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A two-stage multi-objective project selection regarding social welfare and risk optimization factors in BOT type projects: A case study in road construction industry

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Abstract

Infrastructure development is one of the key aspects to be prioritized if economic growth is to be maintained in developing countries. Amongst the bottlenecks in this path which impede the construction and expansion of the infrastructure facilities, lack of public funding is one of the primary issues. To tackle such a problem, governments are launching public-private partnership frameworks to raise funds for these projects. Studies on various methods of public-private partnerships suggest BOT (build, operate, transfer) as one of the most common and most successful ways of participation for the private sector in public projects and establishing a framework for the management of project risks. This project aims to provide a framework by which projects are prioritized according to their social welfare factors in the first step. Second step objective is to minimize the risks of taxes, utilization period, project lifetime, and highway capacity by solving a multi objective mathematical model. This is all done by proposing a two-stage optimization model based on reservation level Driven Tchebycheff Procedure (RLTP) and differential evolution (DE) algorithm to evaluate projects and prioritizing them based on their defined factors and associated risks. The model ensures that the private sector benefits from the execution and operation of the project in the BOT framework and the expected social welfare is also guaranteed. As a case study, data of the projects in transportation and road construction sector is obtained and evaluated.

Keywords: Differential evolution algorithm, Reservation Level Driven Tchebycheff Procedure (RLTP), Project selection, road construction risks

1- Introduction

Governments cannot afford financing infrastructures projects on their own, which is the reason BOT type contracts are so commonplace.

According to World Bank in a typical BOT contract, the public sector grants a private company the right to design and construct a public asset and in return, benefit from the final outcome of the project such as electricity in power plants or pay tolls on roads. Project Company obtains financing for the project, and procures the design and construction of the works and operates the facility during the concession period (Khzaeni and Ahmadi, 2006).

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However regarding their special features, each infrastructure project may have different risk factors that affect the factor selection decision-making and even prevents projects from reaching their objectives (Wang et al. 2014).

Lack of public funds as well as an increasing need to construct and develop infrastructure projects such as roads has incentivized the use of BOT contracts despite some drawbacks associated with this type. The first priority for governments is to select the project with the most attractive payoff.

On the other hand, due to their complexity and long-term duration, BOT projects are always associated with numerous risks ranging from financial issues to expropriation of breach agreements (Yang and Meng, 2000).

BOT[1] contracts are introduced as prototypes warranted by the government on behalf of a governmental system, often denoted as Principal, to outsource the development to private institutions known as Concessionaire. After construction, the developer has the rights to the project for a time period and is known as the project owner and is subject to enjoy the benefits of this development. When the contract expires (usually any period between 20 and 40 years) ownership is transferred to the government. As such, the private company undertakes the monetary responsibilities, builds the project and after a period of use relinquishes the ownership to the government either free or by means of compensation. The government is then the sole owner of the project and will utilize the project to benefit the public (Sebastiaan et al. 1999).

Nurkse (1952) is amongst the first economists who emphasize the importance of investing in developing countries. He believes such investments are the core driver of growth and development in developing countries. According to the literature on the BOT projects' risk management it is apparent that most studies have only focused on a specific area of project development and therefore the entire BOT steps of a project is ignored. Some of the most important risk factors in BOT projects can be grouped into one of the following: monetary, regulatory, supply, production, building and maintenance, utilization, political, market and demand risks (Kang et al. 2005).

Engel (2001) has studied the length of the contract and constructing a scenario in which the government agrees to extend the time for ownership based on demand. Nombela and de Rus (2004) and Tan and Yang (2012) studied a highway construction using BOT under the uncertainty of demand considering two scenarios. First, assuming the contract is absolutely flexible and prone to changes such that the government guarantees profit of the private sector. Second, contract is not as flexible and the demand risk is distributed between government and the private sector (Schaufelberger and Wipadapisut, 2003).

The most important criteria to be considered when taking the monetary support of the BOT projects are: access to monetary sources, project conditions and commercial risks. Mazaheri et al, used the DEMATEL approach applied to analyses interrelationships of the critical success factors for Iranian's BOT projects.

Fakhratov et al. (2020) attempted to first evaluate the concepts of project risk management based on different and valid standards, to evaluate risk management in construction projects. Then, an attempt has been made to present an implementation approach for implementing six stages of risk management in projects. For this purpose, based on the experiences of the project "Lala Residential Complex" in Kabul, as a case study, the experimental application of the proposed method in this study, step by step, along with forms designed for follow-up and Implementation of process steps have been evaluated and evaluated in accordance with the PMBOK standard by the Project Management Institute (PMI) to ensure that it is moving toward achieving project economic risk management goals.

Based on multi-objective programming method, Li (2020) put forward the importance of the research on project selection of government guarantee in Build-Operate-Transfer (BOT) or Public Private Partnership (PPP) project finance. Through the analysis of the selection criteria of guarantee project, they find that the selection problem of government guarantee of BOT/PPP infrastructure projects is essentially a multi-objective decision problem. Moreover, they establish a chance-constrained objective programming model for the government to make the decision to guarantee project selection.

Cherkos et al. (2020) tried to establish a conceptual framework that assists decision makers in the selection of a suitable PPP model in a well-organized way. Accordingly, a conceptual framework has

[1] Build, Operate and Transfer

been developed using PPP modality selection criteria to accommodate project characteristics with the experience of clients, the private sector, and lenders in preferring a specific PPP model. The implementation of the proposed framework has been validated with case study projects.

Patel et al. (2019) prepared a structured questionnaire which was then filled by contractors, government officers, academicians, project managers and consultants. For risk assessment, a systematic quantitative-based fuzzy probabilistic model is proposed with the help of lab-view, as a risk assessment technique to simulate the impreciseness of human judgment and to improve the assessment accuracy.

Due to limited resources, specifically regarding funding and available technologies, many of the previous researchers have focused solely on minimizing costs of implementation in such studies. This has resulted in major factors such as death tolls and accident-proneness of roads to be overlooked. In this paper, the BOT method is used in our mathematical model such that all vital criteria chosen according to experts in transportation technologies in addition to technical factors regarding highway projects are determined, regardless of funding and the technologies available .

Another gap in the literature involves the addition of risk management into this problem. In this paper, decision variables in the second stage of the mathematical model are presented in a way to drive simultaneous minimization of major risks associated with variables and maximization of objective functions: profit of the private sector and increase in social welfare.

This research aims to present a nonlinear multi-objective mathematical model for project selection. Due to the non-linearity and multi objectivity of the models, which put them in the NP- hard realm two solution algorithms, reservation level Driven Tchebycheff Procedure (RLTP) and differential evolution (DE) are proposed accordingly. The output of the system which includes two models would be a list of selected road construction projects regarding their social benefits and risk factors.

2- Model

2-1- Phase one: Project selection

The first step in choosing a project from a selection of many projects is to do a comprehensive evaluation of each of the projects in terms of profit, cost, risk, time, type, scale, benefactor, and necessary technologies. According to previous studies done on the subject and taking into consideration experts' opinions, factors that are needed to drive a decision in highway projects out of many candidate projects and are then utilized in building the mathematical model are as follows: minimizing travel time and distance traveled between two specified points, traffic size of vehicles, minimizing fuel usage, minimizing traffic and number of road accidents. As such, the first step includes two objective functions which is solved using the multi-objective method Reservation level Driven Tchebycheff Procedure (RLTP). The first objective function is solved first through minimizing travel times and distance travelled through the use of difference in average allowed speeds in substitute roads, the implementation of which will be discussed later, and the average speeds in current roads.

The effectiveness measure of highway development in decreasing travel time and consequently minimizing fuel usage and traffic is calculated by the American Association of State Highway and Transportation Officials (ASHTOO).

Equations relating to average travel speeds $\bar{V}$ in freeways are depicted as follows in the rush hour and otherwise:

$70 < FFS < 75$

$(3400-30FFS) < V < 2400$

$$\bar{V} = 1.6\ (FFS - [(FFS - \frac{160}{3})\ (\frac{V+30FFS-3400}{40FFS-1700})^{2.6}]) \tag{1}$$

$55 \le FFS \le 70$

$$(3400-30FFS) \le v \le (1700+10FFS) \tag{2}$$

Equations relating to average travel speeds in highways are depicted as follows:

$55 \le FFS \le 60$

$V \ge 1400$

$\overline{V}=1.6(\text{FFS} - [(\frac{3}{10}\text{FFS}-13)(\frac{V-1400}{40FFS-880})^{1.31}])$ (3)

55≤FFS≤55

v≥1400

In order to consider the value in the parsimony of time for duration of the project we have:

$$C_T^B(L_n,\overline{V_P},\overline{V_{OP}}) = \left[309H_p.(Q_P.\frac{L_n}{V_n}) + (6570-309H_p).(Q_{op}.\frac{L_n}{V_n})\right].(\overrightarrow{P}.\overrightarrow{\rho}) \quad (4)$$

$$P = \begin{bmatrix} P_{MC} \\ P_B \\ P_{2T} \end{bmatrix}$$

In which:

Ln = distance in Kilometer

$\overline{V}_p$ = average speeds during rush hour

$\overline{V}_{OP}$ = average speeds at other times

H_p = rush hours

ρ = cost vector (time-value of various vehicles included)

P = percentage of vehicles (in which P_{MC}, P_B, P_{2T} are light vehicles, buses and trucks respectively in both lanes)

C_T^B = travel cost for the entire route

The mathematical model is implemented assuming (3400 –30*FFS*) ≤ *v* ≤ 2400 and 70 ≤ *FFS* ≤ 75 for the main roads, (3400 –30*FFS*) ≤ *v* ≤ (1700 +10*FFS*) and 55 ≤ *FFS* ≤ 70 for subsidiary roads, and *v* ≤ (3400–30*FFS*) and 55 ≤ *FFS* ≤ 70 for rural roads. Otherwise, based on the v and FFS of each road type the $\overline{V}$ is calculated using above equations and are then plugged into the formula.

2-2- Mathematical model

n= total number of projects

i=index of projects

m= number of projects selected

j= index of selected projects

r= index of months in a year

a_n= length of rural road in Km which is replace with the nth highway

d_{rn}= average speed in rural road in r^{th} month which is replace with the nth highway

b_n= length of subsidiary road in km which is replace with the nth highway

q_{rn}= average speed in subsidiary road in r^{th} month which is replace with the nth highway

c_n= length of main road in Km which is replace with the nth highway

w_m= average speed in main road in r^{th} month which is replace with the nth highway

f_{rn}= average traffic in highway N during month r

T_n= duration of ownership rights (in years) for highway n

φ_n= tax rates for nth highway

L_n= if project n is selected, L = 1 otherwise 0

K_{ln}= Sum of the length (in Km) of all selected projects or projects with Ln = 1

P_n= cost of construction for highway n

t_{nk}= decrease in travel times in hours for each vehicle due to construction of highway n

$\overline{T}_n$= service life of project n

R_{nj}= type j risk of project n

u_a= effectiveness measure of highway instead of main road in decreasing road accidents

u_{bs}= effectiveness measure of highway instead of rural or subsidiary roads in decreasing road accidents

hrn= number of deaths in road accidents during month r in subsidiary or rural roads that are replaced by the nth highway

h_{rn}= number of deaths in road accidents during month r in main roads which is replace with the nth highway

Stage I model:

$$\text{Max} \sum_i \sum_r \text{Li} \left(\left(\frac{\text{ai}}{\text{dri}} . f_{rn} - a_i \left(1.6 \left(\text{FFS} - \left[\left(\frac{34}{205} FFS - \frac{219}{41}\right) \left(\frac{V-1400}{\frac{171}{5} FFS - 1181}\right)^{1.31}\right]\right)^{-1} . f_{ri}\right) + \left(\frac{bi}{qri} . f_i - q_n \left(1.6 \left(\text{FFS} - \left[\frac{1}{9}(7\text{FFS}) - 340 \left(\frac{V+30FFS-3400}{40\,FFS-1700}\right)^{2.6}\right]\right)^{-1} . f_n\right) + \left(\frac{Ci}{Wri} f_{ri} + \frac{Cn}{1.6\,FFS} f_n\right) \quad (6)$$

$$MAX \sum_i \sum_r (L_i\ ((h_{ri}(b_i + c_i)/(b_i + c_i + a_i)).u_{bc} + ((h'_{ri}.a_i)/(b_i + c_i + a_i)) * u_a) \quad (7)$$

$$\sum_i k_{li} \leq 5000$$

$$Ln\varepsilon\{0,1\}$$

Stage II model:

$$MAX \sum_j \sum_r (T_J . \varphi_J . f_{rj} - p_j(T_j, c)) \quad (8)$$

$$MAX \sum_j \sum_r (((B.t(c).f_{rj} . \overline{T_J})) + (\overline{T_j} - T_j).\varphi_j.f_{rj})\ ) \quad (9)$$

$$MINRISK \sum_j ((R_{1(T.c.\varphi.\overline{T})} + R_{2(T.c.\varphi.\overline{T})} + R_{3(T.c.\varphi.\overline{T})} + R_{4(T.c.\varphi.\overline{T})})) \quad (10)$$

$$\sum_j \sum_r (T_j . \varphi_j . f_{rj}) \leq \sum_j p_j\ (T'_j, c) \quad (11)$$

$$0 \leq T_j \leq T'_j \forall j \in m$$

$$3 \leq C_j \leq 6 \forall j \in m$$

$$0 \leq \varphi_j \forall j \in m$$

3- **Solution**

In this section we use a two-step hybrid solution to prioritize and select the projects regarding the factors discussed in phase 1 and phase 2. First, we use reservation levels Tchebycheff metric procedure (RLTP) algorithm to convert the multi objective phase 1 model to a single objective model and solve it in the GAMS software [15].This is an iteration-based algorithm by which we calculate the efficient solutions as the outputs of stage 1. The algorithm works within 4 steps as explained in article [16]. In the second step, a multi objective non-linear mathematical model will be solved using a metaheuristic method, differential evolution, as explained in article [17]. Using RLTP, we have solved the first level model. Given the multi-objective nature of the model and the Pareto figure for obtained solutions, an expert's opinion is sought and the solution with the highest level of effectiveness in lowering accidents is chosen and utilized as the input for the second stage. In the second stage the DE method is used to solve the nonlinear and multi-objective model which is considered as an NP-hard problem.

4- Results

To evaluate the validity of the models and the two-stage solution we gathered the data for more than 100 potential road construction projects in Iran. The data includes estimated distance, average accidents, death tolls, costs etc. by running the codes for two multi-objective mathematical models we will have a table, demonstrating the selected projects. Final projects prioritization is summarized as the table below. However, to make it shorter we only demonstrate the top 10 projects as per the social welfare factors and risk factors.

Table1. Projects' prioritization from the models

Project	Rank	Distance	Road Type			Accidents		Cost Estimates (million Tomans per line)
			Main	Subsidiary	Rural	Deaths	wounded	
Tabas-Deyhouk	1	80	0	0	83	52	972	40000
Jeyroft-Kohnouj-Roudan	2	83	23	52	12	43	804	53500
Hamedan-Sannandaj	3	180	161	23	0	129	2412	124000
Shiraz-FirouzAbad-Jam	4	270	214	48	16	178	2329	153000
Urumieh-Miandwab	5	180	145	27	13	116	2169	142000
KhoramAbad-Kouhdasht	6	75	0	75	0	41	767	575000
Bistoun-Mian Rahan-Sanghar-Gharveh	7	120	54	43	25	76	1421	88000
Ardabil-Meshgin Shahr-Ahar-Varzaghan	8	200	121	59	23	128	2494	158000
Bojnourd-Esfrain-Sabzevar	9	170	149	16	8	89	1664	85000
Marand-Jolfa	10	70	72	0	0	41	767	55000

5- Conclusion

Governments prefer to use BOT type contracts to aid in financing the construction and expansion of many public projects. This contract introduces a framework in which the private sector can participate in public projects by means of taking ownership over all aspects of a project for a time period. However, this framework poses many issues especially in terms of risks associated with projects in many areas such as project life time, taxes and many more. In addition, private companies are eager to choose projects to work on that would drive the highest profits and impact on social welfare. In this paper, projects in transportation and road construction sector in Iran are chosen as case study. Projects are selected based on their effectiveness in decreasing travel times and distances and therefore minimizing fuel usage and traffic. The RLTP method is used for the minimization problem. Then a two-step hybrid method, Differential Evolution, is used to prioritize projects for selection. The two stage multi-objective method introduced provides accurate results and performs well based on experts' opinions.

References

Cherkos, F. D., Jha, K. N., & Singh, A. (2020). Framework to select public–private partnership modalities. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, *12*(4), 04520034.

Engel, E. M., Fischer, R. D., & Galetovic, A. (2001). Least-present-value-of-revenue auctions and highway franchising. *Journal of political economy*, *109*(5), 993-1020.

Fakhratov, M., Chulkov, V., Kuzhin, M., & Akbari, M. S. (2020). Risk Management implementation and presenting the applicable methodology for its implementation in construction projects. In *E3S Web of Conferences* (Vol. 164, p. 10014). EDP Sciences.

Kang, C. C., Feng, C. M., & Khan, H. A. (2005). Risk assessment for build-operate-transfer projects: A dynamic multi-objective programming approach. *Computers & operations research*, *32*(6), 1633-1654.

Khzaeni Garshasb and Ahmadi Loza, (2006) "Risk Management large projects approach BOT,"2nd International project management conference. Tehran. Iran.

Li, P. (2020). Project Selection of Government Guarantee in BOT/PPP Project Finance. *American Journal of Industrial and Business Management*, *10*(6), 1107-1120.

Nombela, G., & de Rus, G. (2004). Flexible-term contracts for road franchising. *Transportation research part A: policy and practice*, *38*(3), 163-179.

Nurkse, R. (1952). Some international aspects of the problem of economic development. *The American economic review*, *42*(2), 571-583.

Patel, T. D., Haupt, T. C., & Bhatt, T. (2019). Fuzzy probabilistic approach for risk assessment of BOT toll roads in Indian context. *Journal of Engineering, Design and Technology*.

Sebastiaan C.M. Meheer, Spiro N. Pollais (1999), BOT Contracts, (Nether lands: Delf University of Technology), p.23.

Schaufelberger, J. E., & Wipadapisut, I. (2003). Alternate financing strategies for build-operate-transfer projects. *Journal of construction engineering and management*, *129*(2), 205-213.

Tan, Z., & Yang, H. (2012). Flexible build-operate-transfer contracts for road franchising under demand uncertainty. *Transportation research part B: methodological*, *46*(10), 1419-1439.

Wang, S. Q., Dulaimi, M. F., & Aguria, M. Y. (2004). Risk management framework for construction projects in developing countries. *Construction management and economics*, *22*(3), 237-252.

Yang, H., & Meng, Q. (2000). Highway pricing and capacity choice in a road network under a build–operate–transfer scheme. *Transportation Research Part A: Policy and Practice*, *34*(3), 207-222.