A MULTI-OBJECTIVE DECISION SUPPORT SYSTEM FOR PPP FUNDING DECISIONS

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Abstract:

PPP is an innovative delivery method used as an option to leverage public funds by attracting private investment into public projects to make the delivery of previously impossible projects possible. Leveraging resources to build more infrastructure increases the output (quantity) of funds; however, besides leveraging resources, the public agency should also increase the outcome (benefits) of those projects by utilizing more efficient funding strategies. Currently, some project level evaluation methods such as VfM and BCA are being practiced to evaluate PPPs; however, those methods fail to consider the overall benefits and costs of PPPs for multiple stakeholders, and they do not provide much assistance in terms of comparison between different projects in portfolio level. This study introduces a Multi-Objective Decision Support System (MODSS) which integrates quantitative and qualitative aspects of PPPs and calculates the utility function based on different interests of multiple stockholders. The ROR on private investment, the regional economic benefits for local people, and long term national level benefits are considered as the main attributes to address different objectives of different stakeholders. This two level MODSS model assists public agencies such as FHWA to better spend their resources in special programs such as TIFIA by helping them in optimizing their funding portfolio by allocating the available funds into the optimal portfolio of PPP projects.

Key Words: Funding Strategy, Multi-Attribute Utility Theory, Multi-Objective Decision Support System, Multiple Stakeholders, Prioritization, Public Private Partnership

INTRODUCTION

Transportation projects in the US have been funded traditionally by excise taxes which are "taxes paid when purchases are made on a specific good, such as gasoline" (IRS). However, in recent years, due to the decrease in the excise tax revenue, and increase in transportation fund needs, the gap between financial resources and needed funds to maintain and improve transportation systems has widened (National Surface Transportation Infrastructure Financing Commission, 2009). There are different options available to fill this gap such as increasing taxes or using new financing resources such as private investment on public projects. However, there is a huge public resistance against tax increase or road privatization in the US. The other available option is increasing the efficiency of public funding strategy in order to maximize the benefits from each dollar of tax payers' money.

Public Private Partnership (PPP) is an innovative financing method which has been recently used by numerous states in the US (Cui, Farajian, & Sharma, 2010) as an option to leverage their resources and attract new financing resources to public projects. A Public-Private Partnership can be broadly defined as a long term agreement between public and private sectors for mutual benefits (HM Treasure 2000), while the private sector is awarded the right to Design Build Finance and Operate (DBFO) a roadway, often times a toll road, and based on the risks

that the private sector takes, it either gets paid through toll payments by users or availability payments by state DOTs. Using PPP agreements, public agencies try to bridge the increasing gap between required investments and limited funding, while increasing the efficiency and shifting some of the risks during the design, construction and operating/maintaining phases of the road to the private sector. However, the private sector usually seeks an incentive such as federal loans, the Transportation Infrastructure Finance and Innovation Act (TIFIA) for instance, or grants such as Transportation Investment Generating Economy Recovery (TIGER). Due to the recent trend in the increase in the number of the states that use PPPs (Cui, Farajian, & Sharma, 2010), the number of projects that compete to receive those loans and grants has increased.

In order to enhance the efficiency of funding decisions, funding agencies are limited by legislation to use PPPs only if there is a well-defined and executed business case analysis showing added value for money for PPPs compared to publicly financed projects. Due to competition among different regions and different projects receiving public funds, decision makers are obligated to decide about the priority of different competing projects before allocating the grants or loans. In addition, the complexity of public private partnership proposals and the existence of multiple objectives of different entities involved in such projects creates a need for funding agencies to use a systematic decision support system that is able to integrate both qualitative and quantitative aspects of those projects into a single model in order to decide which projects among all qualified projects have higher priority in receiving public assistance. The other decision that needs to be made is deciding the optimal amount of money that each project should receive in order to maximize the benefits from each dollar of taxpayers' money. Optimization of this "funding strategy" is of special importance because of the public resistance against an increase in tax rates or privatization of public projects. One of the main criticisms of the public agencies is that they do not efficiently utilize available resources. This research reviews the state of the art of the current "funding strategy" in the US Departments of Transportation, and suggests a Multi-Objective Decision Support System (MODSS) which can integrate both quantitative and qualitative aspects of PPPs, as well as calculate the utility function for the decision maker. The MODSS enables the decision maker to utilize a funding strategy that will allocate resources more efficiently with the available funds to the optimal portfolio of PPP projects in order to increase the output of public investment.

LIMITATIONS OF CURRENT FUNDING STRATEGIES FOR PPPS

Currently some evaluation methods such as VfM and BCA are being used by state DOTs and FHWA for evaluating different projects (Office of the Secretary of Transportation, 2010) (Office of the secretary of transortation, 2009). The TIGER office is required by law to ask for a BCA report along with TIGER application documents based on their standard procedure to conduct BCA which has been published by TIGER in order to set up a fair evaluation process (Office of the Secretary of Transportation, 2010). The BCA study should consider the qualitative and quantitative study of issues such as State of Good Repair, Economic Competitiveness, Livability, Sustainability, and Safety. TIFIA, on the other hand, uses VfM analysis because legislation usually only allows the use of PPPs if there is a well-defined and executed business case analysis showing added value for money for PPPs compared to a publicly financed competitor. Value for Money (VfM) analysis calculates the difference between the costs associated with both traditional and PPP procurements based on the optimal allocation of risks and rewards by converting all costs and risks associated with a project to dollar values.

Although VfM and BCA are both powerful tools that can help decision makers shift from subjective decisions to more well-defined objective decisions, they have some limitations when it comes to investment strategies in PPPs. PPPs are usually complex arrangements between multiple stakeholders with competing objectives over a long period of time. There is also a high uncertainty embedded in PPP governance structure which requires an extra effort to model the benefits and costs of a project delivered using a PPP arrangement. The current evaluation methods are usually useful as a preliminary project evaluation tool in order to demonstrate the availability of PPPs as a delivery option, however, they do not provide enough decision making support when it comes to comparing different competing PPP projects for federal assistance. Therefore, there is a need for strategic planning for improving capital allocation decisions in the investment portfolio of federal programs such as TIFIA while considering the competing objectives of multiple stakeholders. This paper aims to go beyond the available project evaluation analyses for PPPs at the project level, and provides a decision support system at the program level, based on the utility theory and multi objective optimization.

STATE OF THE ART OF APPLICATION OF MODSS IN OTHER INDUSTRIES

When it comes to comparison in a multi objective decision making process, one of the most popular methods is Multi Attribute Utility Theory (MAUT). This method has been widely used in decision support systems as a logical approach to establish meaningful tradeoffs among conflicting objectives (Keeny & Raifa, 1976). This theory usually presumes a single decision maker who faces tradeoffs on two or more criteria or attributes among number of alternatives (Wallas, 1995). Based on this theory, the decision maker intends to prioritize available alternatives based on a utility function which is unique to the decision maker. MAUT is based on a large body of mathematical theory for utility models as well as a wide range of practical assessment techniques that help to assess the tradeoff weight factors among different attributes and identify a unique utility function for the decision maker based on those weight factors (Wallas, 1995). Later in this research we will explain how we can account for objectives of multiple stakeholders by defiling different attributes, and still use MAUT to establish tradeoffs among those attributes in order to get a multi-objective utility function.

There is a wide range of applications for MAUT in engineering and business for both the private sector and public sector. S. Eom and E. Kim (2006) report "most applications of MAUT are for POM (44.16%) followed by marketing, transportation, and logistics (17.53%), MIS (13.64%), and multifunctional areas (8.44%)" (Eom & Kim, 2006). Vinke (1992) and Roy (1996) discuss some of the applications of MAUT in finance and economics; environmental management; energy planning; marketing; transportation, particularly in highway planning and subway design; human resources management in job evaluation and personnel selection; education, and agriculture. Petrovic et al. (2007) presents a new tool for multi-objective job shop scheduling problems based on an interactive fuzzy multi-objective genetic algorithm which considers aspiration levels set by the decision maker for all the objectives. Cox (2002) uses MAUT to develop health status indicators for a multi-party risk management decision process. Walls talks about the need for applying MAUT models to the private sector in order to develop a framework to link the firm's capital allocation process and its business strategy (Wallas, 1995).

Applications of MAUT in the public sector are even more than the applications of this type of decision model in the private sector. Most public sector problems involve multiple conflicting objectives, such as in public health care systems (Stanhope & Lancaster, 2004); environmental policy (Linkov & Ramadan, 2004); climate change issues (Konidari, 2007); site

selection (Burak Canbolat, Chelst, & Garg, 2007); and energy (Sung-Kyun & Ohseop, 2009). In a real life application of MAUT, the Department of Energy's Office of Fissile Materials Disposition funded a project to design a multi-attribute utility model to evaluate different options for disposing excess plutonium (Butler et al., 2005). Rios- Rios-Insua et.al (2006) combine MAUT and Multi Objective optimization to develop" a multi-objective decision support system for optimization in engineering design".

MODEL DEVELOPMENT

The model presented in this paper is based on a two level MAUT and a Bayesian network. Level 1 of MAUT model captures the utility function of different stakeholders based on three attributes; meanwhile Level 2, integrates these utility functions into one centralized utility function based on the preferences of the decision maker which in this case is the program or the office which is going to make the funding decisions. The centralized utility function can change based on events that may happen in the future by using a Bayesian network to update the relative importance weights. The different steps of the model are shown in Figure 1.
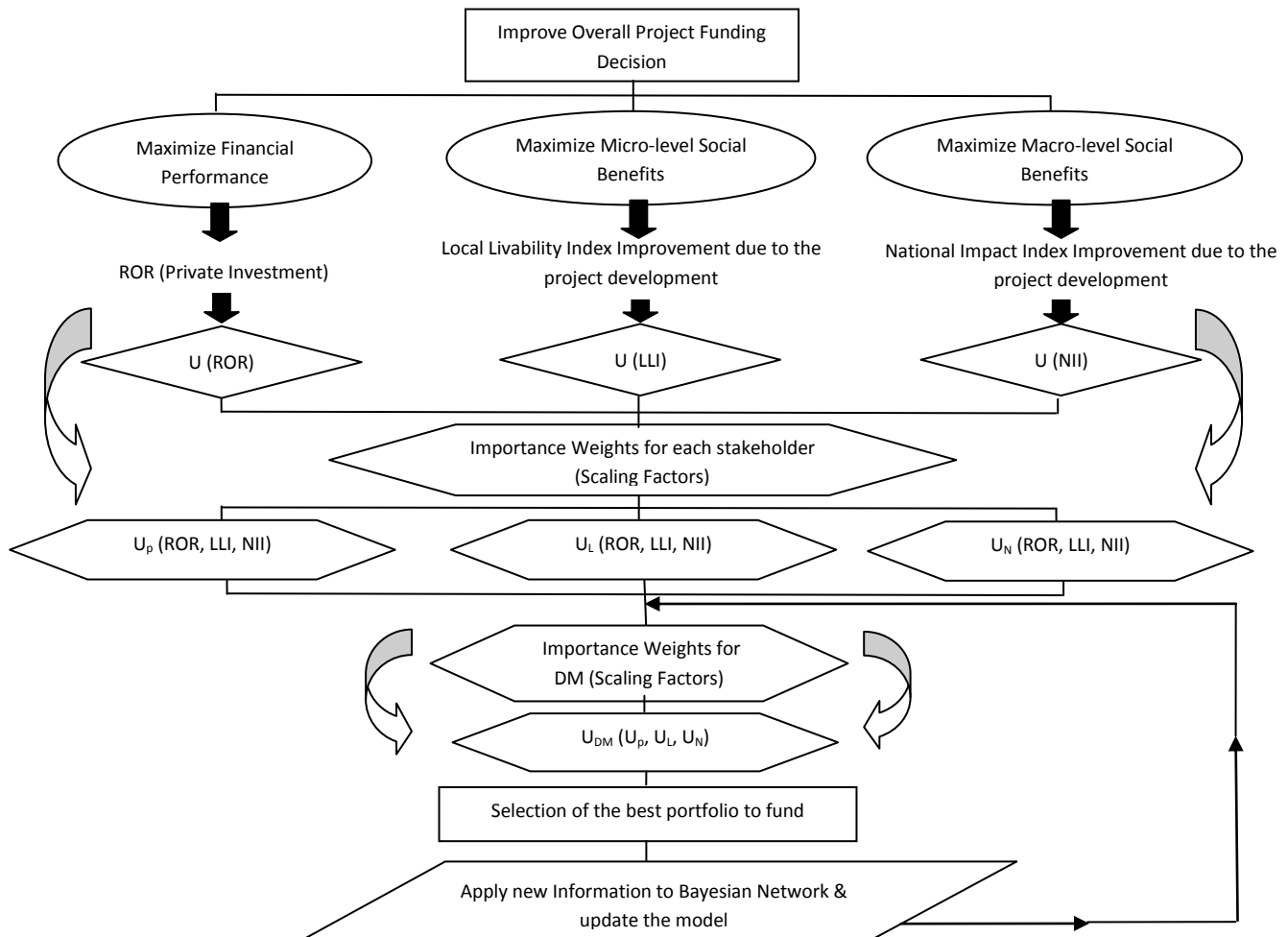
Figure 1: Strategic Decision Process for Project Prioritization

- **Setting Strategic Objectives:**

The first step in creating the model is setting the strategic objectives of the program. Usually these objectives can be achieved by referring to the legislation that has authorized the

funding as well as the objectives of different stakeholders. This process prepares the ground for the establishment of different attributes which will be used in the model. The identification of the attributes is a crucial stage in the evaluating process using MAUT approach. To begin with, the goal of an evaluation for PPP projects is defined as maximizing the overall satisfaction of three different stakeholders: the concessionaire (private company), the local community, and the federal government. As shown in Figure 1, the main objective of the concessionaire is maximizing its profit by reaching a higher Rate of Return (ROR) on his investment. For the local community, issues such as reduction in traffic time, increase in real estate prices, economical benefits, increase in safety and a reduction in life loss, and better accessibility are the main concerns. In this paper, we have integrated all of the mentioned factors and defined an index called the "local livability index" or (LLI). Likewise, a similar index called the "National Impact Index" or (NII) is defined which includes the impacts of the project at the national level, such as carbon emission reduction, induced economic impact of the project at the national level, better interstate connectivity, fair development, and political factors. It should be mentioned that developing such indexes in more details are beyond the scope of this paper, so we assume such index is available and can be obtained through collecting surveys and data analysis.

The first thing that should be mentioned about the three attributes - ROR, LLI & NII - is the fact that they are usually contradictory to each other. For instance, to achieve a better ROR on private investment, there is a need to scarify the design or the quality of the project, which means lower LLI, or receive more funding from federal government, which means lower NII. The other thing that should be mentioned about the model is the fact that the mentioned attributes cannot be easily combined into one simple formula because each stakeholder has different preferences and therefore the importance weights vary from stakeholder to stakeholder. As shown in Figure 1, this paper develops the final utility function into two steps. In the first step, the utility function of each stakeholder based on the mentioned three attributes- ROR, LLI & NII - will be obtained. Each one of these utility functions will be treated as a new attribute in the next step, in which the utility function of the decision maker in the public agency will be obtained based on his preferences for the utility of each stakeholder.

- **Level One: Obtaining Utility Function of Each Stakeholder**
A common method for obtaining the utility function for each stakeholder is to interview key members from each group of stakeholders who are familiar with the preferences of that group or company. Before calculating the utility functions, there should be a determination of the appropriate range of the attributes. In measuring the range of the attributes, an upper limit and a lower limit of the attributes scope should be determined by using existing research results and a scientific analysis on the basis of an engineering model (Goicoechea & Duckstein, 1982).

In the three-attribute utility function, we assess the utility function of the ROR, the Local Livability Index, and the National Impact Index. The utility is assessed assuming mutual utility independence for ROR, LLI, and NII. It is also assumed that preferential independence exists because change in the rank ordering of preferences of one attribute does not change the rank ordering of preferences of other attributes. Thus the utility function can be expressed as:

$$U(ROR, LLI, NII) = \frac{1}{K}\left(\prod_{k=1}^{3}[Kk_i\, U_i(x) + 1] - 1\right) \tag{1}$$

Where $0 < k_i < 1$, $U_1 = U(ROR)$, $U_2 = U(LLI)$ and $U_3 = U(NII)$ and $K \geq -1$ and non-zero.

The next step in developing the utility function for each stakeholder is obtaining the scaling factors. It should be mentioned that we assume the worst case for all utilities is 0 meaning lowest ROR, minimum LLI, and minimum NII. The best case for each utility is assumed to be 1, meaning highest ROR, maximum LLI, and maximum NII.

$$U(lowest\ IRR, Min\ Impact\ LLI, Min\ Impact\ NII) = U(0,0,0) = 0$$
$$U(highest\ IRR, Max\ Impact\ LLI, Max\ Impact\ NII) = U(1,1,1) = 1$$

Third, the k_1 can be assessed by asking the decision maker at what chance 'p' for the following lottery such that he/she is indifference between choice #1 and #2. For instance, if the decision maker is indifferent between choice #1 and #2 at the point where p = 0.5, k_1 = 0.5.
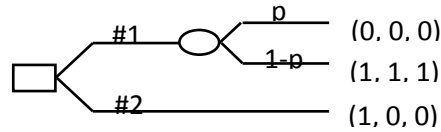
This process should be repeated by setting up similar lotteries to asses k_2 and k_3. In the last step of obtaining the utility function for each stakeholder, the obtained k_i should be applied to equation (1) for the best case, U(1,1,1), in order to calculate K.

$$K = \prod_{k=1}^{3} [K k_i + 1] - 1 \tag{2}$$

It should be noted that this process should be repeated for the private company, U_p (ROR, LLI, NII), the local community, U_L (ROR, LLI, NII), and the federal agency, U_N (ROR, LLI, NII).

- **Level Two: Obtaining Utility Function of the funding agency**
 In Level 2 of this model, the preferences of the funding agency are obtained. The process in this level is similar to the process in Level 1; however, the utility functions which are obtained in Level 1 are used instead of the three attributes. So, $U_p = U_{ROR}$, $U_L = U_{LLI}$ and $U_N = U_{IIL}$.

$$U(U_p, U_l, U_n) = \frac{1}{K} \left(\prod_{k=1}^{3} [K k_i U_i(x) + 1] - 1 \right) \tag{3}$$
$$U(min\ U_p, Min\ U_l, Min\ U_n) = U(0,0,0) = 0$$
$$U(Max\ U_p, Max\ U_l, Max\ U_n) = U(1,1,1) = 1$$

The next step in obtaining the utility function of the decision maker in the public agency is assessing the scaling factors by changing p in a set of lotteries similar to the previous level.
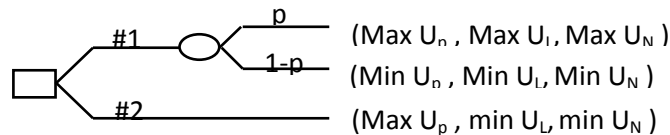
As mentioned before, this process should be repeated by setting up similar lotteries to asses k_2 and k_3. In the last step of obtaining the utility function for funding agency, the obtained k_i should be applied to equation (2) for the best case, U(1,1,1), in order to calculate K. This step finalizes model development by assessing utility function for funding agency.

AN APPLICATION OF THE MODEL

As discussed before, one of the strengths of the model is its ability to account for different objectives of different stakeholders. In order to develop the Level 2 utility function for the funding agency, it is necessary to capture Level 1 utility functions for the concessionaire, local community, and federal agency. This process requires meetings with representatives of each stakeholder to assess their utility functions for each attribute and importance weight factors, but it is beyond the scope of this paper to establish an accurate practical utility function for a funding office such as TIFIA. In order to show an application of the model for funding agencies, a simulation is used for 5 imaginary projects.

First, a random number generator is used to generate data for Level 1's input. ROR is set to be between 0.1 and 0.5, and LLI and NII are set to be between 0 and 1. Then it is assumed that the scaling factors for different stakeholders are obtained using the mentioned lotteries. Based on those scaling factors, K is calculated using equation (2). The results of the calculations of scaling factors are as follows:

Table 1: Calculation of scaling factors for level 1 and level 2 utility functions

	Level 1			
	K_{ROR}	K_{LLI}	K_{NII}	**K**
Concessionaire (P)	0.80	0.30	0.10	**-0.45156**
Local Community (L)	0.20	0.70	0.30	**-0.45156**
Federal Agency(N)	0.10	0.50	0.70	**-0.67191**
	Level 2			
	K_p	K_l	K_n	**K**
Funding Agency	0.30	0.50	0.40	**-0.45156**

Finally, the utility function for each stakeholder is calculated using equation (1) and Level 1 scaling factors. These utility functions are used in Level 2 as inputs. In Level 2, the utility function of the funding agency is calculated using these inputs, Level 2 scaling factors and Equation 2. The results of these calculations are presented in Table 2.

**Table 2: Calculation of utility functions in level 1 and level 2 and project ranking**

	Level 1 Input			Level 1 Output			Level 2 Input → Level 2 Output	
	ROR	**LLI**	**NII**	U_p	U_l	U_n	**U**	**Rank**
Project 1	0.475	0.623	0.512	0.57	0.63	0.62	0.66	2
Project 2	0.195	0.495	0.663	0.35	0.54	0.65	0.58	3
Project 3	0.221	0.858	0.522	0.46	0.74	0.70	0.70	1
Project 4	0.378	0.523	0.147	0.45	0.46	0.37	0.48	5
Project 5	0.281	0.426	0.593	0.39	0.50	0.59	0.55	4

DISCUSSION OF IMPLICATION

As shown in Table 2, this model is able to account for the preferences of different stakeholders and prioritize projects based on the strategic objectives of the funding agency and the preferences of different stakeholders. In order to show how the preference of each stakeholder can change the final utility function of the funding agency, a simulation model is created in which 12 different inputs - scaling weights for the concessionaire, local community, federal agency, and the funding agency, have been defined as input variable, and the changes in the utility function for the funding agency in Level 2 have been studied. Table 3 shows the results of this simulation, and Figure 2 shows the sensitivity analysis for the 9 main inputs that have a great effect on the utility function for the funding agency.

Table 3: What-If Analysis S for Output Utility Function for Funding Agency (Top 9 Inputs Ranked By Percent Change)

Rank	Input Name	Cell	Minimum			Maximum		
			Value	Output Change(%)	Input Value	Value	Output Change(%)	Input Value
1	Funding Agency (Kn)	R8	0.31	-46.31%	-0.093456088	0.84	46.31%	0.893456088
2	Funding Agency (Kl)	Q8	0.35	-39.31%	0.006543912	0.80	39.31%	0.993456088
3	Funding Agency (Kp)	P8	0.45	-22.15%	-0.193456088	0.70	22.15%	0.793456088
4	Knii for Local Community	AE8	0.46	-19.85%	-0.193456088	0.69	19.85%	0.793456088
5	Klli for Local Community	AD8	0.48	-15.98%	0.206543912	0.67	15.98%	1.193456088
6	Knii for Federal Agency	AK8	0.49	-15.66%	0.206543912	0.67	15.66%	1.193456088
7	Klli for Federal Agency	AJ8	0.52	-9.77%	-3.55026E-05	0.63	9.77%	1.000035503
8	Klli for Concessionaire	X8	0.52	-8.97%	-0.193456088	0.63	8.97%	0.793456088
9	Knii for Concessionaire	Y8	0.55	-3.85%	-0.064485363	0.60	3.85%	0.264485363
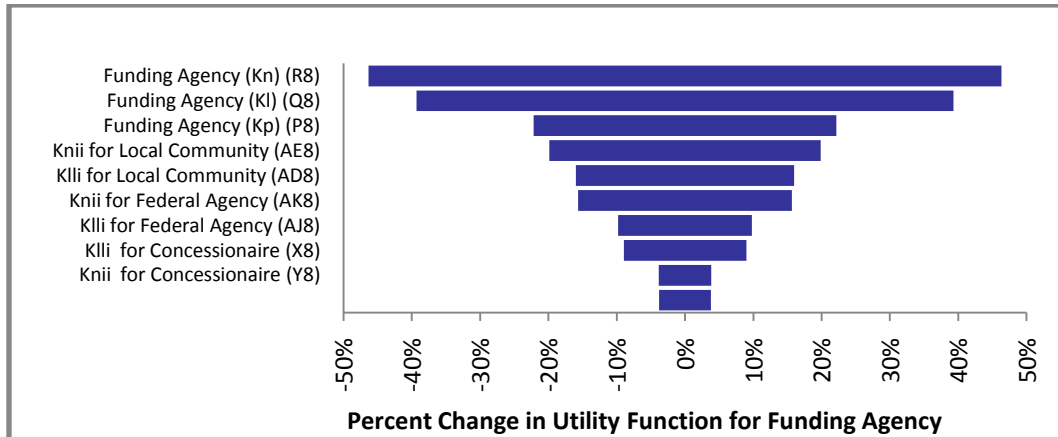
Figure2: Sensitivity analysis results

CONCLUSIONS AND FUTURE RESEARCH

This paper intends to show mathematically how a multi-objective decision support system can be built using utility theory for different stakeholders. In this paper a computer simulation has been used to run the model for 5 imaginary projects. However, in the future, this model will be tested using the data available from TIFIA office from the applicants for a TIFIA loan. The research team will also contact some stakeholders of the projects, particularly funding agencies in order to make the model more accurate by assessing true values for scaling factors.

One of the most important features of this model is the fact that it can be updated easily based on the changes in the strategic objectives of the funding agency, preferences of different stakeholders or even based on the events that may happen for the portfolio. The next feature which will be added to the model is a Bayesian network which can automatically update the scaling factors for the funding agency based on different events. For instance, in the event of a bankrupt PPP project, such as what happened in California to South Bay Express Lane Project, the sensitivity towards ROR will increase, or in the event of election season, the sensitivity towards local benefits or national impact may increase so K_l and K_N in the model should be updated.

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