained from the Super Decisions. The calculation of the consistency ratio allows the decision-makers to refine the pair wise comparison process to achieve reasonable consistency. The developed method was implemented in a spreadsheet application and a case study previously analyzed by the CII was considered to enable a comparison. The contribution of this paper is in establishing a simple approximate method for calculating relative weights based on pair wise comparisons, without compromising the results accuracy. The developed method has been integrated with the CII spreadsheet, thus eliminating the data transfer between different programs. It also can be used as a stand-alone decision support system.

1 Introduction

1.1 Project Delivery Systems in the Construction Industry (PDS) and their Selection

The definition of a project delivery system (PDS) by the Project Delivery Institute states that "a project delivery system defines the structure of the relationships of the parties, the roles and responsibilities of the parties and the general sequence of the activities required to deliver the project" (Moore, 2000). The Primer on Project Delivery defines four major categories of project delivery systems: Design-Bid-Build (DBB), Construction Management at Risk (CMR), Design-Build (DB), and Integrated Project Delivery (IPD), (Joint Committee of the AIA and the AGC, 2011). Other terms signify PDS's, that some of the literature sources consider as distinct, such as Construction Management Agency (CMA).

The literature agrees that, for each particular project, there may be a PDS that is the most suitable, and not one single PDS suits every project. PDS's continue to evolve and new ones emerge. Various factors influence the suitability of a PDS for a specific project, and therefore affect the selection. The PDS selection process is not always methodical. However, as the project size, complexity and the level of risk increase, and particularly if the project is public, owners approach the PDS selection with greater rigour.

Proper choice of a PDS may significantly affect the project success, including meeting its targeted time, cost, quality, and safety objectives and minimizing claims and disputes. Speed has, perhaps, the most obvious relationship to the PDS, as a PDS largely determines the amount of overlap of the project phases, but many other important project aspects, such as cost predictability, owner's preference for involvement and control of the process, and risk allocation are affected by the choice of a PDS.

2 Literature Review

2.1 CII Tool

This paper builds primarily on the Construction Industry Institute publication CII Implementation Resource 165-2, Owner's Tool for Project Delivery and Contract Strategy Selection User's Guide (2003), which will be referred to as the CII Tool. The CII Tool uses the term Project Delivery and Contract Strategy (PDCS) for a project delivery system. It defines twelve PDCS's (1 Traditional Design-Bid-Build (DBB), 2 Traditional (DBB) with Early Procurement, 3 Traditional (DBB) with Project Manager, 4 Traditional (DBB) with Construction Manager, 5 Traditional (DBB) with Early Procurement and CM, 6 CM @ Risk, 7 Design-Build or EPC, 8 Multiple Design-Build, 9 Parallel Primes, 10 Traditional DBB with Staged Development, 11 Turnkey and 12 Fast Track), and twenty criteria (or factors) for selection of the most suitable PDCS (1 Control cost growth, 2 Ensure lowest cost, 3 Delay or minimize expenditure rate, 4 Facilitate early cost estimates, 5 Reduce risks or transfer risks to contractor(s), 6 Control time growth, 7 Ensure shortest schedule, 8 Promote early procurement, 9 Ease change incorporation, 10 Capitalize on expected low levels of change, 11 Protect confidentiality, 12 Capitalize on familiar project conditions, 13 Maximize Owner's controlling role, 14 Minimize Owner's controlling role, 15 Maximize Owner's involvement, 16 Minimize Owner's involvement, 17 Capitalize on well defined scope, 18 Efficiently utilize poorly defined scope, 19 Minimize number of contracted parties, 20 Efficiently coordinate project complexity and innovation). The CII Tool provides relative effectiveness values of each PDCS with respect to each selection criterion on a scale of 0 (lowest) to 100 (highest), in the increments of 10 (CII, 2003). These relative effectiveness values are considered as industry-wide and independent of specific circumstances. The list of project delivery systems and the selection factors were established through a survey of 45 owner organizations and 45 contractor organizations, from twelve different industries, and refined through analysis by the CII research team, (Anderson and Oyetunji, 2004). The relative effectiveness values were developed through a two-part data collection and analysis exercise, validated by consensus of 32 experienced project managers, (Oyetunji and Anderson, 2006).

The CII tool utilizes the simple multi-attribute rating technique with swing weights (SMARTS), a variant of the multi-attribute utility theory. It recommends that between four and six selection factors be chosen for each particular project, and that no two factors should be based on the same objective or idea, to avoid double counting. The chosen selection factors should be ranked in the order of importance and assigned relative weights (preference scores), such that the most important gets the score of 100 and the remaining factors get lower scores in the increments of 5 or 10, but not less than 5. The CII Tool does not suggest a specific method for determining preference scores of selection factors (CII, 2003).

2.2 Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) is a method for selecting one among a number of alternatives developed by Thomas Saaty. One of its major advancements is an objective way of determining the relative weights of the selection factors, through pair wise comparisons. When comparing each pair of factors, their relative importance is expressed either numerically or verbally as follows: Equally important - 1, Moderately or slightly more important - 3, Strongly more important - 5, Very strongly more important - 7, and Extremely more important - 9 with the intermediate values of 2,4,6 and 8. The reciprocals of these whole numbers are used when the word 'more' is replaced by the word 'less'. The AHP includes mathematical methods to compute the relative importance of the selection factors. The judgements are not necessarily consistent, and the AHP theory includes the method of determining their level of consistency and it recommends that the consistency ratio or the inconsistency index (the latter is the term used by the software) be less than 0.1 (Saaty 1980, Saaty, 2003).

2.3 Approximate Methods of Computing Priorities Based on Pair Wise Comparisons

The AHP theory utilizes the mathematical operations with matrices, which are complex and require specially designed software (Saaty, 2003). Several approximate methods of calculating relative weights based on pair wise comparisons have been developed (Saaty, 1980). A special case of the AHP is the Multiple Binary Decision Method (MBDM), also based on pair wise comparisons, but with the possible judgements 'more', 'less' or 'equally' important (Marazzi, 1985, Moselhi 1994).

A decision matrix is an n x n matrix, where n is the number of items to be compared. The headings for each row and column are the items to be compared in the same order from left to right and from top to bottom. Each item of the row headings (on left of the matrix) is compared to each item of the column headings (above the matrix), and the numerical values are entered in each intersecting cell of the upper right triangle of the matrix. The bottom left triangle values follow directly from the upper right triangle. Comparison of an item to itself does not require judgment.

2.3.1 AHP Methods

These methods use the scale of 1 to 9 described above. Comparing an item to itself means equal importance. If A compared to B gives X, then B compared to A gives 1/X, as in Figure 6. Four approximate calculation methods were described by Saaty. AHP-1, the Crudest: sum the elements of each row and normalize so that the resulting numbers add to 1 (divide each of the sums across the rows by their total sum). The result for each row represents the priority of the item in that row. AHP-2, Better: Sum each column, calculate the reciprocals of these sums, normalize similar to above. The result for each column represents the priority of the item in the same column. AHP-3, Good 1: normalize each column, and for this new matrix average each row. The resulting values are the priorities of the items in the corresponding rows. AHP-4. Good 2: Find the geometric mean of each row and normalize the resulting numbers (Saaty 1980).

2.3.2 Multiple Binary Decision Method

The method described by Marazzi (1985), that will be referred to as MBDM-1, consists of the following rules. If A is more important than B, then 1 is at the intersection of row A and column B, and 0 at the intersection row B and column A. Comparison to itself results in a 0. Equal importance results in ½. A variation of this method that will be referred to as MBDM-2 was described by Moselhi (1994) as follows. If A is more important than B, then 1 is at the intersection of row A and column B, and 0 at the intersection row B and column A. Equal importance, including a comparison to itself, results in 1. The calculation Method AHP-1 the Crudest is used with the binary decision methods (Marrazzi, 1985, Moselhi, 1994).

3 Case Study Example

In this paper, one of the case study examples presented with the CII Tool is considered to enable comparisons with the methods described above. The results obtained are also compared to those generated using the Super Decisions software. The case is a Gulf Coast Cogeneration Plant, an industrial facility to generate electric power, steam and high-pressure boiler feedwater within the complex of an existing refinery. The site has been selected at a central location within the complex. The major elements have been indentified, which include a heat recovery steam generator, gas turbine generator, transformer, substation, switchgear building and controls. The first two of these are long lead items. The major piping, electrical lines and controls are to be integrated with the existing lines and equipment. There is time pressure to complete the design and reach mechanical completion within 18 months, because the emissions from the existing steam generation facilities are of environmental concern. The new plant is to be constructed with minimal disruptions to the operation of the existing plant. This is the first co-generation project for this owner. The same set of selection of factors identified and ranked in the CII Tool publication are used as follows: 1) Factor 7 - Ensure shortest schedule, 2) Factor 1 - Control cost growth, 3) Factor 9 - Ease of change incorporation and 4) Factor 13 - Maximize owner's controlling role.

3.1 Binary Methods

It is simple to apply the binary methods as all the judgements are given by the ranking. The MBDM-1 and MBDM-2 are represented in Figures 4 and 5, respectively. The preference scores are entered into the CII Tool spreadsheet, which calculates the sum product for each PDCS (multiplies the relative effectiveness values of each PDCS by the corresponding preference scores and calculates the total score for each PDCS), and ranks the PDCS's. The results are summarized in Table 2.

Factor	7	1	9	13	Sum across rows	Priorities	Preference Scores
7	0	1	1	1	3	0.5	50
1	0	0	1	1	2	0.33	33.33
9	0	0	0	1	1	0.17	16.67
13	0	0	0	0	0	0	0
					6	1	

Figure 1: MBDM - 1

Factor	7	1	9	13	Sum across rows	Priorities	Preference Scores
7	1	1	1	1	4	0.4	40
1	0	1	1	1	3	0.3	30.00
9	0	0	1	1	2	0.2	20.00
13	0	0	0	1	1	0.1	10
					10	1	

Figure 2: MBDM - 2

3.2 AHP Methods

To apply the AHP scale, the verbal clues from the case study analyzed by the CII Tool served as a guide, assuming that the same decision maker would make the same statements regardless of the method used. The following was stated: Factor 1 (Control cost growth) is "not quite as critical" as Factor 7 (Ensure shortest schedule). Factor 9 (Ease change incorporation) "is slightly less important than" Factor 1. Factor 13 (Maximize owner's controlling role) is "important, but not as critical as factors 1, 7 and 9." As there is certain flexibility in interpreting these statements, several possible corresponding sets of judgments were considered. Since the CII Tool instructs to select the PDCS from the top three ranked alternatives, based on their strengths and weaknesses and the default compensation approaches, the focus will be on the top three results when analyzing and comparing the methods considered.

Iteration 1 judgements are shown in Figure 6, and the Table 1 shows the preference scores arising from these judgements, calculated by each of the four approximate methods and by the Super Decisions software, along with the preference scores calculated by the two binary methods and those assigned in the original case study example. The consistency ratios (C.R.), where they apply, were calculated by the method given by Saaty (1980). The C.R. was within the recommended limit, except for the method AHP-1 Crudest, for which the C.R. was over this limit by only 0.01. The ratings and rankings of the PDCS's following from these sets of preference scores are shown in Table 2.

Factor	7	1	9	13
7	1	3	5	9
1	1/3	1	3	7
9	1/5	1/3	1	5
13	1/9	1/7	1/5	1

Figure 3: AHP Iteration 1

Table 1 - Iteration 1

Factor	Preference Scores							CII Tool
	Binary		AHP					
			Approximate methods				Software	
	MBDM-1	MBDM-2	AHP-Crudest	AHP-Better	AHP-Good 1	AHP-Good 2		
7	50	40	48.23	61.70	55.77	56.51	56.60	32
1	33.33	30.00	30.37	22.67	26.76	26.96	26.74	27
9	16.67	20.00	17.51	11.03	13.30	12.60	12.67	24
13	0	10	3.90	4.61	4.17	3.93	3.99	16
Consistency ratio	n/a	-0.83333	0.11	0.09	0.06	0.06	0.06	0

*Original values form the CII Tool were normalized, which does not affect the results.

Table 2 - Iteration 1

CII Tool			Binary				AHP									
							Approximate methods								Software	
			MBDM-1		MBDM-2		Crudest		Better		Good 1		Good 2			
Rank	PDCS	Rating	PDCS	Rating	PDCS	Rating	PDCS	Rating	PDCS	Rating	PDCS	Rating	PDCS	Rating	PDCS	Rating
1	12	76.29	11	83.3	12	76	11	78.6	11	84.36	11	82.53	11	83.47	11	83.34
2	6	66.45	7	81.7	7	70	7	77.7	7	83.66	7	81.6	7	82.43	7	82.33
3	2	65.32	12	75.0	11	70	12	76.5	12	83.09	12	79.95	12	80.04	12	80.15
4	7	60.97	6	70.0	6	68	6	69.6	6	72.34	6	71.15	6	71.3	6	71.32
5	3	60.65	8	68.3	2	61	8	65.4	8	72.31	8	69.76	8	70.52	8	70.46
6	1	60.65	2	55.0	8	59	2	57.2	9	61.88	9	56.61	9	56.92	9	57.06
7	11	59.68	9	48.3	3	55	9	50.4	2	55.61	2	56.07	2	55.75	2	55.79
8	4	59.03	3	48.3	1	53	5	49.8	5	47.42	5	48.33	5	48.05	5	48.07
9	5	56.45	5	48.3	5	53	3	49.4	10	43.73	3	43.2	3	42.57	3	42.51
10	8	51.45	1	43.3	4	52	1	45.3	3	38.56	10	40.87	10	40.91	10	41.02
11	9	48.39	4	43.3	9	49	4	44.9	1	33.31	1	38.46	1	37.71	1	37.65
12	10	37.10	10	36.7	10	37	10	37.9	4	32.85	4	38.04	4	37.31	4	37.25

The Iteration 2 judgements are shown in Figure 7, the corresponding preference scores in Table 3, and rankings and ratings in Table 4. The C.R. for the AHP-Crudest is 1.13.

Factor	7	1	9	13
7	1	2	3	5
1	1/2	1	3	5
9	1/3	1/3	1	5
13	1/5	1/5	1/5	1

Figure 4: AHP Iteration 2

Table 3 - Iteration 2

Factor	Preference Scores							CII Tool
	AHP							
	Binary		Approximate methods				Software	
	MBDM-1	MBDM-2	AHP-Crudest	AHP-Better	AHP-Good 1	AHP-Good 2		
7	50	40	38.24	50.38	44.68	45.38	45.00	32
1	33.33	30.00	33.02	28.99	31.45	32.09	32.05	27
9	16.67	20.00	23.17	14.23	17.74	16.74	17.10	24
13	0	10	5.56	6.40	6.13	5.80	5.86	16
Consistency ratio	n/a	-0.83333	0.13	0.10	0.08	0.08	0.08	0

Table 4 - Iteration 2

	CII Tool		Binary				AHP									
							Approximate methods								Software	
			MBDM-1		MBDM-2		Crudest		Better		Good 1		Good 2			
Rank	PDCS	Rating	PDCS	Rating	PDCS	Rating	PDCS	Rating	PDCS	Rating	PDCS	Rating	PDCS	Rating	PDCS	Rating
1	12	76.29	11	83.3	12	76	12	73.2	11	79.37	11	76.13	11	77.46	11	77.05
2	6	66.45	7	81.7	7	70	11	71.3	7	78.53	12	75.81	7	76.51	7	76.14
3	2	65.32	12	75.0	11	70	7	70.8	12	78.34	7	75.37	12	75.73	12	75.64
4	7	60.97	6	70.0	6	68	6	67.6	6	70.08	6	68.94	6	69.08	6	69
5	3	60.65	8	68.3	2	61	2	59.7	8	66.92	8	63.45	8	64.46	8	64.1
6	1	60.65	2	55.0	8	59	8	58.6	2	57.47	2	58.39	2	57.92	2	58.06
7	11	59.68	9	48.3	3	55	3	57.3	9	53.95	3	51.66	3	51	3	51.34
8	4	59.03	3	48.3	1	53	1	54.6	5	49.73	5	50.92	5	50.55	5	50.68
9	5	56.45	5	48.3	5	53	4	54.0	3	46.94	9	49.27	9	49.41	9	49.18
10	8	51.45	1	43.3	4	52	5	52.5	1	43.18	1	48.42	1	47.63	1	48.01
11	9	48.39	4	43.3	9	49	9	44.1	4	42.54	4	47.81	4	47.05	4	47.42
12	10	37.10	10	36.7	10	37	10	35.0	10	39.12	10	36.97	10	36.82	10	36.76

In Iteration 3, the attempt was to 'force' the pair wise comparisons, to get the preference scores as close as possible to those assigned in the CII Tool, in order to, first, find the consistency of the judgements, and second, to see how well such judgements correspond to the verbal statements of the case study. The simplest way to do this is by choosing 'direct data entry' in the software and entering the values assigned in the case study (100, 85, 75 and 50). The inconsistency index is 0. The corresponding pair wise comparisons are shown in Figure 8.

Factor	7	1	9	13
7	1	1	1	2
1	1	1	1	2
9	1	1	1	2
13	1/2	1/2	1/2	1

Figure 5: AHP Iteration 3

This set of comparisons has three out of six of the required comparisons (upper right triangle) as 'equal importance' and the other three, the value between 'equal' and 'slightly more important,' - the judgements which are not in accordance with the statements that this hypothetical decision-maker expressed. The calculation methods applied to these comparisons give the results in the Tables 5 and 6.

Table 5 - Iteration 3

Factor	Preference Scores							
	AHP							CII Tool
	Binary		Approximate methods				Software	
	MBDM-1	MBDM-2	AHP-Crudest	AHP-Better	AHP-Good 1	AHP-Good 2		
7	50	40	28.57	28.57	28.57	28.57	28.57	32
1	33.33	30.00	28.57	28.57	28.57	28.57	28.57	27
9	16.67	20.00	28.57	28.57	28.57	28.57	28.57	24
13	0	10	14.29	14.29	14.29	14.29	14.29	16
Consistency ratio	n/a	-0.83333	0.00	0.00	0.00	0.00	0.00	0

Table 6 - Iteration 3

	CII Tool	Binary		AHP				
				Approximate methods				Software
		MBDM-1	MBDM-2	Crudest	Better	Good 1	Good 2	
Rank	PDCS	PDCS	PDCS	PDCS	PDCS	PDCS	PDCS	PDCS
1	12	11	12	12	12	12	12	12
2	6	7	7, 11	2, 6	2, 6	2, 6	2, 6	2, 6
3	2	12						
4	7	6	6	1, 3	1, 3	1, 3	1, 3	1, 3
5	1, 3	8	2					
6		2	8	4	4	4	4	4
7	11	3, 5, 9	3	7	7	7	7	7
8	4		1,5	5, 11	5, 11	5, 11	5, 11	5, 11
9	5							
10	8	1,4	4	8	8	8	8	8
11	9		9	9	9	9	9	9
12	10	10	10	10	10	10	10	10

In Iteration 4, the difference between any two factors immediately next to each other in ranking is the smallest difference possible on the AHP scale. Here, the guiding idea was to get results as close as possible to the original case study, while also respecting the verbal statements mentioned with some flexibility. The comparison: Factor 1 is 'slightly more important' than factor 9 is interpreted as 2, rather than 3. This gives the comparisons shown in Figure 9. The corresponding results are shown in Tables 7 and 8.

Factor	7	1	9	13
7	1	2	2	3
1	1/2	1	2	3
9	1/2	1/2	1	3
13	1/3	1/3	1/3	1

Figure 6: AHP Iteration 4

Table 7 - Iteration 4

Factor	Preference Scores							
	Binary		AHP					CII Tool
			Approximate methods				Software	
	MBDM-1	MBDM-2	AHP-Crudest	AHP-Better	AHP-Good 1	AHP-Good 2		
7	50	40	37.21	43.87	40.63	40.94	40.94	32
1	33.33	30.00	30.23	26.70	28.75	28.95	28.95	27
9	16.67	20.00	23.26	19.19	20.81	20.47	20.47	24
13	0	10	9.30	10.24	9.81	9.65	9.65	16
Consistency ratio	n/a	-0.83333	0.06	0.05	0.05	0.04	0.05	0

Table 8 - Iteration 4

	CII Tool	AHP				
		Approximate methods				Software
		Crudest	Better	Good 1	Good 2	
Rank	PDCS	PDCS	PDCS	PDCS	PDCS	PDCS
1	12	12	12	12	12	12
2	6	7	7	7	7	7
3	2	6	11	11	11	11
4	7	11	6	6	6	6
5	3	2	2	2	2	2
6	1	3	8	8	8	8
7	11	8	9	3	3	3
8	4	1	5	5	5	5
9	5	4	3	1	1	1
10	8	5	1	4	4	4
11	9	9	4	9	9	9
12	10	10	10	10	10	10

In Iteration 5, the only difference from Iteration 4 is the comparison of Factor 1 to Factor 9 (value 3), as shown in Figure 10. The results are shown in Table 9.

Factor	7	1	9	13
7	1	2	2	3
1	1/2	1	3	3
9	1/2	1/3	1	3
13	1/3	1/3	1/3	1

Figure 7: AHP Iteration 5

Table 9 - Iteration 5

Results

	CII Tool	AHP				
		Crudest	Better	Good 1	Good 2	software
Rank	PDCS	PDCS	PDCS	PDCS	PDCS	PDCS
1	12	12	12	12	12	12
2	6	11	11	11	11	11
3	2	7	7	7	7	7
4	7	6	6	6	6	6
5	3	2	8	2	8	8
6	1	3	2	8	2	2
7	11	8	9	3	3	3
8	4	1	5	1	5	1
9	5	4	3	5	1	5
10	8	5	1	4	4	4
11	9	9	4	9	9	9
12	10	10	10	10	10	10

Iterations 6, 7 and 8 are shown in Figures 11, 12 and 13 respectively, and their results in the summary Table 10.

Factor	7	1	9	13
7	1	2	3	3
1	1/2	1	2	3
9	1/3	1/2	1	2
13	1/3	1/3	1/2	1

Figure 8: AHP Iteration 6

Factor	7	1	9	13
7	1	2	4	9
1	1/2	1	3	4
9	1/4	1/3	1	2
13	1/9	1/4	1/2	1

Figure 9: AHP Iteration 7

Factor	7	1	9	13
7	1	2	3	9
1	1/2	1	2	3
9	1/3	1/2	1	2
13	1/9	1/3	1/2	1

Figure 10: AHP Iteration 8

4 Analysis of the Results

Both binary methods as well as all four AHP methods in all the iterations except the Iteration 3 gave the same set of PDCS's for the first three places, which were significantly different than the first three rankings by the CII Tool. The PDCS 12 is the only alternative common to all the methods in all the iterations, as one of the top three. The PDCS 6 ranked second by the CII Tool and fourth by all other methods in all but Iteration 3, and the PDCS 2 ranked third by the CII tool and fifth, sixth or seventh by the other methods for the same set of iterations. In Iterations 4 and 5, the AHP methods agree with the CII Tool regarding the highest ranking alternative, but not regarding the second and third alternatives. In Iteration 3, the top three rankings are very close to those of the CII Tool (see Table 10).

The binary methods are quite crude. They do not require judgements any more specific than ranking of the factors. The MBDM-1 implies that if there is one lowest ranked factor, such as in our example, it gets a preference score 0, and therefore does not affect the selection, which is not the idea of the CII Tool. For this reason, the MBDM-1 would not be recommended for this purpose.

The exact AHP calculations require specific software. The more consistent the judgements, the closer the results of the approximate methods are to each other and to the exact results. For perfectly consistent judgments, the results are the same for all the methods presented. The methods AHP-1 Crudest and

AHP-3 Good 1 can easily be used with straightforward calculations, whereas the AHP-4 Good 2 require more computational effort and can be programmed on a spreadsheet software. The CII Tool itself utilizes a spreadsheet application. The difference between the preference scores of the selection factors calculated by the software and those calculated by each of the approximate methods is analysed. An average of the absolute values of the percentage differences of all selection factors is calculated for each of the approximate methods. The method AHP-4 Good 2 gives the closest results to those calculated by the software in all iterations except Iteration 7, for which the AHP-3 Good 1 was closest. Table 10 is the summary of the PDCS rankings for all the eight iterations of the AHP (calculations by software), along with the CII Tool and the binary methods.

Table 10

	CII Tool	Binary		AHP							
		MBDM-1	MBDM-2	Iteration 1	Iteration 2	Iteration 3	Iteration 4	Iteration 5	Iteration 6	Iteration 7	Iteration 8
Rank	PDCS	PDCS	PDCS	PDCS	PDCS	PDCS	PDCS	PDCS	PDCS	PDCS	PDCS
1	12	11	12	11	11	12	12	12	12	11	12
2	6	7	7*	7	7	2*	7	11	11	7	11
3	2	12	11*	12	12	6*	11	7	7	12	7
4	7	6	6	6	6	1**	6	6	6	6	6
5	3*	8	2	8	8	3**	2	8	8	8	8
6	1*	2	8	9	2	4	8	2	2	2	2
7	11	9*	3	2	3	7	3	3	9	9	9
8	4	3*	1*	5	5	5*	5	1	5	5	5
9	5	5*	5*	3	9	11*	1	5	3	3	3
10	8	1*	4	10	1	8	4	4	1	1	1
11	9	4*	9	1	4	9	9	9	4	10	10
12	10	10	10	4	10	10	10	10	10	4	4
C.R.	0.00	n/a	-0.83333	0.06	0.08	0.00	0.05	0.08	0.03	0.01	0.01

*, ** groups of PDCS in the same column, in consecutive cells that have the same rating

Only Iteration 3 has the same first three PDCS's as the CII Tool, and this is the iteration where the numerical values of the comparisons don't match the verbal expressions. However, it could also be argued that Iterations 1, 2, 7 and 8 did not correctly convert the verbal statements, as the comparisons of Factor 7 to Factor 13 have values of 5 or 9. These correspond to 'strongly' and 'extremely' more important respectively, whereas that Factor 13 was 'important, but not as critical' as the other factors.' Iterations 4, 5, and 6 interpret the verbal statements more accurately, and they have the same result as the CII tool for the first place, but not for the second and third places. Iterations 1,2,7 and 8, 'try' to follow the verbal statements, but they also follow the logic: "if A is greater than B, and B is greater than C, then A is greater than C by more than B is greater than B." This leads to the larger differences between the highest and lowest ranked factors than the verbal statements suggest. However, in these cases, even when the judgements don't follow the consistency logic of the type expressed above, the Consistency Ratio is still acceptable as all the iterations respect the same ranking.

The CII Tool, as well as those iterations of the AHP that follow the verbal statements more closely and that are less concerned with the numerical consistency (while respecting the ranking of factors), chose the PDCS 12, Fast Track as the top alternative. The CII Tool ranked PDCS 6, Construction Management at Risk as second, and PDCS 2 Traditional with Early Procurement as third. The AHP chose PDCS 7, Design-Build (or EPC) and PDCS 11, Turnkey as the second or third ranked. The principal difference between the CII choices and the AHP choices is the amount of owner control, which corresponds to the selection factor 13, the lowest ranked of the four factors selected. The case study expressed that the owner's control is important "to insure a smooth interface with existing refinery operations," (CII, 2003). However, the CII Tool explanation also includes a comment that, if the owner desires a single contract for design and construction the PDCS 7 Design-Build, which is similar to PDCS 12, could be used (CII 2003). This makes the results of the AHP methods more consistent with the CII Tool.

The pair-wise comparisons tend to result in greater differences between the factors and give the lowest ranking factor a lesser rating than one would tend to assign intuitively. This could be because the AHP methods express comparisons in multiples of whole numbers. 'Slightly more important' converts to three times more important. Even 'less than slightly more important but more than equally important' converts to two times more important. Moreover, the idea of being consistent (following the logic: if A is 2 times more important than B, and B is 3 times more important than C, then A is 6 times more important than C), may lead to high values.

5 Conclusion and Future Work

An objective method to determine relative weights (preference scores) of the factors for selection of a project delivery system (PDS) for a particular project is presented. The method is an extension to and provides improvement to the decision support system previously developed by the CII. Two variations of the multiple binary decision method (MBDM), as well as the Analytical Hierarchy Process (AHP), all based on pair wise comparisons were implemented in a software application and their results compared on a case study. AHP Method referred to as “Good 2” is suggested, as a very close approximation not requiring a computation device any more complex than the CII Tool already utilizes. One should approach each pair wise comparison as independent, and not calculate any judgement based on judgements already made, in an effort to be consistent. Similar studies could be performed on additional case study examples and results compared. Other extensions to the CII Tool could include additional PDS’s used in practice, such as various Public Private Partnership options and the Integrated Project Delivery. Also, additional selection factors may be identified and their relative effectiveness values determined.

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