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# Selecting Optimal Project Delivery System for Infrastructural Projects Using Analytic Hierarchy Process

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**Abstract** Enormous financial requirements, high technological and scientific level, high work volume are the main differentiations between infrastructural andnormal projects. Given these specifications, selection of suitable project delivery system (PDS) for construction of infrastructural projects is of paramount importance, and making mistake and miscalculation in this field will incur irreparable loss to the development projects. Therefore, adoption of suitable policy in decision-making process with regard to the construction operation of project is of paramount significance, so that development of systems and logistics tools for the decision-making process can help project commissioners to improve current activities in the best form possible. The paper presents a decision-making model to select the optimal PDS for infrastructural construction projects based on identification and comparison of various contracting systems. The viewpoints of 62 expert engineers, contractors, consultants about the advantage and drawbacks of five more common PDSs have been collected via questionnaires and interviews. At the end, a comprehensive methodology has been presented to fine the optimal PDS for each Infrastructural project using Analytic Hierarchy Process (AHP).

***Keywords:*** *project delivery system, project management, construction management, Analytic Hierarchy Process (AHP)*

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## 1. Introduction

In general, project delivery systems and way of fulfilment of process specify main factors in project to materialize objectives of project through clarifying procedures and measures, sequences of events, contractual communications and extent of commitments and responsibilities [1] Generally, other various terms are used for project delivery system such as contract strategy, contract management and project supply method. Experts, specialists and different international institutes have presented different classifications for project delivery systems (PDSs). The following parametersare considered as the most important factors causing classification of delivery systems and also preliminary for genesis of modern construction methods (U.S. Civil Engineers Association, 2005):

- Isolating or merging design and construction contracts;
- Assigning responsibility based on unity or multiplicity and degree of involvement of employer;
- Transferring and sharing risk;
- Participation of isolated management team.

Various qualitative and quantitative decision-making models have been presented for the selection of optimal PDS in recent two decades. Perry and Gordon have presented qualitative removal models for the selection of optimal PDS, details of which are selected with omission of inappropriate system for the construction of desired project. Turner has also presented qualitative matrices model for selecting the optimal contracting strategy. AGC and Jomezadeh developed multiplex qualitative summation attributed weight (SAW) decision-making model for the selection of optimal contracting system and Karamouz [4] presented multi-fuzzy decision-making model. Oyetunji and Anderson [11] have presented quantitative Self-Monitoring, Analysis, and Reporting Technology (SMART) for comparing different contracting systems. This paper first reviews the related literature to PDS. Then, AHP is introduced as a decision-making model to be used for selecting the optimal PDS based on the characteristics of the project and needs of employer. In the next step, the results of questionnaires and interviews are presented, and the validity and reliability of the collected data is investigated by doing analysis like α test. At the end, a case study is done for validating the developed decision-making model.

### 1.1. Common Types of PDSs

Overall, Based on the classifications presented by specialists and factors mentioned in above, PDSs can be classified as follows:

- Design-Bid-Build (DBB),
- Design-Build (DB),
- Construction Management (CM),
- Construction Management at Risk (CM@R),
- Turnkey (TK).

In DBB project delivery system, employer signs separate contracts with designer and contractor. The designer is duty bound to fulfil designing process for selection of contractor. Moreover, designer is tasked with providing construction drawings and documents [5]. In this PDS, supervision on construction operation shall be borne by designer. In the same direction, employer is responsible for coordinating between design, construction and management.

In the CM type of PDS, employer sign management contract with construction manager separately. Moreover, employer sign design contract with designer and also construction contract with contractor separately. Construction manager helps employer in the following fields:

- Making financial decisions,
- Controlling costs and expenses,
- Delegating tenders,
- Setting a prescheduled date for the construction operation of project,
- Reporting various stages of construction operation to the employer.

In the large and infrastructural projects, which are facing with various and frequent complexities, the construction manager can play a leading role on time and cost of project [6]. Usually, construction manager does not undertake any risk in the course of construction operation of project at all. On the whole, construction manager plays the role of consulting engineer to employer.

In the third type of PDS which is known as CM@R, employer signs a separate contract with the construction manager. In this case, construction manager undertakes a pivotal role in construction operation of project. In order to get rid of clashes and construction risks, employer concludes a contract with construction management contractor, so that management contractor assigns construction of project to subcontractors and designers. In general, all risks of management and construction operations of project are delegated to the contractor of construction management [7]. In this system, overlapping design and construction and completing various stages of construction operation of project is possible.

In the last two PDS types, employer assigns the responsibility of designing, procurement, construction and commissioning of project to the contractor completely. When the construction operation of project is completed, employer can deliver the project can commission the project readily. In these methods, employer will interfere in process of tendering session and also monitoring on performance of the contractor in the execution process. Risk of employer in this system will reach to the minimum possible rate, so that contractor is held responsible for any risk as defined in this contract.

### 1.2. Decision-Making Method

Analytic Hierarchy Process (AHP) is chosen as one of the most comprehensive and multiple decision- making models. This model was developed by Thomas L. Saaty, et al.. This approach is a decision-making approach which starts its activity with creation of generalized tree. The decision-making tree of hierarchy analysis indicates parameters and indicators of comparison and rival and goal alternatives. With paired comparison of alternatives with regard to each index and also paired comparisons of criteria, decision maker can obtain weight value of each alternative to each index and also weight value of each index to the main objective. Then, with multiplication of weight value of each option in relevant criteria, the general value of each alternative is obtained and consequently, optimal use will be obtained with the same option and with high weight value. Of salient examples of AHP, it should be referred to the calculation of incompatibility rate of judgments, analysis of sensitivity on criteria and options and possibility of qualitative or quantitative judgment. It has particular application in group decision making, and is used around the world in a wide variety of decision situations, in fields such as government, business, industry, healthcare, shipbuilding and education.

Rather than prescribing a "correct" decision, the AHP helps decision makers find one that best suits their goal and their understanding of the problem. It provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions. Users of the AHP first decompose their decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analysed independently. The elements of the hierarchy can relate to any aspect of the decision problem-tangible or intangible, carefully measured or roughly estimated, well or poorly understood-anything at all that applies to the decision at hand. Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing them to one another two at a time, with respect to their impact on an element above them in the hierarchy. In making the comparisons, the decision makers can use concrete data about the elements, but they typically use their judgments about the elements' relative meaning and importance. It is the essence of the AHP that human judgments, and not just the underlying information, can be used in performing the evaluations.

## 2. Factors Affecting the Selection of Optimal PDS

Relatively comprehensive research activities have been written on scientific texts for recognizing indexes affecting choice of optimal system performance and in this respect, viewpoints of managers of projects, consulting engineers have been taken into consideration in large and mega projects. In the same direction, constructive viewpoints of experts and employers in infrastructural projects were collected and designed within the framework of a questionnaire and interviews. On the whole 52 questionnaires were collected and analysed. Also, the opinions of 12 experts were collected via interview. In the Table 1 and Table 2 show the position and work experience of respondents.

**Table 1. Respondents' positions**

| Position | Percentage |
|---|---|
| Project manager and controller | 18% |
| Supervisor and inspector | 13% |
| Estimator and surveyor | 15% |
| Foreman | 8% |
| Management contractor | 19% |
| University lecture | 13% |
| Others | 25% |

**Table 2. Respondents' work experience in infrastructural construction projects**

| Work Experience (year) | Percentage |
|---|---|
| 2-6 | 33% |
| 6-10 | 39% |
| 10-15 | 18% |
| 15-20 | 8% |
| >20 | 12% |

After fulfilling these researches, finally, a number of 20 factors were selected after merging and rounding up factors affecting choice of optimal execution, details of which have been mentioned in Table 3.

**Table 3. Brief description of evaluated factors**

| No. | Factors | Description |
|---|---|---|
| $F_1$ | Cost increase controlling | Project should be constructed with the initial estimated costs. |
| $F_2$ | Minimum costs guarantee | Project should be executed with minimum costs. |
| $F_3$ | Delay in payment | Projects' cash flow has restriction. |
| $F_4$ | The possibility of estimating costs in the initial phases | Exact cost estimation in the initial phases is needed. |
| $F_5$ | Decreasing or transferring risks | Employer does not accept the responsibility of risks. |
| $F_6$ | Controlling delays | Project should be constructed in the scheduled time. |
| $F_7$ | Minimum time scheduling | Time is a vital factor for the project. |
| $F_8$ | Compatibility with changes in site mobilizations or procurements | There are high level of changes and uncertainties in site layout and procurement |
| $F_9$ | Easiness in implementing changes in project | Employer wants to implement different changes in all phases easily. |
| $F_{10}$ | Compatibility with high level of changes | Project has high level of changes in planning and scheduling. |
| $F_{11}$ | Confidentiality of the project's details | Confidentiality of details is vital in the project success. |
| $F_{12}$ | Similarity in the project's parts | Project is divided into the same sub projects. |
| $F_{13}$ | Maximizing the controlling role of employer | Employer wants to have the highest controlling level on the project. |
| $F_{14}$ | Minimizing employer's involvement | Employer does not want to be involved in the details of the project. |
| $F_{15}$ | performance level in normal initial project plan | The success of project with normal plan is considered. |
| $F_{16}$ | Performance level in the weak initial project plan | Good performance is needed despite weak initial plans. |
| $F_{17}$ | Minimizing involving parties in the contract | Minimizing the involved parties in the project success is vital. |
| $F_{18}$ | Performance in complexities coordination | Project has high level of complexities. |
| $F_{19}$ | Promoting the execution quality | Quality issues have special importance. |
| $F_{20}$ | Observing HSE issues | HSE issues are implemented strictly. |

## 3. Results of Surveying

After determination of factors affecting the selection of optimal PDS, questionnaires and interviews were designed in order to collect information to compare the performance of PDSs. The designed questionnaires and interviews were distributed among designers and employers (19%), consultant engineers (28%), contactors and project managers of infrastructural projects (38%) and also university lecturers (15%). The results of the analysed collected data in this stage have been shown in Table 4.

**Table 4. The results of collected data by questionnaires and interviews**

| NO. | Factors | DBB | CM | CM@R | DB | T-K |
|---|---|---|---|---|---|---|
| $F_1$ | Cost increase controlling | 8 | 12 | 14 | 16 | 17 |
| $F_2$ | Minimum costs guarantee | 12 | 11 | 10 | 15 | 16 |
| $F_3$ | Minimizing costs rate | 15 | 14 | 14 | 17 | 18 |
| $F_4$ | The possibility of estimating costs in the initial phases | 7 | 8 | 13 | 16 | 17 |
| $F_5$ | Decreasing or transferring risks | 7 | 9 | 14 | 16 | 18 |
| $F_6$ | Controlling delays | 8 | 10 | 13 | 15 | 17 |
| $F_7$ | Minimum time scheduling | 7 | 9 | 14 | 16 | 17 |
| $F_8$ | Compatibility with changes in site mobilizations or procurements | 8 | 9 | 14 | 16 | 16 |
| $F_9$ | Easiness in implementing changes in project | 17 | 16 | 12 | 8 | 6 |
| $F_{10}$ | Compatibility with high level of changes | 18 | 17 | 13 | 7 | 5 |
| $F_{11}$ | Confidentiality of the project's details | 16 | 13 | 11 | 8 | 7 |
| $F_{12}$ | Similarity in the project's parts | 9 | 11 | 12 | 16 | 18 |
| $F_{13}$ | Maximizing the controlling role of employer | 18 | 17 | 13 | 10 | 8 |
| $F_{14}$ | Minimizing employer's involvement | 6 | 10 | 13 | 15 | 17 |
| $F_{15}$ | performance level in normal initial project plan | 10 | 12 | 13 | 15 | 16 |
| $F_{16}$ | Performance level in the weak initial project plan | 16 | 16 | 13 | 6 | 5 |
| $F_{17}$ | Minimizing involving parties in the contract | 8 | 7 | 13 | 15 | 17 |
| $F_{18}$ | Performance in complications coordination | 9 | 11 | 14 | 16 | 17 |
| $F_{19}$ | Promoting the execution quality | 10 | 13 | 12 | 16 | 17 |
| $F_{20}$ | Observing HSE issues | 10 | 12 | 11 | 14 | 15 |

Note: DBB: Design-Bid-Build, CM: Construction Management, CM@R:Construction Management at Risk, DB: Design-Build, T-K: Turnkey.

## 4. The Validity and Reliability of Statistical Data

The following criteria were considered in order to increase validity and reliability of data in results of questionnaires and interviews:

- Studying and editing questions of questionnaire by university experts and connoisseurs and also managers of infrastructural projects,
- Accurate defining of terms existing at questionnaire,
- Justification of respondents,
- Heterogeneity and homogeneity of respondents
- Filling out questionnaires in person.

Also, results of questionnaire were developed in Linkert Scale using SPSS software system in order to calculate validity of data of questionnaires. The Cronbach's Alpha Coefficient calculated by the SPSS software was .86 which shows that the collected data by questionnaires and interviews have high level of validity.

## 5. Selection of Optimal PDS Using AHP Model

In this stage, the weighed value of each PDS to each factor is obtained with paired comparison of the PDSs to each factor. Then, with multiplying weighed value of each PDS, weighed value of each factor is obtained and finally, point of each PDS is obtained with summing up these calculated numbers for all factors. Overall, the following stages should be taken into consideration in decision making using AHP for selecting the optimal PDS based on developed factors:

**a. Identifying components of decision-making process**

Three key components are required for each decision-making process which includes: objective, criteria, and options. This principle is also accurate in AHP decision making. Accordingly, the goal includes: selection of optimal PDS, factors which can affect selection of optimal PDS and finally, options which are PDSs.

**b. Determining Relationship between Components and Formation of Structure of AHP** Determining relationship amongst PDSs, factors and optimal PDS is followed up at the next stage of AHP and finally, analytic hierarchy Tree (AHT) is made which is shown in Figure 1. AHT causes levels of a complicated and complex decision making to correlate with one another logically and regularly. Moreover, AHT causes analysis to be comprehendible easily. Optimal PDS, factors and finally PDSs are of the most important and salient indicators of AHT.

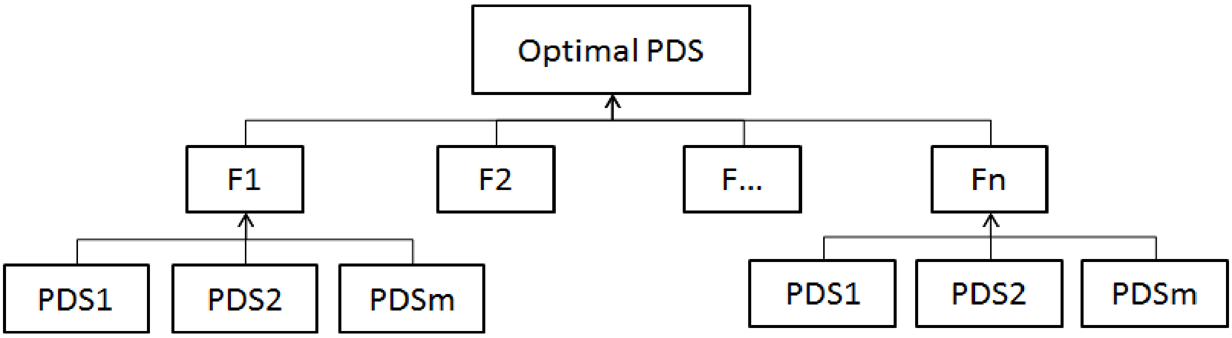


**Figure 1.** AHT of the developed AHP system for selecting optimal PDS

**c. PDSs' Paired Comparisons**

At this stage, paired comparison of PDSs to each factor is conducted in tubular basis shown in the Table 5. So, the weighed value of factors to the main objective is obtained.

**Table 5. Paired comparisons of PDSs to factor 1**

| Factor 1 | PDS 1 | PDS 2 | …… | PDS m |
|---|---|---|---|---|
| PDS 1 | 1 | $a_{i12}$ | | $a_{i1m}$ |
| PDS 2 | $a_{i21}$ | 1 | | |
| …… | | | 1 | |
| PDS m | $a_{im1}$ | $a_{im2}$ | | 1 |

**d. Factors; Paired Comparisons**

Similar to the previous stage, paired comparisons of factors to the main objective is conducted at this stage, based on which, weighed value of indicators to the objective is obtained. This process is done through Table 6 and equation 1.

$$r_{ij} = \frac{\bar{a}_{ij}}{\sum_{i=1}^{m} \bar{a}_{ij}} \qquad (1)$$

**Table 6. Paired comparisons of factors to optimal PDS**

| Factor i | PDS 1 | …. | PDS m | Priority |
|---|---|---|---|---|
| PDS 1 | $r_{i11}$ | …. | $r_{i1m}$ | $A_{i1} = r_{i11}+\ldots+r_{i1m}/m$ |
| PDS 2 | …. | …. | …. | $A_{i2} = r_{i21}+\ldots+r_{i2m}/m$ |
| …. | …. | …. | …. | …. |
| PDS m | $r_{im1}$ | …. | $r_{imm}$ | $A_{im} = r_{im1}+\ldots+r_{imm}/m$ |

**e. Calculation of points of PDSs**

At this state, general score of each option to the main objective is obtained by multiplication of weighed value of each option in weighed value of each relevant indicator and also addition of relevant figures.

## 6. Computation

Various software packages have been developed and designed for Analytic Hierarchy Process (AHP), the most important of which can be referred to: Expert Choice (EC)11 software. It should be noted that this software package enjoys high level of capabilities and potentials in the field of analysis of data and also decision-making process as follows:

- Displaying AHT
- Calculating judgments' inconsistent rate
- Possibility of judging and comparing using different qualitative and quantitative methods
- Providing sensitivity analysis on data

After the collection of questionnaires and study of validity and reliability of data, the obtained results were summed up and inserted into relevant software package. Given the above issues, the software carries out PDSs' paired comparisons with regard to each index and PDSs' relative weight is obtained in each factor. Moreover, this software is able to rank PDSs. Sensitivity analysis on factors that to what extent adoption of change in weighed value of factors and viewpoints of decision makers can affect the obtained ranking using AHP. The negligible difference between two PDSs indicates level sensitivity among them.

# 7. Case Study

In order to evaluate performance and application of proposed mode, in development projects, a petrochemical project was selected in this respect. The cost needed for the construction operation of this giant project was estimated at approximately 500 million dollars as fixed price. This project was decided to be constructed in the form of EPCC (Engineering, Procurement, Construction), including initial and detailed design, procurement and supply of construction materials, construction operation of project, installing and commissioning parts and equipment, testing performance and training staff and personnel related to employer. In order to select optimal system performance, the desired project manager was requested to determine priorities of project and employer with relation to the indictors of optimal system performance. It should be noted that the results of the study have been shown in the Table 7 in efficacy of 0 and 20.

**Table 7. The quantitative results gathered in case study**

| No. | Factors | Quantitative Importance |
|---|---|---|
| $F_1$ | Cost increase controlling | 16 |
| $F_2$ | Minimum costs guarantee | 14 |
| $F_3$ | Minimizing costs rate | 16 |
| $F_4$ | The possibility of estimating costs in the initial phases | 12 |
| $F_5$ | Decreasing or transferring risks | 18 |
| $F_6$ | Controlling delays | 16 |
| $F_7$ | Minimum time scheduling | 14 |
| $F_8$ | Compatibility with changes in site mobilizations or procurements | 18 |
| $F_9$ | Easiness in implementing changes in project | 14 |
| $F_{10}$ | Compatibility with high level of changes | 6 |
| $F_{11}$ | Confidentiality of the project's details | 8 |
| $F_{12}$ | Similarity in the project's parts | 14 |
| $F_{13}$ | Maximizing the controlling role of employer | 12 |
| $F_{14}$ | Minimizing employer's involvement | 14 |
| $F_{15}$ | performance level in normal initial project plan | 12 |
| $F_{16}$ | Performance level in the weak initial project plan | 10 |
| $F_{17}$ | Minimizing involving parties in the contract | 16 |
| $F_{18}$ | Performance in complications coordination | 10 |
| $F_{19}$ | Promoting the execution quality | 16 |
| $F_{20}$ | Observing HSE issues | 10 |

To find optimal system performance for the desired project, EC 11 software package system was used. The following procedures were taken into consideration respectively to select the optimal PDS for considered project:

a. Creation of Analytic Hierarchy Tree

b. Paired Comparisons

c. Observation of Results

d. Sensitivity Analysis

As it is observed in the Figure 2, it is obvious that TURNKEY or EPCC with scoring 0.226 stood at the first rank and CMR, MC and DBB stood at the next ranks respectively.

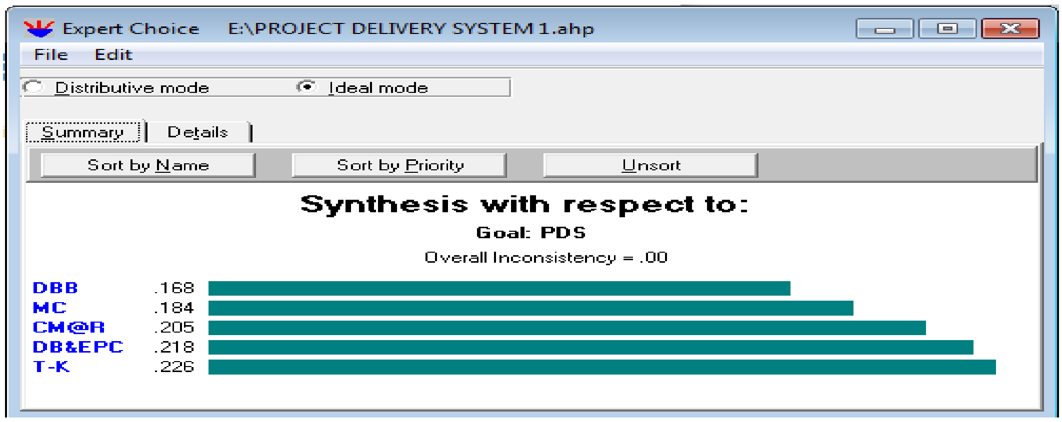


**Figure 2.** The results of the EC analysis on data collected data in the case study

## 8. Conclusions

Since none of project implementation system cannot be introduced and proposed as the best performance system absolutely and since each of various project performance system has its own advantages and disadvantages, the best system should be determined for the construction of project based on terms and conditions of the same project. In other words, with the extraction of requirements and specific condition of project, employer should embark on selecting a system that can produce suitable final output and efficiency for the project. Materialization of this issue requires employer to first identify various methods of execution of projects and specifications of each of them. Then, employer should determine specific conditions of project and also existing capabilities.

In this study, with comprehensive and all-out study of different infrastructural projects, a number of 20 effective indicators were identified and selected in decision making and selection of project performance system. In the same direction, relative significance of each of them was obtained using questionnaires distributed among employers, managers of projects, consulting engineers, and specialist and expert engineers who have though knowledge in related field. In continuation, an analytical approach was used based on Analytic Hierarchy Analysis (AHP) for optimal construction of projects. Then, results of questionnaire were inserted and saved in EC software package, so that weight value of options was obtained in comparison with the indexes. It should be noted that this software is used for the optimal construction of several infrastructural projects. The answers obtained from software were the same that managers of project were proposing them with several years of successful work in large and mega projects. Also, significance of each of factors studied in decision- making and change process in the selected methods based on change in significance of each of decision-making factors using sensitivity analysis. It can be mentioned that this software can be adapted easily to changes, so that an option or index can be removed or added easily and/or adopt some corrections in data of input questionnaire to software. It should be noted that this software can be completed more comprehensively in future studies. Moreover, this software can be used by employers of large and infrastructural projects as contractual management software in line with selecting optimal construction system.

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