A dynamic feasibility analysis of public investment projects: An integrated approach using system dynamics and agent-based modeling

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Abstract

Increasingly, public sector investment projects face a dynamic environment that incorporates both macroscopic system and microscopic individuals. Prior attempts to analyze the feasibility of those projects, however, have been subject to limitations in accommodating such environmental changes. As a remedial measure, the combination of system dynamics (SD) and agent-based modeling (ABM) is proposed due to their complementary strengths. Consequently, this paper suggests a new approach to dynamic feasibility analysis for public investment projects through an integrated simulation model using SD and ABM. The former SD part elucidates the relationships among system elements that constitute project’s benefits and costs, while the latter ABM part depicts users’ emergent behavior with their heterogeneity. A bridge construction case study demonstrates the applicability of the proposed approach. The findings show that the proposed approach can provide a valuable and flexible framework for analyzing project feasibility in a dynamic environment.

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1. Introduction

A feasibility study has played an important role as the first thing to be done before implementing and investing in projects. A feasibility study is important in that it enables decision makers to obtain comprehensive information and results for the viability of an investment project (Jónsson, 2012). Thus, a feasibility study provides a basis for the decision on whether a project is to be implemented or not. Therefore, a feasibility study has been used to support a decision making regarding implementation and prioritization of projects. Especially, a feasibility study has been commonly applied to public investment projects, such as transportation, energy, power, water and sewage, and telecommunication infrastructure investments (Yun and Caldas, 2009; Ziara et al., 2002). For successful implementation of projects, a feasibility study usually considers various types of feasibility, including legal, marketing, technical and engineering, financial and economic, and social feasibility (Abou-Zeid et al., 2007). Therefore, an expert-based analytic hierarchy process (AHP) is applied in a few feasibility studies to evaluate a project’s feasibility and determine a project’s priority by considering multiple criteria of evaluation (Alidi, 1996; Dey, 2001; Dey and Gupta, 2001; Lee and Park, 2011). However, the AHP-based feasibility study may results in a bias and inconsistency because of the nature of the AHP method (Yun and Caldas, 2009).

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On the other hand, a feasibility study can be simply understood as an examination to determine the feasibility of investment alternatives by predicting costs and benefits for every alternative (Abou-Zeid et al., 2007). Traditionally, a cost-benefit analysis, which is a quantitative analysis, has been conducted for a feasibility analysis (Hutcheson, 1984; Shen et al., 2010; Yun and Caldas, 2009) because the two core elements that constitute a feasibility analysis are costs and benefits (Young, 1970).

In this context, recent public sector investment projects have had intense exposure to dynamic environments. The growth of the dynamic aspects of such investment projects can be explained in two parts: the dynamics of (1) a macro level (system level) and (2) a micro level (individual level). First, the dynamics of a macro level results from the fact that public investment projects have a range of potential effects. Because the ripple effects of public investment projects span not only the investment area but also external areas such as economic, social, and environmental (El-Sayegh, 2008; Katrin and Stefan, 2011), the macro elements that construct the benefits and costs, drawn from the investment projects, are diverse and react sensitively to environmental changes. Moreover, the elements of benefits and costs are interrelated in the macroscopic system, where the benefits and costs incurred by the project are formed. Second, the dynamics of a micro level results from the agents that participate in an investment project. The agents have a substantial impact on an investment project because they create a demand that significantly affects the feasibility of the project. Further, these agents interact with one another, following their decision rules over time. This microscopic dynamics that the agents create influences the macroscopic system of project feasibility. Thus, it is difficult to predict the feasibility of a project regarding its macro and micro dynamics with an AHP-based analysis or a traditional cost-benefit analysis that are usually static.

To overcome this limitation, there have been attempts to apply a single simulation method to deal with the dynamic complexity of feasibility analysis (Aldrete Sanchez et al., 2005; Cirillo et al., 2008; Conzelmann et al., 2005; Rode et al., 2001; Turek, 1995). However, such a method lacks the scope to cover the recent characteristics of public investment projects. For instance, Monte Carlo simulation does not reflect a change of system such as the feedback effect; system dynamics (SD) does not consider behavior at user level by focusing only on the dynamics of a system level, and an agent-based modeling (ABM) does not offer a systematic view and a causal relationship by focusing only on the dynamics of an individual level.

Nonetheless, a review of the literature on the simulation field reveals that various attempts to combine SD and ABM have been made to complement each simulation method (Figueroado and Aickelin, 2010; Größler et al., 2003; Kieckhäuser et al., 2009; Kim and Juhn, 1997; Schierz and Größler, 2003; Vincenot et al., 2011). However, there has been no attempt to apply a combined SD and ABM method to feasibility analysis despite the complementary strengths that enable such an analysis to incorporate a dynamics of macroscopic system and microscopic individuals.

Therefore, this paper suggests a new approach for dynamic feasibility analysis that uses a combined SD model and agent-based (AB) model for public investment projects. The combination of a SD model and an AB model is proposed because of the dynamic aspects of the system and individual levels of public investment projects. The proposed model has the potential to analyze dynamic changes in the future and provide comprehensive information for project judges or policy makers in advance. Further, the proposed model is illustrated with a bridge construction case study as an example of the model’s practical use.

2. Feasibility studies

2.1. Feasibility studies for public investment projects

The pre-investment phase of a project comprises several stages: the identification of investment opportunities; the analysis of project alternatives and preliminary project selection as well as project preparation (pre-feasibility and feasibility studies); and project appraisal and investment decisions (Abou-Zeid et al., 2007; Behrens and Hawranek, 1991). A feasibility study is the first and most important factor before undertaking project design and construction because the study’s effectiveness directly affects the project’s success. A feasibility study aims to objectively and rationally uncover the strengths and weaknesses of a proposed project, the opportunities and threats present in the environment, the resources required to complete the project, and ultimately the prospects for success (Justis and Kreigsmann, 1979).

A feasibility study for public investment typically considers the following types of feasibility: legal, marketing, technical and engineering, financial and economic, and social (Abou-Zeid et al., 2007). For instance, the Asian Bond Markets Initiative (ABMI) Group of Experts (2010) evaluated the feasibility of regional settlement intermediary (RSI) options for the Association of Southeast Asian Nations (ASEAN + 3), especially for the following: pre-feasibility to select RSI options, operational feasibility to identify the scope of services of RSI options including interface functional blocks and service flows, legal feasibility to assess the extent of problem regulations or laws as “barriers” for each RSI option, and business feasibility to examine whether RSI options would be viable as commercial entities.

To incorporate the multiple components of feasibility, an expert-based AHP, a multi-attribute decision-making technique, is generally used as an analytical tool for a feasibility study (Alidi, 1996; Yun and Caldas, 2009). For example, Alidi (1996) proposed a methodology based on the AHP to measure the initial viability of projects and rank the priorities of projects. Dey (2001) used the AHP to suggest an integrated framework, which is incorporating technical, environmental, and social assessment, for project feasibility analysis. Dey and Gupta (2001) applied the AHP to select pipeline routes in a cross-country petroleum pipeline project. Lee and Park (2011) applied the AHP to assess the feasibility of Korea National R&D program.
In simple terms, the two core criteria used to judge feasibility are required cost and value to be attained (Young, 1970). Traditionally, cost-benefit analysis has been utilized for the feasibility analysis of public sector investment projects (Shen et. al., 2010; Yun and Caldas, 2009). Since cost-benefit analysis focuses only on final output represented as net present value (NPV), there are several methods that consider NPV changes in order to support static cost-benefit analysis.

2.2. The dynamic approach in a feasibility study

There have been a few organizational projects and academic investigations that use and explain feasibility analysis by a single simulation method. For example, Jacques Cartier and Champlain Bridges Incorporated (JCCBI) (2011) in Canada implemented a pre-feasibility study concerning the replacement of the existing Champlain Bridge and utilized the simulation for evaluating future travel demands (flows) according to scenarios of additional bridges. The ABMI Group of Experts (2010) used a simulation for predicting revenue-side cash flows and included such variables as market share, revenue, running cost, and start-up cost according to scenarios for legal environmental change. The New South Wales (NSW) Department of Environment, Climate Change and Water (2010) used a pre-feasibility study for solar power precincts in Australia and conducted a simulation to estimate electricity generation for each precinct. A UCTE-IPS/UPS study (2008) carried out a feasibility study on the synchronous interconnection of the countries of the Commonwealth of Independent States and the Baltic States (IPS/UPS) and the Union for the Co-ordination of Transmission of Electricity (UCTE). The study modeled low flows for steady state and dynamic system simulations, and analyzed a dynamic change of power capacity in a synchronized system and the effect of synchronous coupling and transient stability. However, the study did not provide detailed explanations of specific simulation methods.

Other cases have offered specific methodology. Aldrete Sanchez et al. (2005) developed a feasibility evaluation model for toll highways based on Monte Carlo simulation that derived the probability distribution for the development cost of toll highways and analyzed financial feasibility and risk. Rode et al. (2001) suggested Monte Carlo methods for the appraisal and valuation of a nuclear power plant. They insisted that the valuation of large-scale technology-based projects such as power plants should incorporate political, technological, and economic risks, and that Monte Carlo simulation is effective in this task. Similarly, Turek (1995) suggested an SD model to analyze the impact of resource constraint because of social factors, political factors, and information on the long-term financial performance and safety of a nuclear power plant. These studies only simulated system interactions at macro level and did not consider the individual level.

The European Union (EU) Transport Corridor Europe-Caucasus-Asia (TRACECA) program (2008) studied the feasibility of the development of maritime transport links in the Black Sea region. The program developed a trade model using ABM to forecast the evolution of trade flows (import and export) in the region. As a result, countries were modeled as autonomous individuals that had their own variables and behavior, and that existed as separate entities within the system. Elsewhere, a research group from the Argonne National Laboratory developed the electricity market complex adaptive system (EMCAS), a software, to model and simulate the electricity market and its decision structures, and defined heterogeneous companies, regulators, physical elements, etc. as agents (Citillo et al., 2008; Conzelmann et al., 2005). The research group had the advantage of considering the macro environment and micro-elements together by operating multi-dimensional interaction layers (i.e., regulatory, business, and physical layers). However, the study specialized in the general-purpose electricity market and did not conduct a feasibility study, even though the software tool can support issues similar to a feasibility study by providing the framework to conduct experiments for the potential effects of various elements on the costs and benefits of an electricity system.

The approaches to dynamic evaluation for a feasibility analysis are very limited. In particular, the attempt to apply a simulation technique directly to the dynamic evaluation of economic feasibility is rarely found in the public investment project area. Prior practical studies were limited in that they utilized conventional simulation models in order to predict and evaluate only partial information, such as market shares and sizes, static or dynamic technical validity, and expected technical impacts. They did not actively set economic feasibility as the determinant target variable and did not engage with the comprehensive dynamic nature of investment projects.

3. A combined system dynamics (SD) and agent-based modeling (ABM) approach

Although SD and ABM are the most important simulation methods that are available to understand complex systems (Phelan, 1999), they pursue totally different or competing viewpoints. (See the appendix for supplementary information about SD and ABM). SD models present a highly aggregated and feedback-rich view of the system using a deductive approach that understates behavior, whereas AB models present a highly disaggregated view of the system in which behavior emerges by using inductive reasoning to generate it (Martinez-Moyano et al., 2007). Lättilä et al. (2010) described the idea of contrasting the differences of the two modeling approaches based on the prior literature. SD has strength in that it can infer the emergence of a certain behavior because of the transparency of system behavior; however, it also has weakness in that the structure of simulation is fixed. On the other hand, ABM has strength in that it can model endogenous interactions of individual agents based on decision rules; however, it has weakness in that it is not suited to modeling macro system factors such as policy.

The different mechanisms of the two successful modeling approaches mean that they can have complementary roles and achieve an enhanced understanding of complex systems (Schieritz and Milling, 2003; Scholl, 2001). For example, Schieritz and Größler (2003) combined SD and ABM in order to simulate supply chains, because ABM is effective at
modeling the evolution of individual interactions, such as creating new partnerships and discrete events that include mimicking certain types of action, whereas SD is useful to model ordering policies controlled by individual agents. Thus, a wide variety of views about combining the two modeling approaches are presented in prior literature (See the appendix for supplementary information about topics of the prior studies). The prior models that have integrated SD models and AB models can be categorized into three types according to the degree of, and direction of, interaction: (1) an independent model, which models the same problem through a SD model and an AB model respectively, and compares their simulation results; (2) a connected model, which utilizes the partial schemes of an AB model as the input of a SD model, and vice versa; and (3) an intertwined model, where the input and output of a SD model and an AB model are joined so that they alternate with each other (agents interacting with a single SD model and SD sub-models embedded in agents) (Vincenot et al., 2011).

Most of the attempts to combine a SD model and an AB model utilized SD to model a macroeconomic system and ABM to model processes that involve social interaction (Hines and House, 2001; Kieckhäfer et al., 2009; Martinez-Moyano et al., 2007; Schieritz and Milling, 2003). Similarly, it is appropriate to use an integrated approach that combines SD and ABM for the feasibility analysis of public sector investment projects in order to take into account the macroscopic system, where the benefits and costs incurred by the project are formed, and the microscopic interactions of users that affect the system. In other words, an integrated approach using SD and ABM has the ability to reflect the micro and macro changes that can vary depending on a particular situation, such as the implementation of a new policy after a project is underway. Specifically, the benefits and costs that occur can be modeled as a single SD model while the decision and interactions of users who participate in the project, and thus should be considered when evaluating project feasibility, can be modeled with an AB model. Further, it is necessary to combine a SD model and an AB model because the behavior and interactions of users affect the overall system of benefits and costs, and vice versa.

4. Proposed SD-ABM approach to dynamic feasibility analysis

4.1. Conceptual framework

To incorporate the dynamic aspects of agents and the system of public investment projects into a feasibility analysis, this research combines a SD model and an AB model to model each system and individual level of a project. For such a purpose, the conceptual framework is generated based on the structure that is suggested by Sterman (2000) as the general structure of a model when agents exist in the system. As shown in Fig. 1, the conceptual framework for the proposed model consists of two parts: (1) the structure of the system for feasibility analysis and (2) the decision rules of the agents.

This framework is similar to the structure suggested by Sterman (2000) in that it distinguishes the decision process of the agents from the institutional structure of a model and represents an information feedback system. However, the difference is that in this framework, the agents’ decisions are considered outcomes of their emergent behavior, which is hardly predictable with SD approach because they utilize the information from the system and themselves in their decision-making with a high degree of heterogeneity.

Specifically, among the various types of feasibility, such as technological feasibility and political feasibility, we focus on economic feasibility, which is widely used in public investment and assessed by a cost-benefit analysis. Here, costs and benefits are formed by numerous elements and variables; moreover, there are complex causal relationships between the elements and variables. In particular, the behavior of agents that participate in the project is the most important element because it significantly affects benefits. However, behavior emerges from diverse factors and is therefore difficult to predict.

In sum, the conceptual framework considers two main parts for feasibility analysis. The first conceptual part, the structure of the system, is modeled as a SD model, and the second part, the decision rules of the agents, is modeled using an AB model; thus, each part can be depicted appropriately. The structure of the system, the first conceptual part, contains the overall process for assessing feasibility and generates the information that will transfer to the participating agents. The agents absorb the information from the system and from themselves and utilize it for their decisions in the second part, the decision process of the agents. The decisions, the outcome of decision rules, become action that changes the state of the system and consequently alters the information from the system that will be passed to the agents. The cycle of information exchange between the two parts continues in the process of estimating project feasibility. In addition, the process of exchanging information between the two parts is embodied in the model through combining the SD model and the AB model in an integrated model.

4.2. Composition of modules

On the basis of the conceptual framework, a combined SD model and AB model for dynamic feasibility analysis is composed of eight modules, which are agent, stock, input, intermediate, benefit, cost, feasibility, and event. Descriptions of the modules are presented in Table 1.

The agent module represents people who potentially use and participate in the object that takes the form of a public investment project. For example, a driver can be an agent in a bridge construction project and a household or a power plant can be an agent in a water/electricity resources-related project. The agent module also implies that users behave according to their decision rules and heterogeneity, although who the agents are and which decision process they adopt depend on the properties of the project.

The stock module represents the users’ changes of state and the amounts of certain types of user that should be considered
when evaluating feasibility. The module plays the same role as in single SD modeling because it represents entities that accumulate or deplete over time. However, in this research, and unlike single SD modeling, the rate of change in a stock module is determined by user behavior. The traffic in the aforementioned bridge construction project and the demand for water/electricity in the resources-related project are examples of stock modules.

The input module is referred to as the given parameters. The variables that are initially defined according to the specific characteristics of the investment project belong to this module. For example, the length or capacity of a road in the bridge construction project, and the ratio of households to a power plant or the price of water/electricity in the resources-related project can be parts of input modules. All the other intermediate variables, which are placed in the costs and benefits calculation process and consequently altered by the other variables, such as the velocity of a car on the bridge and consumer surplus in the water/electricity market, belong to the intermediate module.

The benefit module and the cost module are two core components for economic feasibility. Each module usually has several elements that constitute the total benefit or cost. For example, the benefit of bridge construction can include reductions of travel time and vehicle operating time. The benefit of the water resources project, especially a multipurpose dam construction, can be composed of the supply of water for living/industrial use and flood control. Generally, the total cost of the project mainly consists of construction, incidental, compensation, maintenance, and extra costs. Some elements of benefit and cost can have predetermined and fixed values similar to the input module, while others can be obtained by interacting with other modules such as input, intermediate, and stock.

<table>
<thead>
<tr>
<th>Module</th>
<th>Component</th>
<th>Description</th>
<th>Type of model to which it belongs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agent</td>
<td>People who potentially use and participate in the object of the public investment project and their behavior</td>
<td>AB</td>
<td></td>
</tr>
<tr>
<td>Stock</td>
<td>The state changes, and the amount of certain type of users that should be considered</td>
<td>SD and AB (Overlapped)</td>
<td></td>
</tr>
<tr>
<td>Input</td>
<td>The predefined variables according to the specific characteristics of the project</td>
<td>SD and AB (Overlapped)</td>
<td></td>
</tr>
<tr>
<td>Intermediate</td>
<td>The intermediate variables for computing benefits and costs</td>
<td>SD</td>
<td></td>
</tr>
<tr>
<td>Benefit</td>
<td>Total benefit</td>
<td>Total benefit</td>
<td>SD</td>
</tr>
<tr>
<td>Benefit element</td>
<td>Components of total benefit</td>
<td>SD</td>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td>Total cost</td>
<td>Total cost</td>
<td>SD</td>
</tr>
<tr>
<td>Cost element</td>
<td>Components of total cost</td>
<td>SD</td>
<td></td>
</tr>
<tr>
<td>Feasibility</td>
<td>NPV</td>
<td>Net present value</td>
<td>SD</td>
</tr>
<tr>
<td>Feasibility</td>
<td>BC ratio</td>
<td>A ratio of the benefits relative to its costs when the benefits and costs are expressed in discounted present values in monetary term</td>
<td>SD and AB (Overlapped)</td>
</tr>
<tr>
<td>Event</td>
<td>The event that is happening in the future</td>
<td>SD and AB (Overlapped)</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1. Conceptual framework of a dynamic feasibility analysis.
Based on the total benefit and total cost, the NPV and benefit-cost (BC) ratio are computed over time and are the two components that determine the feasibility module. Here, all benefits and costs are expressed in discounted present values in monetary terms. The BC ratio represents the ratio of the benefits of a project relative to its costs.

The last module is the event module. The objective of this module is to reflect future events. The event module plays the most important role in scenario analysis. The scenarios themselves can be constructed to reflect reality. Policy or other situations, which are expected to influence how the agent behaves and how feasibility is derived, can also be depicted as scenarios and modeled as event modules.

Each module belongs to either/both the SD model or/and AB model and interacts in the model or across the model. As shown in Fig. 2, the SD model embraces all modules except the agent module because it models the whole system structure in order to assess feasibility. In particular, the agent module is significantly associated with the agents’ decision rules while other modules mainly constitute the system structure. Hence, to model the system structure, a SD model is established through the predefined causal relationship among the variables in all the modules except the agent module. On the other hand, an AB model encompasses the agent, stock, input, intermediate, and event modules, which are related to agents’ decision-making. The core module in an AB model is the agent module because determining agents who are involved in the project and making decisions, which will affect the project’s feasibility, should first be considered in order to develop the agents’ decision rules. Then, the variables that influence the agents’ decisions are considered. Usually, these variables belong to the stock, input, intermediate, and event modules, and consequently the agent module interacts with these modules.

Because the SD model and the AB model encompass some of the same modules, there are overlaps among stock, input, intermediate, and event modules. These modules conceptually represent a link between the SD model and the AB model and reflect that there are partially or wholly shared parts in the modules due to the interactions between the outputs and the inputs of the SD model and the AB model. Specifically, the overlap between the two models occurs where the outputs of the SD model are used as the inputs of the AB model; similarly, the outputs of the AB model are used as inputs of the SD model. In addition, from the beginning, some components remain common to both the SD model and the AB model and are therefore also considered an overlap. However, the core modules and variables that link the SD model and the AB model vary depending on the project.

4.3. Overall process

To depict the system- and individual-levels in feasibility analysis, this study suggests using a combined SD and ABM approach, thereby supporting the conceptual framework. The overall process for the dynamic feasibility analysis with the proposed approach is shown in Fig. 3. The process consists of five steps: identification of the variables, modeling of the system/individual level, combining a SD model and an AB

Fig. 2. Composition of the modules in a combined SD model and AB model.
model, a simulation with scenario analysis, and interpretation of the simulation results.

The first stage of the process is to identify the variables in each module that should be considered in the feasibility study depending on the type of project. For example, in the bridge construction project, the benefits can consist of the reductions of travel time and vehicle operating time, while in the water resources project, the benefits are the supply of water for living/industrial use and flood control. Consequently, the variables related to the feasibility of each project are different from each other and should therefore be identified at the first stage.

The second stage is to model the system structure and the agents’ decision rules at system-level and individual-level respectively. The interactive modules in the system structure for feasibility analysis, such as stock, input, intermediate, benefit, cost, feasibility, and event modules, are modeled using SD. A SD model can vary according to the structure or method of calculating benefits and costs. Hence, the specific relation between the components and their variables should be predefined. Second, the dynamics emerging from individuals are modeled using ABM. Once the agent is defined, his or her decision process is described through the agent’s state and decision criteria. An AB model can also be altered depending on the agents or the decision criteria that we focus on.

The third stage is to combine the SD model and AB model into an integrated model through an overlap between the models, as addressed in Section 4.2. The overlap between the models can be observed when one uses the outcome of the other as its input or when they both use the same component from the beginning. Therefore, the core modules and variables that link the two models vary depending on the project. The way in which the SD model and AB model are intertwined with one another also varies.

Finally, in the fourth and fifth stages, the combined model for feasibility analysis is simulated using various conditions and scenarios. A synthesis diagnosis of the feasibility analysis of the investment project is then obtained based on the results of the simulations. The proposed model delivers results that incorporate macro- and micro-impacts that occur in the scenarios. In addition, within the scenarios, the range of multiple variables can be tested; therefore, multifaceted analysis is possible in accordance with the interests of project judges or policy makers. In this way, more comprehensive and useful information on the feasibility of the project is acquired from the simulation results using diverse scenarios and conditions. Then, the dynamic feasibility analysis of the project is complete.

5. Case study: a bridge construction project

5.1. Background

A feasibility analysis on a bridge construction project has been conducted by comparing the associated costs and resulting benefits with their diverse elements (Korea Development Institute (KDI), 2008). For instance, the costs include construction, incidental, and compensation costs, and the benefits consist of reductions in vehicle operating cost, travel time, accidents, and air pollution cost, which are estimated based on traffic. Here, most elements are not independent of each other. Instead, they influence one another, which leads to complex causal relationships in the system. Further, when it comes to benefits in particular, the behavior of drivers that emerges from their own decision rules and creates the traffic is a very important factor. This is because the emergent behavior of drivers affects the benefits and consequently the feasibility of the project. In addition, behavior is intertwined with the system because the drivers make decisions using system information such as

![Overall process for a dynamic feasibility analysis.](image-url)
real-time traffic information. The result of the drivers’ behavior also influences the state of the system.

In this situation, SD is appropriate to model the whole system structure because of the complicated causal relationships. On the other hand, ABM rather than SD is better at depicting the emergent behavior of drivers through intuitive modeling of the agents’ decision rules. Moreover, a combined approach of SD and ABM is suitable in order to incorporate the interactions between the system structure and the drivers’ decision rules. Consequently, an illustrative case study of a bridge construction has been conducted to examine how the proposed model can be applied in practice.

5.2. The modeling process

5.2.1. The identification of variables in modules

To simplify the case study of a bridge construction project, we established a situation whereby one bridge already connects two regions and an additional bridge is being considered. With regard to such a bridge construction project, the general modules from the proposed combined SD model and AB model take concrete shape in accordance with the characteristics of the project as shown in Fig. 4. For the purpose of practical investigation, this study follows the guidelines from the KDI (2008) for feasibility studies for road and railroad projects, in which bridge construction is included, in order to specify the components and variables that constitute the basic modules and the relationships among them.

Specifically, according to the KDI guidelines, the feasibility of a road project is assessed by estimating the benefits and costs. The benefits are obtained from reductions in vehicle operating cost, travel time, accident cost, and air pollution cost, and the costs are estimated by combining construction, incidental, compensation, maintenance, and extra costs. On this basis, the total benefit in the benefit module has four elements and the total cost in the cost module has five elements.

In addition, based on the formulas of each element of the benefits and costs from the guidelines, the necessary variables are identified. These constitute the input and intermediate modules according to whether or not they are initially defined. For example, the capacity of a road, ideal velocity, road length, and time value are assumed in advance to be certain values that are not affected by the other variables. Therefore, they compose the input module. The intermediate module incorporates variables such as velocity, road-using time (time spent on the road), operating cost per velocity, and air pollution cost per velocity, which cannot be determined before the other related variables are provided.

In addition, the velocity of a car and road-using time (time spent on the road) are calculated based on traffic, and the amount of traffic is determined by the number of drivers who currently use the road. Accordingly, the stock module consists of several stocks that represent the traffic of each road or region that arises from the behavior of drivers. The agent module represents drivers who potentially/actually use an existing road or a new road and their behavior. Consequently, the real-time traffic of each road or region, detected from each stock, fluctuates according to the rate of change in the states of drivers from the agent module.

![Fig. 4. Composition of the modules and variables in a bridge construction case.](image-url)
Lastly, the event module is composed of three events that reflect the impacts of increases in traffic that result from population growth, regional development policy, and feedback from the bridge construction.

5.2.2. The modeling of the system level: a SD model

The primary purpose of the SD model is to capture the system structure, calculate the final benefits and costs on the basis of real-time traffic estimated through the AB model, and finally to compute the indicators of economic feasibility such as the NPV and the BC ratio. For such purposes, the SD model covers stock, input, intermediate, benefit, cost, feasibility, and event modules, which are all the modules except for the agent module.

In the SD model, as shown in Fig. 5, two parts representing the situation before and after construction are modeled because the project’s benefits, as previously described, are calculated through reduced costs before and after construction. In other words, because the benefits are calculated by subtracting the costs incurred after construction from the costs generated before construction, two parts are modeled. However, regardless of the part, each module and variable play the same role, and the only difference between the two parts is the number of alternative roads.

Specifically, based on the guidelines from the KDI, there are four elements in the total benefit. The first element is reduced vehicle operating cost. This element is calculated through differences in vehicle operating cost incurred after and before construction. Vehicle operating cost is computed by using the operating cost per road length per car depending on velocity multiplied by road length and total traffic. The second element is the reduced travel time cost that results from construction. Travel time cost is calculated by multiplying road-using time (time spent on the road) by time value per car and total traffic. The third element is reduced accident cost; and the accident cost is derived through the following equation: ((number of traffic accidents/deaths per road length per car * accidents/deaths cost + amount of property damage per road length per car * property damage cost) * road length * total traffic). The last element is reduced air pollution cost; and the air pollution cost is calculated by air pollution cost per road length per car depending on velocity multiplied by road length and total traffic. All these relationships among each element of the benefits and the variables are represented as arrows in a stock-and-flow diagram of the SD model.

Among the variables that compose the benefit elements, road length, time value, number of traffic accidents/deaths per road length per car, amount of property damage per road length per car, accidents/deaths cost, and property damage cost are not related to the amount of traffic and thus have constant value. However, the other variables such as the velocity of a car and road-using time change over time according to the traffic of a road. Therefore, these variables are linked to the stocks that represent the traffic of each road, where the real-time traffic of each road is detected from the AB model. Further, the velocity of a car according to the traffic is derived by the equation that was developed by the U.S. Bureau of Public Roads (BPR), based on

![Fig. 5. The SD model for a dynamic feasibility analysis in a bridge construction case.](image-url)
the guidelines from the KDI. When the velocity is calculated, the operating cost per velocity and air pollution cost per velocity are derived through tables used in the KDI guidelines, where the tables represent operating cost and air pollution cost per velocity. Moreover, road-using time is computed as the road length divided by velocity.

In addition, there are five elements, in the total cost based on the KDI guidelines. Among these elements, construction, incidental, compensation, and extra costs are assumed to be incurred once at the point of the opening of a bridge, and maintenance cost is assumed to be incurred every year once a bridge has been constructed. Finally, every element of the costs and benefits is converted to discounted present value. Then, the NPV and the BC ratio are computed based on the discounted total cost and total benefit.

5.2.3. The modeling of the individual level: an AB model

The AB model covers agent, stock, input, intermediate, and event modules and primarily aims to estimate real-time traffic through modeling drivers’ behavior with regard to road decisions. In the AB model, there are two parts: (1) entering and (2) the decision stage. At the entering stage, drivers determine the traffic of regions as they move from the outside regions to the regions surrounding the two bridges, and from the surrounding regions to the entrance regions of the bridges. Here, each state of the drivers during the entering stage is modeled as shown in Fig. 6. Specifically, drivers in the outside regions are defined as potential users. As they move into the surrounding regions of the two bridges, they become zone users. Finally, if they reach the entrance regions of the bridges they become area users. The rate of flow from potential users to zone users is determined by the parameter, zone user rate, and the rate of flow from zone users to area users is determined by area user rate. Once the drivers become area users, they are supposed to enter the decision stage where they must choose between two roads, an existing and a new road, based on their decision rules.

The decision process of each driver mainly considers two factors: traffic and intimacy. Based on the assumption that a new road has bigger capacity and ensures higher velocity, we propose a scenario whereby a driver considers using a new road as a priority, unless there is too much traffic. If the velocity of a car on the new road is lower than the driver’s affordable velocity, where each driver has his or her own affordable velocity, drivers would take the existing road instead. Similarly, drivers evaluate the existing road by comparing their affordable velocity with the velocity of other cars on the existing road, which is determined by the traffic of this road. Meanwhile, drivers’ choice is also affected by the intimacy of a road. Even though there is not much traffic on the new road, a certain level of traffic on the existing road is maintained because of its higher intimacy. In this model, the levels of intimacy of the existing and new roads are considered through introducing a parameter, new road selection probability, which reflects the possibility of preferring a new road and differs according to each driver. By comparing the possibility of selecting a new road with the assumed level, drivers are arranged into two groups where one represents a person who is willing to select a new road while the other represents a person who is not. Finally, the traffic of each road is decided upon after considering all the decision processes of each driver.

5.2.4. Combining the SD model and the AB model

For a comprehensive analysis of a dynamic feasibility assessment system, the SD model and the AB model are combined into a single model based on the overlapped modules. As introduced in Section 4.2, the SD model and the AB model share stock, input, intermediate, and event modules. Among these modules, in this case study, a core module that intertwines the SD model and the AB model is the stock. In addition, the core variable is the velocity, which is derived from the stock module and included in the intermediate module. Once the result of each driver’s state and the road that has been selected are drawn from the AB model, the overall results cause varying traffic in each region and each road in the stock module that belongs to the combined SD model and AB model. Then, in the SD model, the traffic determines the speed of a car in each road, depending on the parameters of the capacity of the
road and the ideal velocity in the input module. Subsequently, the velocity of a car in each road is transferred to the AB model and used for the driver’s decision rule. In this way, the two models become an integrated model that interacts. The output of the AB model is used as the input of the SD model and then the output of the SD model is used as the input of the AB model on the premise that drivers can receive real-time traffic information and that the traffic is used as a key variable in determining the road.

5.2.5. Scenario analysis

This study aims to suggest a dynamic feasibility analysis and illustrate a process of analysis rather than obtain accurate results from scenario analysis. Hence, a basic scenario composed of certain assumptions, and not exact parameters, was constructed, and the other scenarios, such as population growth, regional development policy, and feedback, were developed through altering some part of the assumptions from a basic scenario.

For a basic scenario, it is assumed that the number of potential users is 10,000, 50% of whom become zone users, and that 20% of zone users become area users. The variables such as ideal velocity and capacity of a road are assumed on the basis of a one-lane road in a metropolitan city in accordance with the guidelines of the KDI. The maintenance cost is assumed based on a standard maintenance and administrative cost of a general national road and the other costs are assumed in consideration of the number of users. (See the appendix for information about overall parameters and their data/assumptions).

To reflect the changes in feasibility in response to future environmental changes, additional scenarios for population growth, regional development policy, and positive feedback were configured along with a basic scenario. Each scenario was developed as a parameter variation of a basic scenario with the help of the event module. Specifically, a population growth scenario represents an increase in the number of users that results from natural population growth. Here, an average annual growth rate is assumed as 1%, and the numbers of zone and area users increase accordingly. A regional development policy scenario reflects an increase in traffic in the immediate area of the bridge that is caused by regional development policies such as new town construction, relocation of government agencies, and development of a tourist location. In this scenario, traffic in the zone and immediate areas is assumed to increase by 10% after the three years since bridge construction. Lastly, a feedback scenario indicates that the flow of traffic from other regions increases because the local economy is vitalized in accordance with improved accessibility to the region that results from the construction of a bridge. For this scenario, the number of area users is assumed to increase annually in proportion to the number of users who select the new road.

5.3. Results

5.3.1. Results of the basic scenario

First, according to the assumptions for a basic scenario, the integrated model for a dynamic feasibility analysis of the bridge construction project was simulated over a ten-year period.

Fig. 7 shows the average daily traffic of each road. This fluctuates over time depending on the status of drivers in the AB model that results from the interaction with the SD model. As shown, the average traffic of the new road, which is colored red, is about one-and-a-half times the average daily traffic of the existing road. Further, the feasibility of the project is ensured after about six years, and over ten years, the NPV reaches about 1.8 billion won (about US $1.6 million) and the BC ratio becomes about 1.3.

Moreover, in the basic scenario, a sensitivity analysis was performed through varying the initial value of the parameters, such as capacity of the road and ideal velocity, in order to examine the changes in the NPV and BC ratio. As a result, when the initial road capacity is changed, the final NPV and BC ratio increase as the initial road capacity increases. This result indicates that the total benefit increases in accordance with increases in the velocity of a car because as the road capacity becomes greater, more traffic can be handled.

In addition, when the initial ideal velocity is changed at 1000 days, it is observed that the final NPV and BC ratio increase rapidly as the differences between the ideal velocity of a new and an existing road become bigger.
5.3.2. Comparison of scenarios
Second, the integrated model for dynamic feasibility analysis of the bridge construction project was simulated over a ten-year period according to four scenarios: the basic, population growth (scenario A), regional development policy (scenario B), and positive feedback (scenario C). The results of the four scenarios are compared in terms of the final NPV and BC ratio ten years hence, and turnaround time.

Compared to the basic scenario, the other three scenarios create an early surplus, and the final NPVs and BC ratios of them increase. In particular, scenario C, which represents the vitalization of a local economy caused by the construction of a bridge, results in a rapid increase in the final NPV and BC ratio compared to the other scenarios. It is possible to guess that the reason is that, in scenario C, the area users in the AB model increase considerably more than in the other scenarios because as the number of area users increases, the number of area users who select a new road will increase, and then the number of area users will increase again in proportion to that in accordance with our assumption. This positive feedback effect on the number of area users in the AB model can result in substantial growth in the final NPV and BC ratio.

Specifically, in scenario A, the feasibility of the project is guaranteed after about five years, down from six years in the basic scenario. Moreover, ten years later, the NPV is about 3.3 billion won (about US $3 million), up from 2 billion won (about US $1.8 million), and the BC ratio becomes about 1.5. With regard to scenario B, the project begins its turnaround about four-and-a-half years later, which is about 400 days less than the original. In addition, the NPV is about 3.6 billion won (about US $3.3 million), 1.6 billion won (about US $1.5 million) higher than the original, and the BC ratio becomes about 1.6 after ten years. Lastly, the result of scenario C shows that the project is expected to show a profit after about four years, and after ten years, the NPV is about 6.4 billion won (about US $5.8 million) and the BC ratio becomes about 2.1, the highest value among the scenarios.

6. Discussion

6.1. Theoretical and practical implications
To support a feasibility analysis of public investment projects in a dynamic environment, an integrated approach using SD and ABM was suggested in this study. In the proposed approach, SD was used to model the system structure for feasibility analysis while ABM was used to depict the heterogeneous agents’ behavior. The illustrative case study of a bridge construction was conducted to present how the proposed approach can be used for a practical feasibility analysis.

In sum, the results of the case study imply that the various factors in the present and the future can have a significant effect on the final feasibility measures because of the dynamic aspects of the project both at the system and the individual levels. Thereby the results indicate the importance for the feasibility analysis to consider such dynamic aspects and diverse scenarios. Moreover, the results demonstrate that the proposed model, with its integrated approach, has the potential to analyze dynamic changes in the future and provide comprehensive and useful information for project judges or policy makers in advance. Further, the proposed approach is expected to provide a robust framework that can be applied to a wide range of investment projects.

Specifically, the results of a basic scenario and a sensitivity analysis, which have been described in 5.3.1, show that the changes in parameters in the SD model can cause critical differences in the final feasibility measures. These significant changes in the final feasibility measures emerge from the interactions between the SD model, which depicts the macroscopic system, and the AB model, which captures the individual behavior. In other words, through the proposed approach, the impact of the changes in system elements on the project feasibility can be estimated by simultaneously considering the system level, individual level, and their interactions. Because various settings can be easily analyzed and depicted with the help of the proposed model, project judges or policy makers can consider diverse situation in a short time.

In addition, the results of the four scenarios, which have been described in 5.3.2, show that the changes in parameters in the AB model can make significant differences in the final feasibility measures. Therefore, the impact of the changes in the individual level on the project feasibility can be appropriately analyzed through the proposed approach by considering the system level, individual level, and their interactions. Moreover, these four scenario analysis show that the event, such as a change in policy, that may occur in the future can be easily simulated through the proposed model.

6.2. Generalization
Furthermore, other projects, instead of a bridge construction project, can be considered through the proposed approach by considering their characteristics regarding system and individual level. Specifically, as shown in Table 2, projects can be classified into four categories by whether an agent exists in a

<table>
<thead>
<tr>
<th>General type</th>
<th>Agent</th>
<th>Standardized formula</th>
<th>How to model</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>○</td>
<td>○</td>
<td>Bridge construction projects, water resource-related projects</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Construct both a SD model and an AB model; specify the modules in a SD model by the standardized formula for feasibility</td>
</tr>
<tr>
<td>2</td>
<td>○</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Construct both a SD model and an AB model; specify the modules in a SD model by the experts of a survey</td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>○</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Do not need an AB model; specify the modules in a SD model by the standardized formula for feasibility</td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>X</td>
<td>R&amp;D projects</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Do not need an AB model; specify the modules in a SD model by the experts of a survey</td>
</tr>
</tbody>
</table>
project and affects the project feasibility, and whether a method of calculating benefits and costs is standardized.

A bridge construction project is an example of a project that have agents and standardized methods of calculating benefits and costs. In such projects, both a SD model and an AB model are constructed and moreover, the modules in a SD model are specified by the standardized calculation methods of feasibility. A water resource-related project is also included in this type of projects, where the agent can be a household or a power plant and the calculation methods of feasibility is standardized. On the other hand, a project that has no agents and no standardized calculation methods of feasibility does not need an AB model, and the modules in a SD model can be specified by the experts or a survey. For instance, generally, a R&D project has no specific agent, and the calculation method of feasibility is defined depending on the characteristics of the project. Similarly, the proposed model can be applied to a project that has an agent and unstandardized calculation methods or a project that has no agent and standardized calculation methods as well. However, the details of a SD model, an AB model, and an integration process should be specified and developed depending on the project with an in-depth consideration.

7. Conclusion

In this paper, in order to analyze the feasibility of public investment projects, we suggested a combined SD and ABM approach, where the SD model depicts the relationships among components that shape the benefits and costs of a project and the AB model considers a user’s behavior and heterogeneity. To illustrate the proposed approach, the proposed model was applied to a case study involving the construction of a bridge using certain assumptions and conducting an analysis under various scenarios. This case study demonstrates the significant importance of the proposed approach because it can incorporate both macro- and micro-elements that result in dynamic feasibility changes.

The integration of SD and ABM can provide a useful framework for analyzing the feasibility of a project. The framework offers a more valuable and flexible feasibility analysis than traditional (static) feasibility analysis because it can enable feasibility simulation that incorporates individuals’ behaviors and heterogeneity, overall system-level elements, the relationships among these elements, a sensitive analysis of individual- and system-level elements, and a test for future events. Consequently, a dynamic feasibility analysis enables project judges or policy makers to decide whether they should invest in a project or not taking into account the uncertainty of the environment and unexpected impacts.

However, some aspects of the approach can be improved. In particular, future research should develop a set of criteria or attributes of the modules/elements that are significant when a modeler integrates the SD model and the AB model. In this study, the interacting modules were described using a holistic perspective, and the interacting elements were specifically represented in the case study because the elements that relate to the integration of the SD model and the AB model differ depending on the project. Thus, a typological guideline on the integration of the SD model and the AB model would be useful.

Also, the inclusion of other types of feasibility, instead of considering only economic feasibility, can allow the examination of feasibility from multiple perspectives.

Conflict of interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.ijproman.2015.07.002.

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