A DYNAMIC APPROACH FOR EVALUATING INFRASTRUCTURE
PROJECTS' SUSTAINABLE PERFORMANCE

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Abstract: Construction activity is commonly considered to have adverse impacts on the environment, which is the basis of sustainable development for human being. Proper development and operation of a construction project can make significant contribution to the mission of sustainable development, especially for large-scale infrastructure projects where large amount investment and public interests are involved. Whilst the concept of sustainable construction has become popular in research, there is little existing work to provide appropriate methods to assess the degree of contribution of an infrastructure project to the attainment of sustainable development. This paper introduces a simulation model, using system dynamics methodology, to assess the sustainable performance of an infrastructure project across its life-cycle. The procedures of developing the model are explained in detail. A real life case is presented to evaluate the feasibility of an infrastructure project in terms of its sustainable performance.
Keywords: Evaluation; Infrastructure Projects; System Dynamics; Sustainable Performance

1 Introduction

Sustainable development stresses the long-term compatibility of the economic, social and environmental dimensions of human well being, while acknowledging their possible competition in the short-term. Two conclusions stem from this realization. First, development must balance different objectives and exploit their synergies, as progress in a specific area may be short-lived if not accompanied by simultaneous advances in others. Second, development must be undertaken with a long-term view of its implications, which ensure the costs of one generation's activities do not compromise the opportunities of future generations, as some key features of the environmental and social system cannot be easily restored once damaged (OECD,2001). This philosophy which lies at the heart of the concept of sustainable development requires the construction project to maximize the social and environmental benefits and minimize social and environmental costs, apart from economic considerations.

Construction industry and its relevant activities are widely considered as major contributors to environmental pollution and adverse effects on the mission of sustainable development. Traditionally, one of the most frequently used approaches is Cost Benefit Analysis (CBA). It generalized the classical criterion of financial gain by considering the market effects as well as the non-market effects of decisions, positive(benefit) and negative(cost) and bringing these to a monetary value (TANCZOS, 2001). Further methods for supporting decision-making in project evaluation include cost effectiveness analysis (CEA), multi-criterion analysis(MCA) (Abelson, 1996; Fuguitt, 1999; Harding, 1998). However, a major limitation in using these methods is that it does not consider the impacts of various dynamic factors on project performance through a project life cycle. In fact, a construction projects' development is a dynamic process. Shen et al (2005) presented a conceptual prototype model using system dynamics to evaluate the sustainable performance of construction project. It is considered that the effectiveness of project feasibility study can not be assured without considering the impacts of dynamic factors. This paper extends the dynamic model for assessing the sustainable performance of an infrastructure project

2 Dynamic factors affecting sustainable performance of infrastructure projects

Project evaluation is the process whereby a public agency or private enterprise determines whether a project meets the country's economic and social objectives and whether it meets these objectives efficiently (Adler, 1987).

Project performance traditionally refers to the outcomes of construction cost, construction time, and construction quality; the identification of dynamic factors in the existing studies mainly concerns these three aspects. When the contents of project performance are extended to incorporating project sustainable performance, factors affecting project performance need to be reviewed. As it is to be measured by the contribution of the construction project concerned, to attain sustainable development, factors affecting project sustainable performance can be identified through examining the attributes to which a construction project contributes for attaining sustainable development. According to the general principle of sustainable development, there are three attributes to sustainable development; these are the sustainability of economic development(E), and the sustainability of social development (S), and the sustainability of environmental development(En) (WCED, 1987). These three contributors are used in this study to examine the sustainable performance of an infrastructure project.

During implementation of a construction project, the performance of the three aspects is affected by various factors at different stages across its life cycle. In a typical classification, the life cycle of a construction project is divided into five stages, which are inception stage, construction stage, commission stage, operation stage, and demolition stage (Shen et al, 2002). Some studies have examined the factors affecting these three aspects at different stages of a project (Hill and Bowen, 1997; Shen et al., 2002). By referring to such studies, a list of dynamic factors affecting sustainable performance of an infrastructure project across its life cycle can be identified. These factors are shown in Table 1.

Table 1 Major factors affecting sustainable performance of an infrastructure project

Economic Attributes	**Social Attributes**	**Environmental Attributes**
Net present Value	Economic net present value	Air pollution
Discount rate	Social discount rate	Noise pollution
Benefit stream	Social benefit stream	Water pollution
Cost stream	Social cost stream	Waste management
Payback period	Economic payback period	Ecology impacts
Internal rate of return	Economic internal rate of return	

3 A Dynamic Approach for Evaluating an Infrastructure Project's Sustainable Performance

Shen et al (2005) developed a model for assessing the sustainable performance of a construction project. By modifying and applying the model, the sustainable performance value (SPV) of an infrastructure project in its life cycle can be quantified through the below model:

$$\begin{cases} \text{SPV}=\int_0^t w_E(t)I_E(t)dt+\int_0^t w_S(t)I_S(t)dt+\int_0^t w_{En}(t)I_{En}(t)dt \\ W_E(t)+W_S(t)+W_{En}(t)=1 \end{cases} \qquad (1)$$

Where $I_E(t)$, $I_S(t)$ and $I_{En}(t)$ denote respectively the dynamic functions of generating economic impact, social impact and environmental impact from implementing an infrastructure project. Variables W_E, W_S and W_{En} denote respectively the weights of economic impact, social impact and environmental impact on SPV. The weights, at the same time, also reflect the trade-off between the economic impact, social impact and environmental impact.

All the variables I_E, I_S and I_{En}, W_E, W_S and W_{En} are changeable. To demonstrate the model SPV in a simple way, it is assumed that the weighting factors, W_E, W_S and W_{En} are constants. The model (1) can be revised as the flowing SPV model (2).

$$\begin{cases} \text{SPV}= \int_0^t I_E(t)dt + \int_0^t I_S(t)dt + \int_0^t I_{En}(t)dt \\ W_E + W_S + W_{En} = 1 \end{cases} \qquad (2)$$

4 Development of the Simulation Model

The *ithink* software is used to develop the simulation model based on model (2). The simulation model is based on the principles of system dynamic methodology. The software enables users to visualize interrelationships, which constitute a process, a strategy, or an issue. The modeling and simulation capabilities of the software are ideally suited for capturing the operational dynamics and complexities of management issues depicting them as a flow chart or schematic (SDP, 2006). An overview of the model framework is illustrated in Figure 1.

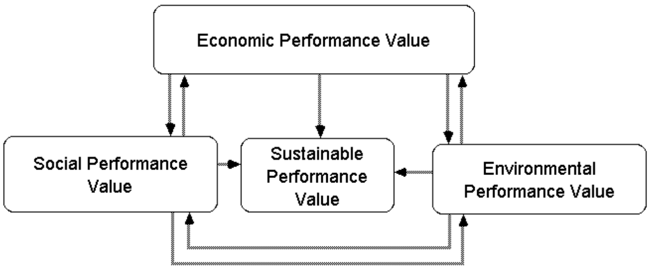
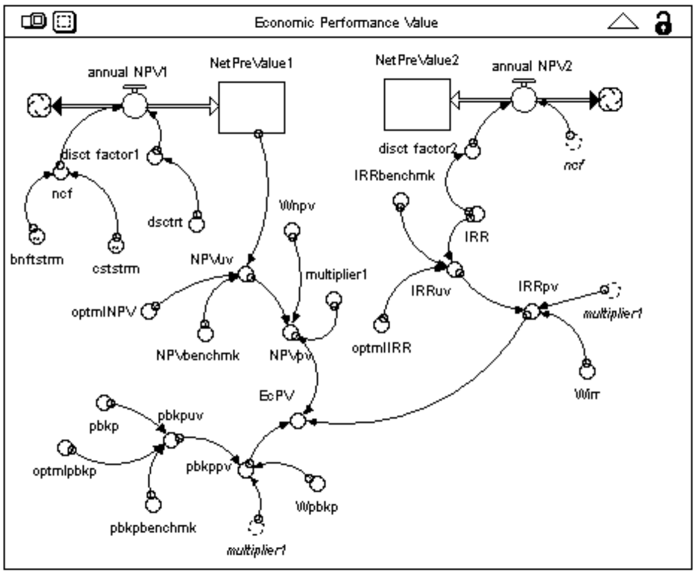


Figure 1 Overview of the model framework

The model framework delineates three subsystem used for measuring the sustainable performance of an infrastructure project, depicting the high-level components. The relationships between these subsystems formulate the structure of the system. The structure operating over time generates its dynamic behavior patterns. The typical purpose of a system dynamics study is to understand how and why the dynamics of concern are generated and search for "policies" to improve the performance.

The simulation model for measuring the sustainable performance of an infrastructure project is constructed by the building blocks (variables) categorized as stocks, flow and converters, as shown in Figure 2. Stock variables symbolized by rectangles are the state variables and they represent the major accumulations in the system. Flow variables symbolized by valves are the rate of change in stock variables and they represent those activities, which fill in or drain the stocks. Converters represent by circles are intermediate variables used for miscellaneous calculations. Finally, the connectors represented by simple arrows are the information links representing the cause and effects within the model structure (HPS, 2005; Saysel and Barlas, 2001).


Economic Performance Value
annual NPV1
NetPreValue1
NetPreValue2
annual NPV2
disct factor1
disct factor2
ncf
IRRbenchmk
dsctrt
Wnpv
IRR
bnftstrm
cststrm
NPVuv
multiplier1
IRRuv
IRRpv
optmlNPV
multiplier1
NPVbenchmk
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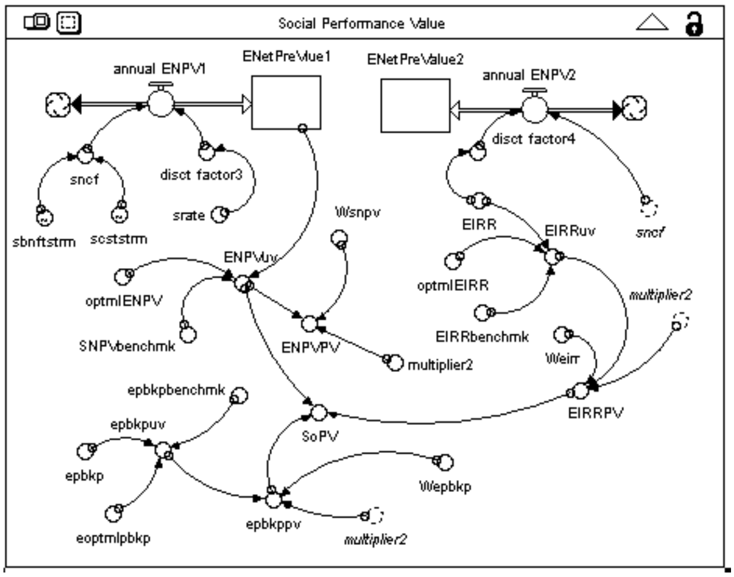
Social Performance Value
annual ENPV1
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sncf
sbnftstrm
scststrm
ENPVuv
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optmlEIRR
multiplier2
SNPVbenchmk
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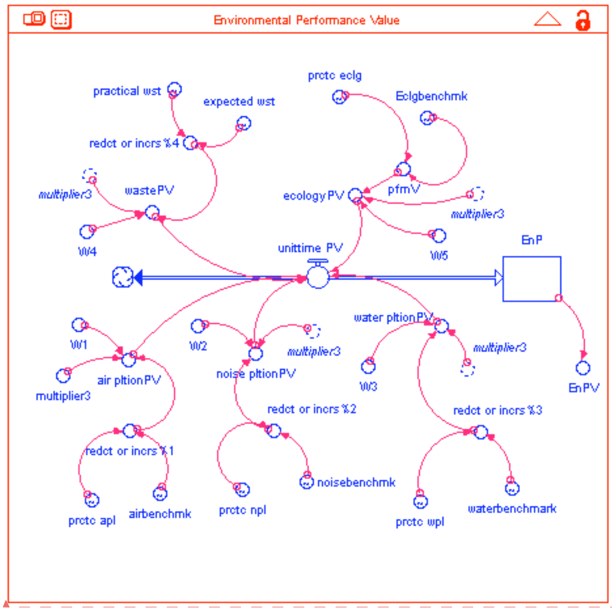

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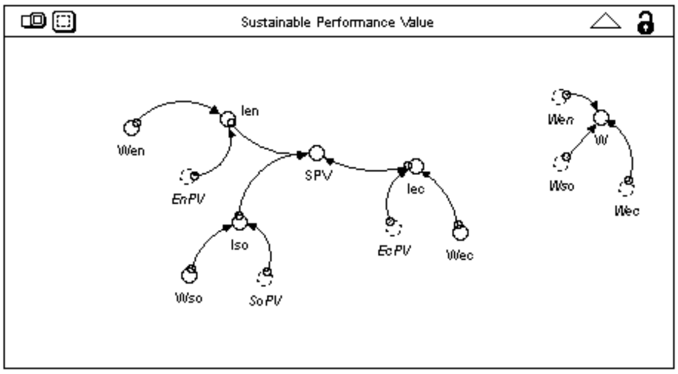

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Figure 2 Simulation model for measuring the SPV

All the variables, their definitions, and associated formulations are detailed in Table 2.

Table 2 Variables and formulations

Variables	**Brief definition**	**Formulation**

Economic performance value subsystem		
NetPreValue1	Practical accumulated financial net present value	NetPreValue1= $\int_0^t (Net\Pr eValue1(t-dt)+annualNPV1*dt)$; Used for calculating the net present value
NetPreValue2	Accumulated financial net present value	NetPreValue1= $\int_0^t (Net\Pr eValue2(t-dt)+annualNPV2*dt)$; Used for calculating the IRR and the value is zero
annual NPV1	Yearly net present value	------
annual NPV2	Yearly net present value	------
disct factor1	Discount factor	------
disct factor2	Discount factor	------
optmlNPV	The optimal net present value	The expected value by the decision makers of a project
NPVbenchmk	The benchmark of the net present value	Generally, the value is zero
NPVuv	The utility value of the accumulated net present value across project's life cycle	NPVuv=(NEtPreValue1-NPVbenchmk)/(optmlNPV-NPVbenchmk)
W_{npv}, W_{pbkp1} and W_{irr}	Weights for the net present value, payback period, and internal rate of return respectively	-------
multiplier1	Multiplier	Be incorporate for the purpose of limiting the range of utility value from 0 to 100.
NPVpv	Performance value of accumulated net present value across project's life cycle	NPVpv= W_{npv} * Multiplier1 * NPVuv
bnftstrm	Financial benefit stream	Graphical function of time
cststrm	Financial cost stream	Graphical function of time
dsctrt	Discount rate	------
pbkp	Practical payback period	------
optmlpbkp	Optimal payback period	The expected value by the decision markers of a projects
pbkpbenchmk	Benchmark of payback period	The maximum payback period of capital investment
pbkpuv	Utility value of payback period	pbkpuv=(pbkpbenchmk-pbkp)/(pbkpbenchmk-optmlpkp)
pbkppv	Performance value evaluated of payback period	Pbkppv=pbkpuv*W_{pbkp1}*multiplier1
IRR	Practical internal rate of return when NetPreValue2 is zero	------
IRRbenchmk	Benchmark of internal rate of return	Be determined according to the industry standard
optmlIRR	Optimal IRR	Expected value by the decision makers of a project
IRRuv	Utility value of IRR	IRRuv=(IRR-IRRbenchmk)/(optmlIRR-IRRbenchmk)
IRRpv	Performance value evaluated of IRR	IRRpv=W_{irr}*multiplier1*IRR
EcPV	Accumulated economic performance value of project across project's life cycle	Ecpv= NPVpv+ pbkppv+ IRRpv
Social performance value subsystem		
ENetPreValue1	Practical accumulated economic net present value	ENetPreValue1= $\int_0^t (ENet\Pr eValue1(t-dt)+annualENPV1*dt)$; Used for calculating the economic net present value

ENetPreValue2	Accumulated economic net present value	ENetPreValue1= $\int_0^t (ENet\Pr eValue2(t-dt)+annualENPV2*dt)$; Used for calculating the IRR and the value is zero
annual ENPV1	Yearly economic net present value	------
annual ENPV2	Yearly economic present value	------
disct factor1	Social discount factor	------
disct factor2	Social discount factor	------
optmlENPV	Optimal economic net present value	The expected value by the decision makers of a project
ENPVbenchmk	Benchmark of economic net present value	This value is zero
ENPVuv	Utility value of the accumulated economic net present value across project's life cycle	ENPVuv=(ENetPreValue1-ENPVbenchmk)/(optmlENPV-ENPVbenchmk)
W_{enpv}, W_{epbkp} and Weirr	Weights for the economic net present value, economic payback period, and economic internal rate of return respectively	-------
Multiplier2	Multiplier	Be incorporate for the purpose of limiting the range of utility value from 0 to 100.
ENPVpv	Performance value of accumulated economic net present value across project's life cycle	ENPVpv= W_{enpv} * Multiplier1 * ENPVuv
sbnftstrm	Social benefit stream	Graphical function of time
scststrm	Social cost stream	Graphical function of time
srate	Social discount rate	------
epbkp	Practical economic payback period	------
eoptmlpbkp	Optimal economic payback period	Expected value by the decision markers of a project
epbkpbenchmk	Benchmark of the economic payback period	Maximum economic payback period of capital investment determined by project's decision maker
epbkpuv	Utility value of the economic payback period	epbkpuv=(epbkpbenchmk-epbkp)/(epbkpbenchmk-eoptmlpkp)
epbkppv	Performance value evaluated of economic payback period	epbkppv=epbkpuv*W_{epbkp}*multiplier2
EIRR	Practical economic internal rate of return when ENetPReValue2 is zero	------
EIRRbenchmk	Benchmark of economic internal rate of return	Be determined according to the industry standard
eoptmlIRR	Optimal EIRR	Expected value by the decision makers of a project
EIRRuv	Utility value of the EIRR	EIRRuv=(EIRR-EIRRbenchmk)/(optmlEIRR-EIRRbenchmk)
EIRRpv	Performance value evaluated of IRR	EIRRpv=W_{irr}*multiplier2*EIRR
SoPV	Accumulated social performance value of project across project's life cycle	Sopv=EIRRpv+ epbkppv+ ENPVpv
Environmental performance value subsystem		
prctc apl	Practical air pollutant emission in unit time	Graphic function of time

	across project's life cycle	
airbenchmk	Relevant criteria or standards stipulated by authoritative bodies	Graphic function of time
redct or incrs%1,2,3,and 4	Percentage of projected pollutant emissions/waste lower or higher than the benchmarks or expected value in unit time across project's life cycle	redct or incrs%1= (prctc apl-airbenchmk)/airbenchmk redct or incrs%2= (prctc npl-noisebenchmk)/noisebenchmk redct or incrs%3= (prctc apl-waterbenchmk)/waterbenchmk redct or incrs%4=(practical wst-expected ws)/expected wst
W_1, W_2, W_3, W_4 and W_5	Weights for air pollution, noise pollution, water pollution, waste management and ecology impacts, respectively	------
multiplier3	Multiplier	Be incorporate for the purpose of limiting the range of performance value from 0 to 100.
air pltionPV	Performance value evaluated of air pollution in unit time across project's life cycle	air pltionpv=redct or incrs%1*W_1*multiplier3
prctc npl	Practical noise pollutant emission in unit time across project's life cycle	Graphic function of time
noisebenchmk	Benchmark of noise pollution	Relevant criteria or standards stipulated by authoritative bodies
prctc wpl	Practical water pollutant emission in unit time across project's life cycle	Graphic function of time
waterbenchmk	Benchmark of water quality	Relevant criteria or standards stipulated by authoritative bodies
noise pltionpv	Performance value evaluated of noise pollution in unit time across project's life cycle	noise pltionpv=redct or incrs%2*W_2*multiplier3
water pltionPV	Performance value evaluated of water pollution in unit time across project's life cycle	water pltionpv=redct or incrs%3*W_3*multiplier3
wastePV	Performance value evaluated of waste management in unit time across project's life cycle	wastepv=redct or incrs%4*W_4*multiplier3
prctc eclg	Practical ecological impacts	Measured by the extent of affected species. The value is obtained through judging subjectively based on the Eclgbenchmk
Eclgbenchmk	Ecological benchmarks	Adopt the Liker Scales: 1- seriously affect; 2-affect; 3- generally affect 4-slightly affect; 5-not affect
pfmV	Practical performance value based on ecological benchmarks in unit time across project's life cycle	pfmV= prctc eclg/ Eclgbenchmk
ecologyPV	Performance value evaluated of ecology impact in unit time across project's life cycle	ecologyPV=multiplier3*W_5*pfmv
unittime PV	Environmental performance value evaluated in unit time across the project's life	untime PV= ecologyPV+wastePV+ air pltionPV+noise pltionPV+water pltionPV +wastePV

	cycle	
EnP	Accumulated performance value of environmental impact across project's life cycle	EnP= $\int_0^t EnP(t-dt)+(unittimePV)*dt$
Sustainable performance value subsystem		
Wen, Wso and Wec	Weight for the environmental impact, social impact and economic impact, respectively	
W	Total weight	W=Wen+Wso+Wec=1
Ien	Accumulated environmental impact value across project's life cycle	Ien=Wen*EnPV
Iec	Accumulated economic impact value across project's life cycle	Iec=Wec*EcPV
Iso	Accumulated social impact value across project's life cycle	Iso=Wso*SoPV
SPV	Accumulated sustainable performance value across project's life cycle	SPV=Ien+Iec+Iso

5 Case study

In order to demonstrate how the simulation model is applied, a highway project is used, a highway is proposed to construct in the northern China, and the project is currently in question.) The initial year of construction is in 2007 and the estimated completion year in 2029. Construction period is 3 years and operation life is planned 20 years. Due to the short period of time of commission stage, it is ignored in this case study. The projected total investment of the project is 776.18 (in RMB million). The project is designed to promote economic and social development in northern China by providing the road infrastructure and improving access to poor villages. Specifically, the project comprises construction of a 28.10 kilometer, linking provincial capital, a major commercial center and county roads in designated poverty counties.

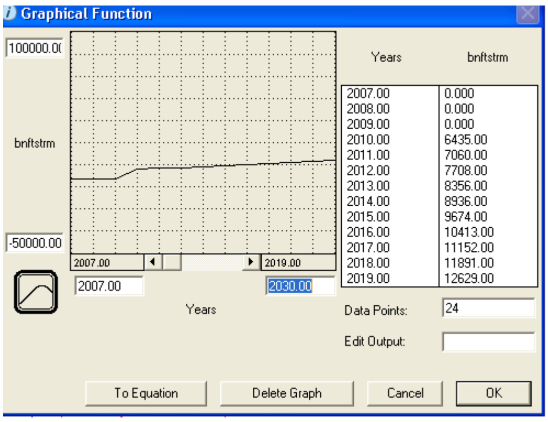

Figure 3 The input of variable 'bnftstrm'

The data used for this study are from the feasibility study of the highway project, which includes economic, social and environmental evaluation. Here, we take an example of the subsystem of economic performance value. The initial inputs for variables "bnftstrm" and "cststrm" are from the financial cash flow statement in the project's feasibility study. Figure 3 shows the example of the input for variable "bnftstrm".

Variable "IRR" can be obtained by letting variable "NetPreValue2" be zero. Variable "pbkp" can also be determined based on the calculated value of the variable "NetPreValue1". Variable "disctrt" is 3.978% according to the feasibility study. When the following values, "optmlpbkp", "pbkpbenchmk", "optmlIRR", "IRRbenchmk", "optmlNPV", "optmlNPV", "w_{npv}", "w_{pbkp}" and "w_{irr}" are given by the project's decision makers based on their expected value, simulation can then be processed. Here, we assume:

ptmlpbkp=0
pbkpbenchmk=20
optmlIRR=0.2
IRRbenchmk=0.03978
optmlNPV=10,0000
$w_{pbkp}= w_{irr}= w_{irr}= 1/3$

Figure 4 shows the result of economic performance value. Its value is 44.7, indicating practical economic impact of the project to the contribution of total SPV arrives at value of 44.7 when the satisfactory level for the economic impact is set to the value of 100.

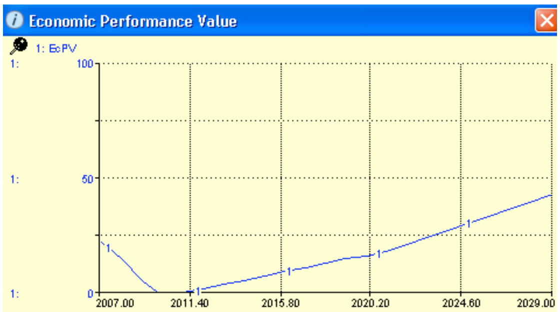

Figure 4 Simulation in subsystem of economic performance value

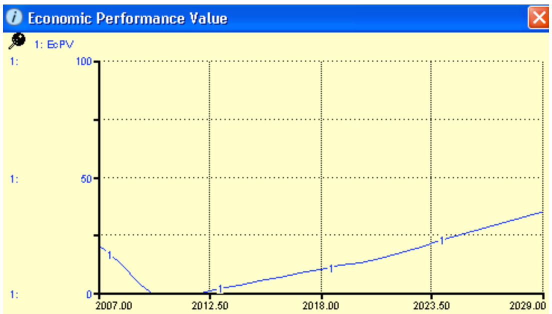

Figure 5 Simulation in subsystem of economic performance value

In fact, the initial input values of variables are affected by many factors, and they can be revised as needed. For example, assuming the variable "dsctrt" change 0.0512, considering the inflation and the interest rate, the economic performance value will change to 35.9, lower than value of 44.7 when variable "dsctrt" is 0.03978, as shown in Figure 5. Similarly, other variables input can be regulated by considering some uncertainty factors. At the same time, the performance value will also change respectively. This implies some policies can be made by the decision makers to regulate the relevant variable value to the satisfactory level.

After all the variables in three subsystems are determined, simulation for calculating the SPV can then be processed and performed. Figure 6 shows the results of SPV.

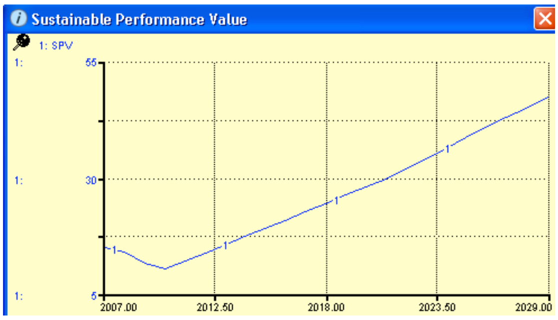

Figure 6 Simulation results on SPV for the highway project

6 Conclusions

With the impetus to attain sustainable development of construction projects, this paper has introduced a simulation developed by using system dynamics approach. A real life infrastructure project presented its unique features and solutions based on the simulation outputs. It is limited to capture the behavior of construction projects at a holistic overview over time by using traditional evaluation approaches due mainly to its static nature. However, a construction project's impact on economic, social, and environmental aspects is dynamic. It can be seen that through the simulation process, the SPV model could be used for evaluating the dynamic impact of a construction project on the aspects. The simulation-based SPV model presented in this paper indicates that a project's contribution to sustainable development varies due largely to the impact of various dynamic variables throughout its life cycle. Such a dynamic approach may provide a variety of possible causative models and unveil hidden uncertainties which traditional methods fail to do. This clearly indicates that the sustainability attainment from implementing a construction project could be better achieved with the help of using the developed approach.

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