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Optimization Model in Subcontractors Assignment in Jordan

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Abstract

Contracting companies carry out important construction projects in cooperation with subcontractors, that makes subcontractor selection is an important part of the project management. Consequently, when awarding construction contracts depending on the price only, it is not always a successful strategy and it may result in many problems like delay, cost overrun, and bad quality. The main objective of this research is to identify and rank the factors used by main contractors in the selection of suitable subcontractors in Jordan and to propose recommendations for improving the selection of subcontractors. A structured questionnaire was constructed to rank the importance of each of these factors in Jordan, next a model using linear programming (Assignment Model) was constructed to study the effect of selecting subcontractor based on prequalification criteria and optimization procedure. The suggested model for subcontractors' selection is an attempt to be able to make a tradeoff between tender price, time, financial ability, technical ability, and management capabilities and safety. A case study for distributing ten subcontractors between ten bids is studied The distribution of these bids among subcontractors are different when distributing bids depends on price only and using the suggested model, it will be very important when dealing with large and specialist project.

Keyword: Subcontractor, Prequalification, Optimization, Assignment.

INTRODUCTION

Subcontractors are specialty contractors who are hired to perform specific tasks on an engineering project. **(Shash, 1998)** indicates that many general contractors act as construction management agents only and subcontract a large volume of their work to subcontractors.(Wang, **2000)** argues that it is usual for a construction project to involve over 50 subcontractors working on the job site. Therefore subcontractors are playing a vital role in engineered projects and several successful construction projects were carried out by the efficient cooperation between the contractors and subcontractors. Subcontractors support general contractors to overcome problems related to the need for special expertise, shortage of resources and limitation in finances **(Elazouni and Metwally, 2000)**.Therefore, the selection of a subcontractor by the contractor is a significant decision, because the progress and completion of the projects for a large part are depended on the selected subcontractors. In this context, the proper selection of subcontractor is considered as an important parameter in the successful management of the various construction projects (**Arditi and Chotibhongs; 2005**). Qualified subcontractors are usually able to perform their work specialty more quickly and at a lesser cost than the general contractor can **(Arditi andChotibhongs, 2005).**

As a result, researchers emphasize the importance of selecting appropriate subcontractors **(Kumaraswamy and Matthews, 2000; Ng et al., 2008 a&b; Arditi and Chotibhongs, 2005; Arslan et al., 2008)**

(Ang et al., 1984) showed that in the selecting subcontractors in procurement and tendering the lowest price found to be a suitable procedure in the routine project only. But many studies referred that in case of selecting the subcontractor depending on only the tendering price presented by subcontractors, is not always a successful strategy because this is sometimes produced negative effects on the construction process like delay, cost overrun, and bad quality (**Ng et al., 2003; Nerija and Audrius, 2006**). To overcome these problems, it was recommended for organizations to use additional parameters like the costs, quality, delivery time, risk, past experience with contractor and reputation (**Lavelle, 2007; Hartmann, 2009**). As result, a multi-parameter evaluation is recommended, that mainly consist of: technology and equipment, management, experience and knowledge of the technical staff, financial stability, quality, being familiar with the area or being domestic, Reputation, and creativity and innovation (**Darvish et al. (2009); El-Mashaleh, M. S. (2009); Wong *et al.(* 2000)).**

In Jordanian construction project there are two types of projects beyond its fund, at first **projects funded by the treasury**; these projects are submitted by classified contractors with category appropriate to the nature and size of the tender, those tenders are usually financial proposals only, and the tender will be awarded to the bidder of the lowest total price.

Secondary, i**nternational Tenders** which are either fully or partially funded by international agencies, the tendering procedures in these tenders would be in accordance with the regulations and requirements of the financier. The tendering procedures are usually done in two stages. The first stage called **pre-qualification stage ;** where technical and financial capacities of the company specialized in the area of work is evaluated, depends on : the experience of the firm in projects of similar nature and complexity, the experience and qualifications of the technical and administrative employee, the financial situation, equipment and machinery available to the company are all evaluated. The result concluded from this stage gives a list of pre-qualified bidders who would be

invited to bid and obtain the tender documents. The second stage called the **proposal stage; where** the lowest total price bidder will award the tender.

This research will attempt to improve the Jordanian construction industry by advancing the current system of subcontractors' selection criteria based on prequalification criteria and optimization selection procedure.The evaluation technique used in this research combined the price of bids and the time needed to finish the project beside the prequalification technique; others research don't combine these in one model; all of them starts with a prequalification technique for the financial and technical ability then the lowest bid price is chosen. There is a lack of similar research on subcontractor's selection in Jordan, only a research for(**El-Mashaleh, M. S., 2009)** who contributes a Data Envelopment Analysis (DEA) model which combines both subcontractors bid price with other subjective criteria. The evaluation technique used in this research can be used with any other prequalification parameters and with any number of jobs and subcontractors.

METHODOLOGY

Prequalification criteria

Prequalification is a process of qualifying and investigating subcontractors prior to the award of bids, based on their skills, ability, integrity, and responsibility. An effective qualification process will serve both owners and contractors because it eliminates incompetent, underfinanced, and inexperienced subcontractors from consideration.

Prequalification criteria start from defining the main factors that affect subcontractor's selection these factors are extracted from the literature. (**Marzouk, 2012)** determines 34 sub-criteria of subcontractor selection driven from other studies. These factors were grouped into eleven criteria. (**Lavelle, 2007)** shows the top rankings were health and safety, closely followed by insurance, price and past performance". **(Talukhaba, 2007)** discussed the factors necessary for domestic subcontractor's selection in the South African construction industry. He concludes that experienced and financially stable subcontractors should have good chances of winning tenders. In addition, reputation is one that many contractors highly depend on when deciding whether or not a sub-contractor will be chosen, as highlighted by **(Hartmann, 2009).** From these studies and others (like **Lavelle (2007), Hartmann (2009),** and **abed.I(2015))** which gives important factors for selecting subcontractors, a structured questionnaire is constructed and used to rank these factors depending on consultants and main contractor's opinion. Table1 summarized the factors used for subcontractors selection. After ranking these factors according to the important, each of them should take a weighted index used in the next step for optimization.

Table 1. Factors used for subcontractors prequalification

1	**Estimated cost of project / Tender price**
2	**Estimated time of project**
3	**Financial Ability** • Share capital for subcontractor • Amount of work (financial) in the last five years
4	**Technical Ability** • Ranking of subcontractor • Level of technology (physical equipment) • Number of similar successful projects in the past five years • The qualifications of staff
5	**Management Capabilities and Safety** • Reputation (Past Performance)(based on the number of successful projects carried out) • Health and safety record • Acknowledgement certificates from government agencies • The overall impression (includes the information provided and how subcontractor respond to the required documents)

Optimization procedure

The optimization problem is maximizing or minimizing some function relative to some set, often representing a range of choices available in a certain situation. The function allows comparison of the different choices for determining which might be "best." Common applications: Minimal cost, maximal profit, minimal error, optimal design, optimal management, variational principles.

Optimization is achieved usually by using linear programming techniques of operations research; in the research linear programming by using assignment approach will be used. Depending on the prequalification results, the rank of factors is found and the weighted index is calculated for each factor; that reflect the importance of each factor. For the optimization procedure, two cases for submission of tenders are compared. At first bids are submitted depend on tendering price only; to find the minimum total cost for the ten projects. In the second case the optimization technique will be used to find the maximum total weight that given for each subcontractor, related to the prequalification criteria (that depends on the weight resulted from questionnaire analysis).

The distribution of the ten bids among ten subcontractors and the total cost of the ten project will be compared to the two cases.

RESULTS OF QUESTIONNAIRE

The respondent asked to rank the factors by rating the importance of the factors on the five-point Likert scale as follows (1-Not important, 2-slightly important, 3- neutral, 4-important, 5- extremely important).The data collected from the returned questionnaire were analyzed using Statistical Package for Social Sciences (SPSS), the mean score then used to rank factors in descending order of importance.

Tables 2 and 3 show the rank for the group of factors and for all factors separately

Table 2. Rank and weight index for factors

Factors	Mean	Std. Deviation	Rank	Level of importance	Weight Index
Estimated time of project	4.32	0.66	1	VERY HIGH	9.62
Reputation (Past Performance)(based on the number of successful projects carried out)	4.11	0.94	2	VERY HIGH	9.15
Estimated tender price	4.05	0.80	3	HIGH	9.02
The qualifications of staff	3.89	1.09	4	HIGH	8.66
Level of technology (physical equipment)	3.86	1.03	5	HIGH	8.59
Number of similar successful projects in the past five years	3.79	1.03	6	HIGH	8.44
Share capital for subcontractor	3.74	1.13	7	HIGH	8.32
Ranking of subcontractor	3.66	1.19	8	HIGH	8.15
Health and safety record	3.64	1.15	9	HIGH	8.1
The overall impression (includes the information provided and how subcontractor respond to the required documents)	3.62	1.08	10	HIGH	8.1
Amount of work (financial) in the last five years	3.45	1.11	11	HIGH	7.68
Acknowledgement certificates from government agencies	2.77	1.11	12	MEDIUM	6.17
					100

Table 3. Comparison of all factors groups

Groups of factors	Mean	Rank	Level of importance
Estimated time of project	4.32	1	VERY HIGH
Estimated tender price	4.05	2	HIGH
Technical Ability	3.80	3	HIGH
Financial Ability	3.60	4	HIGH
Management Capabilities & Safety	3.53	5	HIGH

CASE STUDY

The case study taken is for ten projects for adding extra classrooms and maintenance project for schools in Jordan. These projects are usually submitted by third, fourth and fifth-degree contacting companies. Ten subcontractors submitted for these projects, each of them submits a request for all projects, in addition, a financial, technical, management, and safety proposal is submitted according to the factors mentioned before.

subcontractor1, subcontractor2, and subcontractor3 are third-degree subcontractors, subcontractor4, subcontractor5, subcontractor6, subcontractor7, and subcontractor8 are fourth-degree subcontractors, and at last, subcontractor9 and subcontractor10 are fifth-degree subcontractors. All information about the submitted proposal seen in Appendix A.

MODELING

Linear programming used to obtain an optimal result, i.e., a result that best reaches the specified goal (according to the mathematical model) among all feasible alternatives **(Padberg, M., 2013**).

The general form for linear model is allocating resources to activities. This model is to select the values for $x_1, x_2, \ldots, x_n$ so as to**(Padberg, M., 2013):**

Minimize $\mathbf{Z = \sum_{j=1}^{n} c_j x_j}$ **(1)**

Subject to

$\sum a_{ij} x_j \leq b_i$ (i=1,2,3,…,m)

$x_j \geq 0$ (j=1,2,...,n)

The assignment problem is a special type of linear programming problem where assignees are being assigned to perform tasks (one task for each assignee). Assigning people to jobs is a common application of the assignment problem. The total cost is denoted by Z, so the assignment equation is written (**Winston, et al.2004**):

Minimize $\mathbf{Z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij}}$ **(2)**

Subject to

$\mathbf{\sum_{j=1}^{n} x_{ij} = 1}$ For i = 1, 2, …, m (this means that each assignee performs one job)

$\mathbf{\sum_{i=1}^{m} x_{ij} = 1}$ For j = 1, 2, …, n (this means that each job is done by one assignee)

Where $\boldsymbol{x_{ij}}$: binary, for all I and j.

So, $x_{ij} = 0 \; or \; 1$ where,

1: if assignee i performs job j

0: if not

Reseach used program WIN QSB (Quantitative system for business) to find a solution for the linear model, this programming is a software package that use the simplex algorithm to solve large linear models to find the optimum solution **(Chang, Y. L. 1998**), the outputs generated are:

1) An optimal solution satisfies the objective function.
2) An optimal value for the decision variables.
3) Maximum or minimum cost for the objective function.

The projects will be initially distributed using assignment approach depending on price only, that meant to make the best distribution of projects between the subcontractors to achieve the minimum total cost for all project. Projects then will be distributed depends on modified approach taking into account the prequalification of each subcontractor according to the main factors which analyzed previously, and using the weighted index assigned to each factor according to their mean score.

A comparison between this two cases will be done; the distribution of projects and the total cost of all projects.

Bid evaluation depends on price only

In the first case the optimum minimum price for all projects will be determined depending on assignment approach; so each subcontractor will take only one project. The following equation is the linear modeling for this case (**Winston, W. L., and Goldberg, J. B., 2004**):

By letting Z denote the total cost

Minimize $\mathbf{Z = \sum_{i=1}^{m} \sum_{j=1}^{n} cij \; xij}$ **(3)**

Subject to

$\mathbf{\sum_{j=1}^{n} x_{ij} = 1}$ **For i = 1, 2, …, m**

$\mathbf{\sum_{i=1}^{m} x_{ij} = 1}$ **For j = 1, 2, …, n**

Where,

C_{ij}= the cost submitted by subcontractor i for project j.

X_{ij}= 0 or 1 where,

1: if subcontractor i performs project j

0: if not

Table 4 summarized the solution taken from Win QSB software with a total minimum price of 163,287 JOD.(Results are seen in Appendix B)

Table 4. Distribution of bids depends on tender price

SUB.CONTR	BIDS	PRICE(JD)
SUB.CONTR1	**BID H**	6814
SUB.CONTR2	**BID I**	7934
SUB.CONTR3	**BID E**	15782
SUB.CONTR4	**BID G**	6224
SUB.CONTR5	**BID B**	27029
SUB.CONTR6	**BID J**	7008
SUB.CONTR7	**BID C**	26407
SUB.CONTR8	**BID F**	10096
SUB.CONTR9	**BID A**	35800
SUB.CONTR10	**BID D**	20193
	Total price	163,287

Bid evaluation depends on prequalification technique

The suggested prequalification technique gives weights to the factors for the price, time, technical ability, financial ability, and management capacities and safety.

These weights are given to each subcontractor depends on their financial and technical proposal submitted related to the factors. For example (for financial ability) each subcontractor will take a score from 10 according to the submitted financial proposal , this will be done for each factor under this section separately, if all admission requirements are verified ;score 10 will be given, otherwise a score less than 10 will be given, this score used with the weight of each factor (calculated from questionnaire analysis) to find the overall weight for each single factor . the summation of all factors weight gives the overall weight for financial section. Similarly is done for technical ability and management and safety sections.

On the other hand for price and time sections, every subcontractor will have a score related to the approved values of contract; that's mean every bid price approaching to the approved value will take a higher score however it is higher or lower than the approved value.

Table 5 shows a sample of the calculated weight which is a weight summation for the price, time, financial, technical, and management for subcontractor1. And Figure 1 shows the calculated weight from 100 for each subcontractor for every bid.

Table 5. Sample of weight summation

Group of factors	**BID A**	**BID B**	**BID C**	**BID D**	**BID E**	**BID F**	**BID G**	**BID H**	**BID I**	**BID J**
Price	8.35	8.81	8.33	8.80	7.43	6.61	8.85	8.19	8.17	8.02
Time	8.55	8.55	8.55	8.02	8.02	8.02	9.62	9.62	3.21	9.62
Financial	13.44	13.44	13.44	13.44	13.44	13.44	13.44	13.44	13.44	13.44
Technical	33.50	33.50	33.50	33.50	33.50	33.50	33.50	33.50	33.50	33.50
management	25.35	25.35	25.35	25.35	25.35	25.35	25.35	25.35	25.35	25.35
sum for SUB.CONTR1	89.19	89.65	89.17	89.11	87.74	86.91	90.76	90.10	83.67	89.93

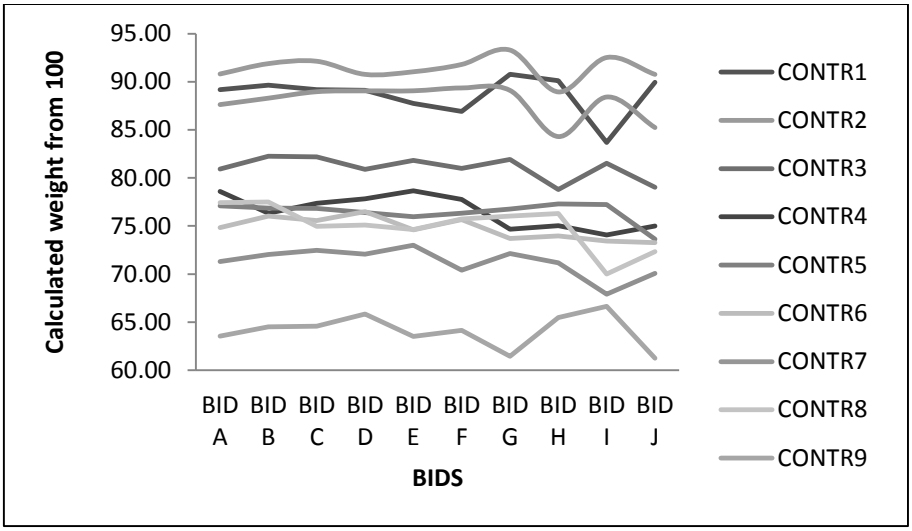

Figure 1. Calculated weight for each subcontractor

The modified assignment equation constructed is linear modeling for maximizing the qualification of each subcontractor, so bids will be distributed among the degree of qualification of subcontractors; this is called the prequalification technique.

This approach will not exclude the submitted price, but it will give it a percentage from the evaluation of all remaining factors. The following equation is the linear modeling for this case:

Maximize $\mathbf{Z} = \sum_{i=1}^{m} \sum_{j=1}^{n} wij\ xij$ **(4)**

Subject to

$\sum_{j=1}^{n} x_{ij} = 1$ For i = 1, 2, …, m

$\sum_{i=1}^{m} x_{ij} = 1$ For j = 1, 2, …, n

X_{ij}= 0 or 1 where,

1: if subcontractor i performs project j

0: if not

Where w_{ij} is the calculated weight given to each subcontractor depending on the prequalification technique. These weights will be maximized to find the optimum selection for subcontractors; depending on their qualifications. The following table 6 summarized the solution taken from Win QSB software with a total price of 188683 JOD. (Results are seen in Appendix C)

Table 6. Distribution of bids depends on prequalification

SUB.CONTR	**BIDS**	**PRICE(JD)**
SUB.CONTR1	**BID J**	8883
SUB.CONTR2	**BID G**	7226
SUB.CONTR3	**BID C**	28352
SUB.CONTR4	**BID A**	45500
SUB.CONTR5	**BID H**	8091
SUB.CONTR6	**BID D**	21917
SUB.CONTR7	**BID F**	10642
SUB.CONTR8	**BID B**	31634
SUB.CONTR9	**BID I**	9144
SUB.CONTR10	**BID E**	17294
	Total price	188683

Although the total bid price is greater than the previous case which depends only on the tender prices, but this distribution of bids among each subcontractor is best; because it depends on their qualification added to their submitted price, so it is sure that the best-qualified subcontractor will take the bid he can do without any problems in execution. This will reduce the problems in quality, overrun, and over cost.

It was noticed that there is a difference between this distribution of bids and the previous distribution which depends only on tender price, but this selection is less riskiness; because each subcontractor is given the suitable bid relating to their abilities and their qualifications.

CONCLUSIONS

The researcher devised the following conclusions:

1) The factors used in this study are not compulsory, therefore each company can identify the important factors related to the nature of their work.
2) The possibility of using assignment linear modeling in any number of project and subcontractors to achieve the highest profit depending on the suggested evaluated criteria.
3) The possibility of using the suggested evaluation criteria with the lowest prices.
4) The possibility to find the number of losses arising from the random distribution of projects.
5) The distribution of bids among subcontractors differs when the prequalification is used and the total price of all project will be increased more than when the evaluation depends only on price , but in this case it is sure to obtain the required quality and to finish at a time without overrun, and this is very important when dealing with large and specialist project.
6) It is possible to exclude one or more of subcontractors as his qualification don't match the required specification.
7) The possibility of using this new evaluation criterion in all kinds of contracts in Jordan except the consultancy services tenders where all specifications are must require.

RESEARCH CONTRIBUTIONS

1) The evaluation technique used in this research combined the price of bids and the time needed to finish the project beside the prequalification technique; others research don't combine these in one model; all of them starts with a prequalification technique for the financial and technical ability then the lowest bid price is selected.
2) There is a lack of similar research on subcontractor's selection in Jordan, only a research for El-Mashaleh, M. S. (2009) who contributes a Data Envelopment Analysis (DEA) model which combines both subcontractors bid price with other subjective criteria.
3) The evaluation technique used in this research combines prequalification technique and optimization technique.
4) This technique can be used with any number of jobs and subcontractors even if it's not equal

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Appendix A

Table 1-A, 2-A, 3-A, 4-A, 5-A summarized the submitted proposal from subcontractors (tender prices, estimated time to finish the projects, technical ability, financial ability, and management capabilities and safety) that needed for the prequalification procedure.

Table 1-A Submitted tender price from all subcontractors

Subcontractors	BID A	BID B	BID C	BID D	BIDE	BID F	BID G	BID H	BIDI	BID J
SUB.CONTR1	50500	30267	30130	25608	22345	13309	7132	6814	8151	8883
SUB.CONTR2	43640	28814	29206	28384	24372	10283	7226	8703	7934	10506
SUB.CONTR3	39900	31133	28352	27380	15782	9598	8121	6361	10827	7002
SUB.CONTR4	45500	36030	29417	27850	18552	11792	6224	6968	10597	11431
SUB.CONTR5	47800	27029	27638	20580	23309	10413	7969	8091	9758	11868
SUB.CONTR6	50200	32701	30969	21917	16067	10882	7527	7140	8036	7008
SUB.CONTR7	51100	31407	26407	26185	19886	10642	7293	9144	10063	7077
SUB.CONTR8	45700	31634	33093	22316	22012	10096	5724	8655	10272	9881
SUB.CONTR9	35800	35102	31500	27537	22490	9300	5363	8574	9144	10056
SUB.CONTR10	45100	28626	28804	20193	17294	14434	8296	9679	6317	8460

Table 2-A Submitted projects time from all subcontractors (months)

Subcontractors	BID A	BID B	BID C	BID D	BID E	BID F	BID G	BID H	BID I	BID J
SUB.CONTR1	8	8	10	7	7	5	3	3	5	3
SUB.CONTR2	11	10	8	5	6	5	3	4	3	3
SUB.CONTR3	8	8	10	7	6	7	3	4	3	4
SUB.CONTR4	9	8	10	6	6	6	4	4	4	3
SUB.CONTR5	10	9	8	6	6	7	3	3	3	3
SUB.CONTR6	11	8	8	6	5	5	4	4	4	4
SUB.CONTR7	10	10	9	6	6	6	3	4	3	4
SUB.CONTR8	9	9	8	5	7	7	3	3	5	4
SUB.CONTR9	8	8	10	6	7	5	4	3	3	4
SUB.CONTR10	11	8	10	6	6	6	3	3	4	4

Table 3-A Financial Ability for subcontractors

	Financial Ability	
Subcontractors	**Share capital of subcontractors (JOD)**	**Amount of works in the last 5 years (JOD)**
SUB.CONTR1	160000	2000000
SUB.CONTR2	155000	3000000
SUB.CONTR3	150000	1800000
SUB.CONTR4	75000	1500000
SUB.CONTR5	80000	1400000
SUB.CONTR6	70000	1800000
SUB.CONTR7	60000	1200000
SUB.CONTR8	65000	1000000
SUB.CONTR9	20000	850000
SUB.CONTR10	25000	900000

Table 4-A Technical ability for subcontractors

	Technical Ability			
Subcontractors	**Ranking of subcontractors**	**level of technology (physical equipment)**	**Number of similar successful projects in the past 5 years**	**The qualification of staff**
SUB.CONTR1	3	have all needed equipment	24	technical manager, engineers
SUB.CONTR2	3	have all needed equipment	17	technical manager, engineers
SUB.CONTR3	3	have all needed equipment	19	technical manager, engineers
SUB.CONTR4	4	have all needed equipment	25	technical manager, engineers
SUB.CONTR5	4	have all needed equipment	17	technical manager, engineers
SUB.CONTR6	4	don't have all needed equipment	20	technical manager, engineers
SUB.CONTR7	4	have all needed equipment	22	technical manager, engineers
SUB.CONTR8	4	have all needed equipment	22	technical manager, engineers
SUB.CONTR9	5	don't have all needed equipment	17	engineers
SUB.CONTR10	5	don't have all needed equipment	19	engineers

Table 5-A Management capabilities and Safety for subcontractors

	Management capabilities and Safety			
Subcontractors	**Reputation**	**Health and safety records**	**Acknowledgements certificates**	**The overall impression**
SUB.CONTR1	all past projects delivered on time and with good quality	excellent	no	excellent
SUB.CONTR2	some projects were delayed	v.good	yes	excellent
SUB.CONTR3	all past projects delivered on time and with good quality	v.good	no	good
SUB.CONTR4	some projects were delayed	good	no	excellent
SUB.CONTR5	all past projects delivered on time and with good quality	v.good	no	v.good
SUB.CONTR6	some projects were delayed	v.good	No	excellent
SUB.CONTR7	all past projects delivered on time and with good quality	excellent	yes	v.good
SUB.CONTR8	some projects were delayed	v.good	No	excellent
SUB.CONTR9	all past projects delivered on time and with good quality	v.good	no	good
SUB.CONTR10	some projects were delayed	v.good	yes	v.good

Appendix B

Branch-And-Bound Node Solution -- Iteration 1						
6/2/2016	Decision	Lower	Upper	Solution	Variable	
21:55:47	Variable	Bound	Bound	Value	Type	Status
1	X1	0	1	0	Binary	Yes
2	X2	0	1	0	Binary	Yes
3	X3	0	1	0	Binary	Yes
4	X4	0	1	0	Binary	Yes
5	X5	0	1	0	Binary	Yes
6	X6	0	1	0	Binary	Yes
7	X7	0	1	0	Binary	Yes
8	X8	0	1	1	Binary	Yes
9	X9	0	1	0	Binary	Yes
10	X10	0	1	0	Binary	Yes
11	X11	0	1	0	Binary	Yes
12	X12	0	1	0	Binary	Yes
13	X13	0	1	0	Binary	Yes
14	X14	0	1	0	Binary	Yes
15	X15	0	1	0	Binary	Yes
16	X16	0	1	0	Binary	Yes
17	X17	0	1	0	Binary	Yes
18	X18	0	1	0	Binary	Yes
19	X19	0	1	1	Binary	Yes
20	X20	0	1	0	Binary	Yes
21	X21	0	1	0	Binary	Yes
22	X22	0	1	0	Binary	Yes
23	X23	0	1	0	Binary	Yes
24	X24	0	1	0	Binary	Yes
25	X25	0	1	1	Binary	Yes
26	X26	0	1	0	Binary	Yes
27	X27	0	1	0	Binary	Yes
28	X28	0	1	0	Binary	Yes
29	X29	0	1	0	Binary	Yes
30	X30	0	1	0	Binary	Yes
31	X31	0	1	0	Binary	Yes
32	X32	0	1	0	Binary	Yes
33	X33	0	1	0	Binary	Yes
34	X34	0	1	0	Binary	Yes
35	X35	0	1	0	Binary	Yes

Branch-And-Bound Node Solution -- Iteration 1						
6/2/2016	Decision	Lower	Upper	Solution	Variable	
21:55:47	Variable	Bound	Bound	Value	Type	Status
36	X36	0	1	0	Binary	Yes
37	X37	0	1	1	Binary	Yes
38	X38	0	1	0	Binary	Yes
39	X39	0	1	0	Binary	Yes
40	X40	0	1	0	Binary	Yes
41	X41	0	1	0	Binary	Yes
42	X42	0	1	1	Binary	Yes
43	X43	0	1	0	Binary	Yes
44	X44	0	1	0	Binary	Yes
45	X45	0	1	0	Binary	Yes
46	X46	0	1	0	Binary	Yes
47	X47	0	1	0	Binary	Yes
48	X48	0	1	0	Binary	Yes
49	X49	0	1	0	Binary	Yes
50	X50	0	1	0	Binary	Yes
51	X51	0	1	0	Binary	Yes
52	X52	0	1	0	Binary	Yes
53	X53	0	1	0	Binary	Yes
54	X54	0	1	0	Binary	Yes
55	X55	0	1	0	Binary	Yes
56	X56	0	1	0	Binary	Yes
57	X57	0	1	0	Binary	Yes
58	X58	0	1	0	Binary	Yes
59	X59	0	1	0	Binary	Yes
60	X60	0	1	1	Binary	Yes
61	X61	0	1	0	Binary	Yes
62	X62	0	1	0	Binary	Yes
63	X63	0	1	1	Binary	Yes
64	X64	0	1	0	Binary	Yes
65	X65	0	1	0	Binary	Yes
66	X66	0	1	0	Binary	Yes
67	X67	0	1	0	Binary	Yes
68	X68	0	1	0	Binary	Yes
69	X69	0	1	0	Binary	Yes
70	X70	0	1	0	Binary	Yes

Branch-And-Bound Node Solution -- Iteration 1						
6/2/2016	Decision	Lower	Upper	Solution	Variable	
21:55:47	Variable	Bound	Bound	Value	Type	Status
71	X71	0	1	0	Binary	Yes
72	X72	0	1	0	Binary	Yes
73	X73	0	1	0	Binary	Yes
74	X74	0	1	0	Binary	Yes
75	X75	0	1	0	Binary	Yes
76	X76	0	1	1	Binary	Yes
77	X77	0	1	0	Binary	Yes
78	X78	0	1	0	Binary	Yes
79	X79	0	1	0	Binary	Yes
80	X80	0	1	0	Binary	Yes
81	X81	0	1	1	Binary	Yes
82	X82	0	1	0	Binary	Yes
83	X83	0	1	0	Binary	Yes
84	X84	0	1	0	Binary	Yes
85	X85	0	1	0	Binary	Yes
86	X86	0	1	0	Binary	Yes
87	X87	0	1	0	Binary	Yes
88	X88	0	1	0	Binary	Yes
89	X89	0	1	0	Binary	Yes
90	X90	0	1	0	Binary	Yes
91	X91	0	1	0	Binary	Yes
92	X92	0	1	0	Binary	Yes
93	X93	0	1	0	Binary	Yes
94	X94	0	1	1	Binary	Yes
95	X95	0	1	0	Binary	Yes
96	X96	0	1	0	Binary	Yes
97	X97	0	1	0	Binary	Yes
98	X98	0	1	0	Binary	Yes
99	X99	0	1	0	Binary	Yes
100	X100	0	1	0	Binary	Yes

Figure 1-B Evaluation of bids to the lowest tender price

Appendix C

Branch-And-Bound Node Solution -- Iteration 1

6/2/2016 23:02:07	Decision Variable	Lower Bound	Upper Bound	Solution Value	Variable Type	Status
1	X1	0	1	0	Binary	Yes
2	X2	0	1	0	Binary	Yes
3	X3	0	1	0	Binary	Yes
4	X4	0	1	0	Binary	Yes
5	X5	0	1	0	Binary	Yes
6	X6	0	1	0	Binary	Yes
7	X7	0	1	0	Binary	Yes
8	X8	0	1	0	Binary	Yes
9	X9	0	1	0	Binary	Yes
10	X10	0	1	1	Binary	Yes
11	X11	0	1	0	Binary	Yes
12	X12	0	1	0	Binary	Yes
13	X13	0	1	0	Binary	Yes
14	X14	0	1	0	Binary	Yes
15	X15	0	1	0	Binary	Yes
16	X16	0	1	0	Binary	Yes
17	X17	0	1	1	Binary	Yes
18	X18	0	1	0	Binary	Yes
19	X19	0	1	0	Binary	Yes
20	X20	0	1	0	Binary	Yes
21	X21	0	1	0	Binary	Yes
22	X22	0	1	0	Binary	Yes
23	X23	0	1	1	Binary	Yes
24	X24	0	1	0	Binary	Yes
25	X25	0	1	0	Binary	Yes
26	X26	0	1	0	Binary	Yes
27	X27	0	1	0	Binary	Yes
28	X28	0	1	0	Binary	Yes
29	X29	0	1	0	Binary	Yes
30	X30	0	1	0	Binary	Yes
31	X31	0	1	1	Binary	Yes
32	X32	0	1	0	Binary	Yes
33	X33	0	1	0	Binary	Yes
34	X34	0	1	0	Binary	Yes
35	X35	0	1	0	Binary	Yes

Branch-And-Bound Node Solution -- Iteration 1

6/2/2016 23:02:07	Decision Variable	Lower Bound	Upper Bound	Solution Value	Variable Type	Status
36	X36	0	1	0	Binary	Yes
37	X37	0	1	0	Binary	Yes
38	X38	0	1	0	Binary	Yes
39	X39	0	1	0	Binary	Yes
40	X40	0	1	0	Binary	Yes
41	X41	0	1	0	Binary	Yes
42	X42	0	1	0	Binary	Yes
43	X43	0	1	0	Binary	Yes
44	X44	0	1	0	Binary	Yes
45	X45	0	1	0	Binary	Yes
46	X46	0	1	0	Binary	Yes
47	X47	0	1	0	Binary	Yes
48	X48	0	1	1	Binary	Yes
49	X49	0	1	0	Binary	Yes
50	X50	0	1	0	Binary	Yes
51	X51	0	1	0	Binary	Yes
52	X52	0	1	0	Binary	Yes
53	X53	0	1	0	Binary	Yes
54	X54	0	1	1	Binary	Yes
55	X55	0	1	0	Binary	Yes
56	X56	0	1	0	Binary	Yes
57	X57	0	1	0	Binary	Yes
58	X58	0	1	0	Binary	Yes
59	X59	0	1	0	Binary	Yes
60	X60	0	1	0	Binary	Yes
61	X61	0	1	0	Binary	Yes
62	X62	0	1	0	Binary	Yes
63	X63	0	1	0	Binary	Yes
64	X64	0	1	0	Binary	Yes
65	X65	0	1	0	Binary	Yes
66	X66	0	1	1	Binary	Yes
67	X67	0	1	0	Binary	Yes
68	X68	0	1	0	Binary	Yes
69	X69	0	1	0	Binary	Yes
70	X70	0	1	0	Binary	Yes

Branch-And-Bound Node Solution -- Iteration 1

6/2/2016 23:02:07	Decision Variable	Lower Bound	Upper Bound	Solution Value	Variable Type	Status
71	X71	0	1	0	Binary	Yes
72	X72	0	1	1	Binary	Yes
73	X73	0	1	0	Binary	Yes
74	X74	0	1	0	Binary	Yes
75	X75	0	1	0	Binary	Yes
76	X76	0	1	0	Binary	Yes
77	X77	0	1	0	Binary	Yes
78	X78	0	1	0	Binary	Yes
79	X79	0	1	0	Binary	Yes
80	X80	0	1	0	Binary	Yes
81	X81	0	1	0	Binary	Yes
82	X82	0	1	0	Binary	Yes
83	X83	0	1	0	Binary	Yes
84	X84	0	1	0	Binary	Yes
85	X85	0	1	0	Binary	Yes
86	X86	0	1	0	Binary	Yes
87	X87	0	1	0	Binary	Yes
88	X88	0	1	0	Binary	Yes
89	X89	0	1	1	Binary	Yes
90	X90	0	1	0	Binary	Yes
91	X91	0	1	0	Binary	Yes
92	X92	0	1	0	Binary	Yes
93	X93	0	1	0	Binary	Yes
94	X94	0	1	0	Binary	Yes
95	X95	0	1	1	Binary	Yes
96	X96	0	1	0	Binary	Yes
97	X97	0	1	0	Binary	Yes
98	X98	0	1	0	Binary	Yes
99	X99	0	1	0	Binary	Yes
100	X100	0	1	0	Binary	Yes

Figure 1-C Evaluation of bids depending on subcontractors prequalification