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ENGINEERING MANAGEMENT THEORIES AND METHODOLOGIES

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Sustainable Program Quality Management of International Infrastructure Construction

Abstract Management of the program quality for international infrastructure construction projects is complicated. Sustainability of these programs is the key for them to succeed in their lifecycles. This paper investigated current program quality management and compared it with the results of recent surveys of KGMP. A method for the sustainable program quality management of the international infrastructure construction management is proposed and demonstrated by research projects. The cycle of accountability, predictability, balance ability, and policy was proposed. The findings from the KGMP's survey and this research show that the trend of the sustainable program quality management of the international infrastructure construction is transferring from agility to alacrity in the balancing of the metrics among economy, ecology, culture, and politics.

Keywords: sustainability, program, infrastructure

1 Introduction

Programs include several projects and sometimes are also called megaprojects. Their life cycles are longer than general projects, and budgets are massive. Among the programs, construction of infrastructures may be critical for the local economic growth if construction programs are sustainable. However, the definition of sustainability of these programs is the key for them to succeed in their lifecycles. This paper investigates the current program quality management and compares it to the results of the recent surveys of KGMP. A method for the sustainable program quality management of the international infrastructure construction management is proposed and demonstrated by the research projects. The cycle of accountability, predictability, balance ability, and policy is proposed.

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2 Surveys of the status of infrastructure management from KGMP

2.1 The global demand and supply of infrastructures in the next decade

Establishment of infrastructures in societies provides the local people with a good quality of life and may also help the economic growth of these communities. Regarding KGMP's forecast in 2016, several factors which may affect the demands of infrastructures include the distribution of population changes, the phenomenon of global warming, and the new communication channels for global networking. In the upcoming decade, a major population increase will happen in Africa. On the other hand, the increasing aging population in developed countries will revolutionize their economic activities. Global warming causing severe weather will influence the ecosystem of the global environment and economic activities. People may need more aviation vehicles for traveling. The maturity of the technology of driverless cars could increase the safety of commuting, and virtual organizations will save peoples' time by allowing them to work at home.

2.2 Survey of the maturity of global construction management

The research team of Armstrong (2015) from KPMG interviewed 109 senior leaders including CEOs who are managing global construction projects with budgets from ten million to five billion USD. Twenty-six percent of these projects, such as energy, nature resources, technology, and healthcare, belong to the public sector. KPMG surveyed four perspectives of a specific project. They are maturity in preparation; risk, controls, and governance; performance; and relationships.

The shortage of human resources in the global construction industry is still a problem. About 44% of the projects for craft labor and 45% for staff are needed in the global construction market. More than 5% of the works are outsourced for 69% of these construction projects. Fifty percent of the projects use Project Management Information System (PMIS) to manage their projects. Among these projects with PMIS, 32% of them integrate their project accounting and procurement processes with software. Regarding the performance of the projects, 53% of all the surveyed projects and 90% of the public projects suffer the status of underperforming. Sixty-nine percent of the project managers believe that the major reason causing a project to underperform is poor contractor performance. Thirsty-one percent of the projects overspend their reserves by 10% of their total budgets. Twenty-five percent of the projects run past their schedules' deadlines by 10%.Thirty percent of the projects develop quantitative contingencies for risk management. Earned Value Management System (EVMS) has been adopted by 49% of the projects for management of project-level contingencies and reserves.

Regarding the report from KGMP, construction management may need to focus on the following five issues. They are (1) recruiting talented people, as both newly hired and experienced retiring workers are needed in the future job market of the construction industry to solve the shortage of human resources, (2) developing a sustainable PMIS and BIM, (3) solving scheduling problems as the first priority, (4) calculating contingency through EVMS to predict uncontrollable risks, and (5) managing a good contractor relationship.

2.3 KPMG survey of the status of international infrastructure management

Stewart, Beatty, and Vella (2014) developed a survey of international construction projects for 100 infrastructures. The survey categorized these projects into four groups. Group one is Economic Powerhouses (EP). The project market in this group opens slowly for private finance. The representative countries for these projects are the US, Brazil, Russia, India, and China. The second group is the Emerging Markets (EM). These countries need infrastructures. A feasible national plan may help them to grow their local economy through infrastructure construction and attract private finance. The typical countries in this group are located in Asia, Europe, and Africa. The third group is Mature International Markets (MIM). These countries have well-designed plans of their infrastructure projects, but they may have uncertainty for landing these projects. These countries include nations in the EU, Canada and Australia. The last group is Small Established Markets (SEM).This group has a strong need for their domestic market; their project management systems for private finance are established. Examples of the countries in this group include Denmark and Japan. Based the selected KPMG projects, Table 1 illustrates the distribution of the major types of projects for these four groups. Transportation and energy are the major two types of the infrastructure projects.

The findings and suggestions for KGPM surveys of the infrastructure of the group of Economic Powerhouses addressed that the Public Private Partnership (PPP) is important. Evolving global financial resources may be a solution for the shortage of their national budgets. According to the sustainable development of these infrastructures, natural resources, especially water, must be efficiently managed, and the renovation of old cities and facilities is as important as creating new ones. For the group of Emerging Markets, the poor quality of infrastructures retards economic growth. Social justice and globalization are two important factors for the success of these countries' international infrastructure construction. The transformation of the structure of human resources in the group of Mature International Markets is a major issue in recruiting talented people, preserving government stability, and caring for an aging population. For the group of Smaller Established Markets, incentives are needed to attract international investors to help enable the long-term success of the program, which is based on stable national policies.

3 Methodology for sustainable program quality management

Earned Value Management System (EVMS), which developed in the 1960s, is the major tool for program or megaproject management, especially in system engineering. The cores of project management are cost, time, quality, and risk. The details of program quality management are illustrated in *Figure 1*. The inherent availability

Table 1

Distribution of the Types of Infrastructure Projects for these Four Groups

	Transportation	Energy	Waste	Community	ICT	Health	Water	Education	Mine	Total
EP	10	8	2	6	2		2			30
EM	9	4	2	1	1	2			1	20
MIM	12	7		1		1	1	2	1	25
SEM	14	3	4		3			1		25
Total	45	22	8	8	6	3	3	3	2	100

includes manufacturability, reliability, supportability, and maintainability. The sustainability of the system is based on a cradle to cradle lifecycle (Wang, Williams, Shi, & Yang, 2015).

The research of sustainability of construction project management is multidisciplinary. Table 2 shows that the departments of some of the research include civil, environmental, planning, design and construction, architecture, construction management, and engineering management. The major methods include Life Cycle Analysis, Operations Research, Value Engineering, Structural Equation Modeling, and some qualitative methods (Wang, Williams, Shi, & Yang, 2015).

For the future, the sustainable program quality management of international infrastructure construction may have four checking points before policy making. The first question is whether the metrics for the performance evaluation are accountable or not. The precision and accuracy of the data must be justified. Sometimes the data of the metrics needs a third party or other scientific ways to prove the existence of the phenomena. The difficulty with the data collection of the metrics, especially in social sustainability, may cause uncertainty in the accountability of the system. The second question is whether or not we can create a model to predict the future trend of the system. The robustness of the model is needed to be considered to be justified. Most of the trend analyses are based on the data collected in the past. However, their predictions may not be realized if the results of data regression of the model cannot reflect these predictions. The third question is how to balance the three perspectives, which are society, economy, and environment. Development of the tools to determine better "end states" or equilibriums of systems through dynamic simulation is needed. The last question is whether we can make a better policy for managing the program or not. This question requires program management in societies to mature. Also, an understanding of the diversity of the cultures in international infrastructure construction is needed. *Figure 2* shows the cycle of accountability, predictability, balance ability, and policy (APBP).

4 Examples of the research projects at the University of Alaska

To form a public policy to implement an infrastructure program, the APBP cycle for the sustainable program quality management of the infrastructure construction is longer than the cycle of program construction. In this section, four research projects at the University of Alaska include calibration of weather forecasting data (accountability), prediction of the cost of the side effects by adopting new technology (predictability), balancing the factors for the material selection (balance ability), and the sensitivity analysis of the energy policy-making in rural Alaska (policy).

4.1 Accountability – Monitoring system for prediction of mountain fires

Mountain fires caused by low relative humidity, similar to flooding by heavy rain, may generate the local loss. Monitoring and predicting local relative humidity needs to calibrate to control the accuracy and precision of the forecasting results. Fode (2010) developed a comparative study between two relative humidity forecasting methods in South central Alaska. The parameters of the predicted

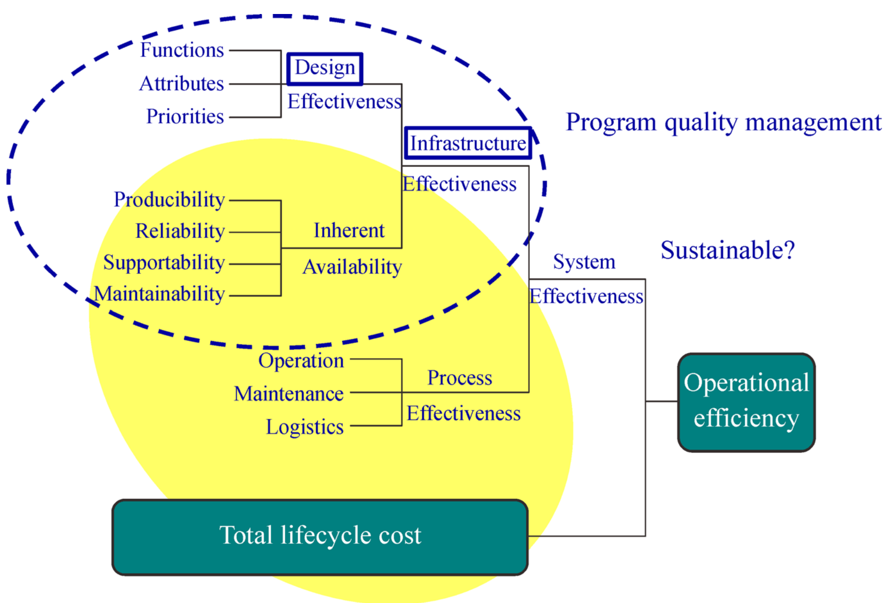

Figure 1. Scope for sustainable program quality management.

Table 2

Research of Sustainable Construction Management in Academics

Author	Issue	Mehtod	Department
Attallah	Environmental impact/policy	Agent-based modeling	Civil
Berghorn	Risk	Life cycle based risk model	Planning, design and construction
Kwok	Low carbon	Life cycle analysis	Environmental/Architecture
Yoo	LEED, LCC	Assessment tool	Environment and resources
Abdallah	Optimize metrics for existing building	Operations research	Civil/Environmental
Karatas	A single home	Operations research	Civil/Environmental
Arroyo	Multiple-criteria decision-making building	Choosing by advantages	Civil/Environmental
Lin	Design decision	Geretic algorithm based multi-objective optimization	Architecture
Wao	Outcome improvement	Value engineering	Construction management
Vanhoozer	Behavior effects	Post-occupancy evaluation	Environmental science
Wang	Balancing	Structure equation modeling	Engineering management
Hogan	Tax appraisal/Energy star	Market value	Architecture
Johnson Ferdinand	Urban development	Spatial decision support system	Earth and environmental
Langevin	Human behavior/energy	Human building interaction toolkit	Engineering

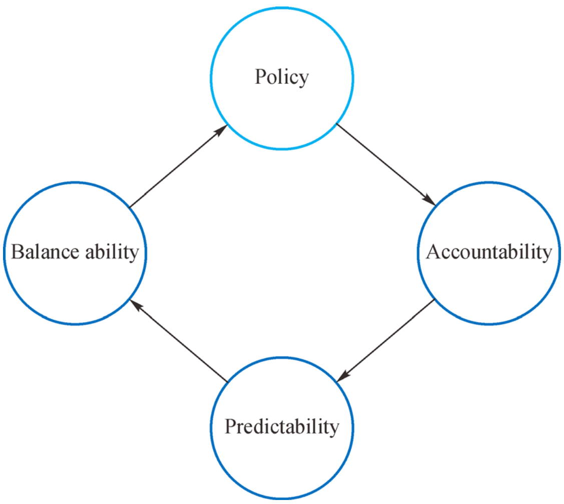

Figure 2. Cycle of accountability, predictability, balance ability, and policy (APBP).

model, observed results, and correlation skill score (γ) included sea level pressure (p), daily accumulated short wave downward radiation ($R_s^{\downarrow}$), 2m air temperature (Ta), relative humidity (RH), and wind speed (v) for the 24 h forecast lead time, and ensemble (in parentheses) for the monthly averages over all sites for which data were available. Table 3 illustrates the statistical results of the parameters of the forecasting model.

4.2 Predictability- The cost of side effects by adopting plasma gasification process for solid waste handling

To understand the lifetime cost caused by air pollution from the poor quality of the plasma gasification process, Alabanzas (2012) developed a research project on risk analysis of human health if the plasma gasification process for solid waste management is adopted. The research estimated the change in ambient concentration of the pollutant in facilities using the plasma gasification process based on standards and incineration data as shown in Table 4. The concentration of heavy metals found is the most toxic of pollutants generated by the process. The results by using lifetime health cost per person in 2011 constant dollars are shown in *Figure 3*.

Table 3

Statistical Results of Parameters of the Forecasting Model for Relative Humidity

Quantity	Predicted	Obs	RMSE	SDE	Bias	r
p (hPa)	1011.1±4.3 (1011.2±4.2)	1006.9±8.1	8.3 (8.4)	7.1 (7.2)	4.3 (4.3)	0.482 (0.478)
$R_s^{\downarrow}$ (W/m^2)	6545±1567 (6532±1536)	5936±1640	1641 (1597)	1524 (1482)	609 (596)	0.549 (0.566)
T_a (°C)	14.0±3.5 (14.4±3.5)	15.9±4.2	2.8 (2.6)	2.1 (2.1)	–1.9 (–1.5)	0.865 (0.866)
RH (%)	57±15 (57±14)	55±17	13 (13)	13 (13)	2 (2)	0.679 (0.669)
v (m/s)	2.37±1.05 (2.40±1.06)	1.61±1.01	1.3 (1.33)	1.04 (1.06)	0.77 (0.80)	0.483 (0.474)

Table 4

Estimated Significant Impact Level of Ambient Concentration of Pollutant on Facilities Based on Standards and Incineration Data

Pollutant	Ambient concentration (μg/m^3)	Source
Particulate matter	0.3*	Significant impact level (EPA)
Mercury	0.00019**	Calculated maximum to meet European standards
Lead	0.00042**	Calculated maximum to meet European standards
Dioxins and furans	3.86×10^{-10}**	Calculated maximum to meet European standards

Note: *, 40 CFR 51 and 52, EPA, USA; **, Rabl, A. & Spadaro, J. V. (Rabl & Spadaro, 1998)

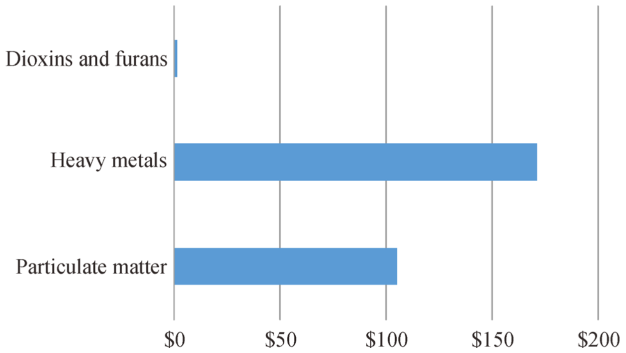

Figure 3. Lifetime health cost per person in 2011 constant dollars.

4.3 Balance ability – Developing metrics for material selection

Poly Lactic Acid (PLA), molecular formula $(C_3H_4O_2)_n$, comes from renewable plant resources such as corn, sugar beets, sugarcane, or wheat. It is non-toxic, renewable, biodegradable, biocompatible, and bioabsorbable. To understand the relationship of the metrics or factors for material selection, a hierarchical structure with the three following perspectives: economy, environment, and society, is illustrated in *Figure 4*. The metrics for the economic sustainability include raw materials, investment, energy consumption, and profit. Green house gas, particular matter, water consumption, and wastes are the metrics for environmental sustainability. The social metrics have social justice, operation, governance, and health.

The statistical data collected from a manufacturing company are used for establishing a Structure Equation Modeling (SEM) model and are simulated by the LISREL software. After the simulation, the local balances for both economy and society are found. The weighting factors for economical and social sustainability are shown in *Figures. 5 and 6* respectively (Wang, Williams, & Chang, 2015).

4.4 Policy – Sensitivity analysis of the factors for energy subsidization

Forty percent of the population lives in rural Alaska. Based

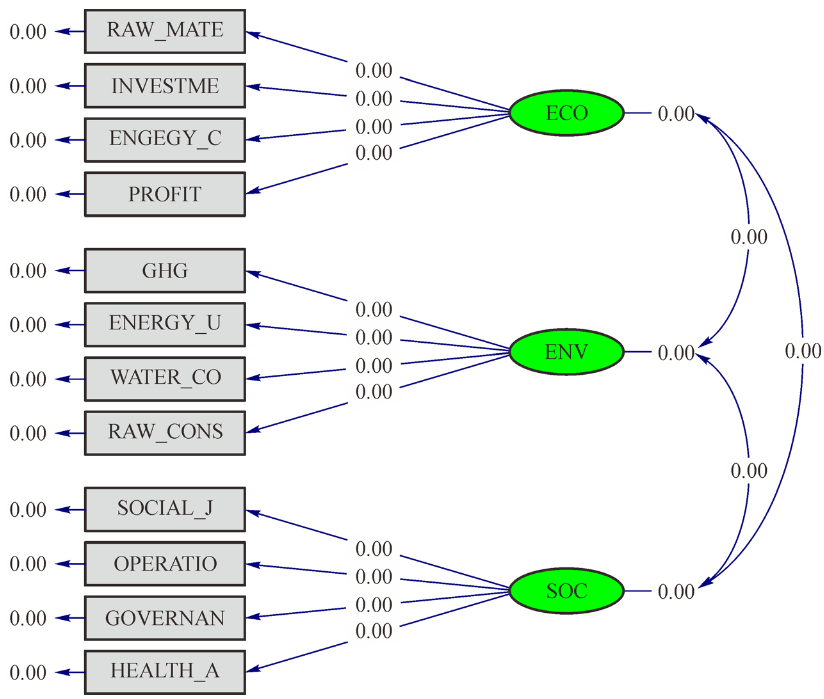

Figure 4. Hierarchical structure of the factors needed for sustainable development.

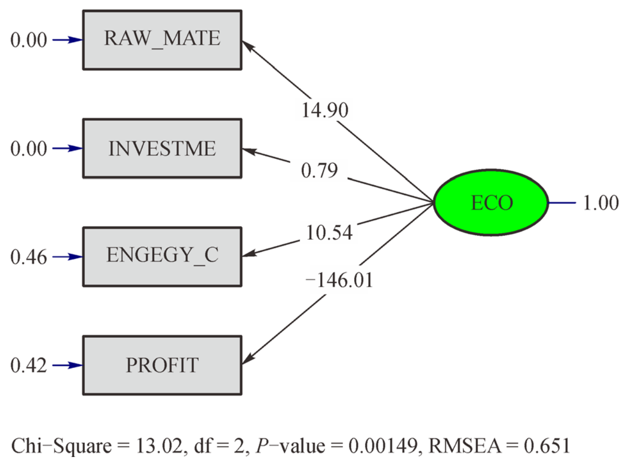

Figure 5. Weighting factors for the metrics of economic sustainability.

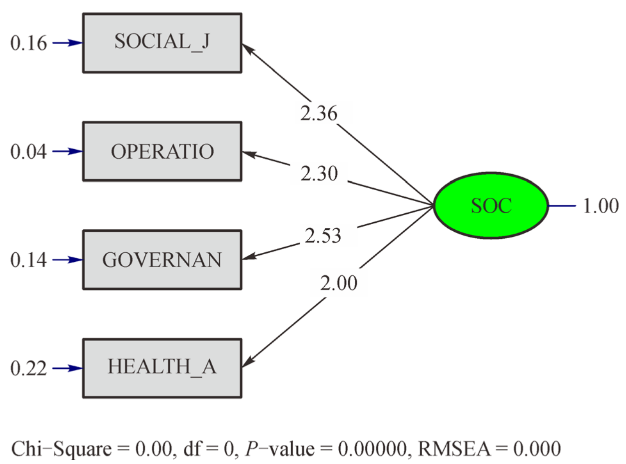

Figure 6. Weighting factors for the metrics of social sustainability.

on the data from the Alaska Energy Authority and the US Energy Information Administration, 2013, electricity prices in rural Alaska are much higher than average. The distribution of Alaska electricity prices by community is shown in *Figure 7*.

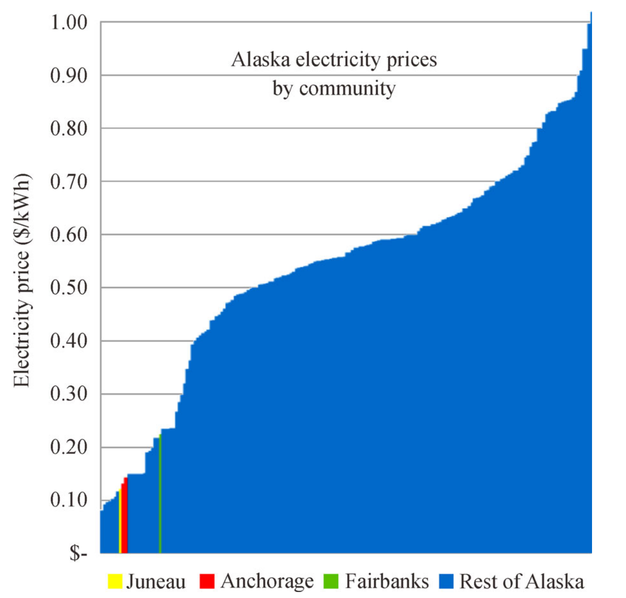

Figure 7. Electricity prices for each community in Alaska.

The Alaska state government adopts a subsidization policy to compensate the energy cost for the people living in the rural area. Based on the cash flow analysis, the funding of subsidies may have a shortage in 2023 as shown in *Figure 8*.

The sensitivity analysis of the factors of the funding management is depicted in *Figure 9*. Returns on investment and discount rate are the most sensitive factors (Wang & Casper, 2013).

5 Conclusions

Among infrastructure programs, transportation and energy

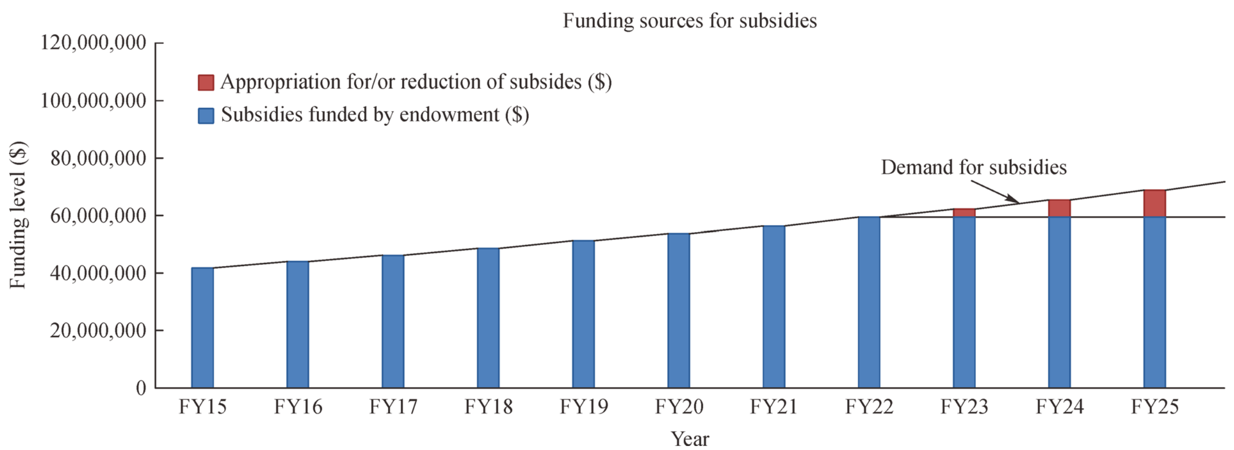

Figure 8. Cash flow analysis of the funding of subsidies for the rural Alaskan energy cost.

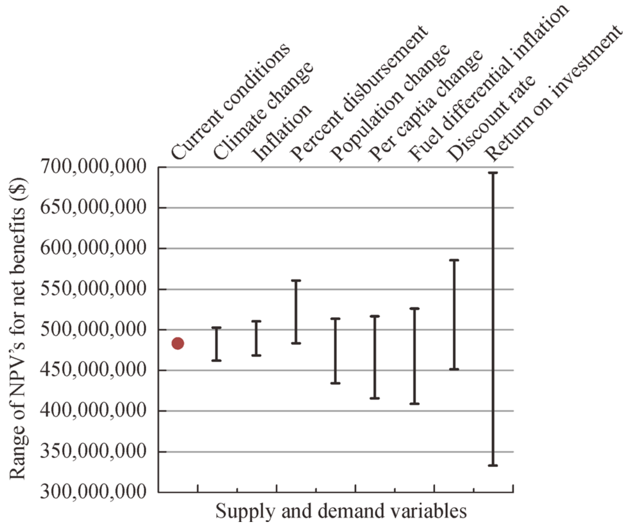

Figure 9. Sensitivity analysis of the factors of the funding management.

are the major programs around the world. This research excludes the issues of international politics and diversity of cultures. International program management may include different factors for different areas in the world. A sustainable program quality management based on Accountability, Predictability, Balance ability and Policy (APBP) cycle has been developed. The technology changes in information and computer technology may transform the sustainability for the program management of the international infrastructure construction. The maturity of program quality management may highly depend on a systematic approach, and the organizations in these programs may need the capability of agility and alacrity.

References

Alabanzas, C. (2012). *Human health risk analysis of adapting plasma gasification process for solid waste management*. University of Alaska, Anchorage.

Armstrong, G. (2015). *Climbing the curve – 2015 global construction project owner's survey*. Retrieved from http://www.kpmg.com/Global/en/IssuesAndInsights/ArticlesPublications/global-construction-survey/Documents/global-construction-survey-2015.pdf

Fode, L. (2010). *A comparative study between two relative humidity forecasting methods in southcentral Alaska*. University of Alaska, Anchorage.

Rabl, A., & Spadaro, J.V. (1998). Health risks of air pollution from incinerators: A perspective. *Waste Management & Research Waste*, 16, 365–388.

Stewart, J., Beatty, S., & Vella, J. (2014). *The infrastructure 100, world markets report*. Retrieved from KPMG International website: https://home.kpmg.com/xx/en/home/insights/2012/11/infra100-world-market.html.

Wang, S., & Casper, J.C. (2013). *Scenario analysis of Alaska's power cost equalization endowment fund for electrical subsidies in rural Alaska*. *Proceedings of 2013 International Annual Conference of ASEM, Minneapolis, Minnesota–MN*. Retrieved from https://www.researchgate.net/publication /289742615_Scenario_analysis_of_Alaska's_power_cost_equalization_endowment_fund_for_electrical_subsidies_in_rural_Alaska.

Wang, S., Williams, P., & Chang, S.P. (2015). *Using balanced score card for design-centered manufacturing*. Proceedings of the ASME 2015 International MSEC, UNC Charlotte, North Carolina, USA.

Wang, S., Williams, P., Shi, J., & Yang, H. (2015). From green to sustainability-trends in the assessment methods of green buildings. *Frontiers of Engineering Management*, 2, 114–121.