Application of DMDU (Decision Making Under Uncertainty Methodology) on Korean Transportation Infrastructure Feasibility Study

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Abstract

Feasibility assessment has been conducted in order to make a decision for investment on transportation infrastructure in Korea. With respect to the feasibility assessment, the Ministry of Finance has conducted a pre-feasibility study and the Ministry of Land, Infrastructure and Transportation has implemented a feasibility evaluation. However, the methodology for real application in consideration of deep uncertainty has been limited to a sensitivity analysis and scenario evaluation. In this regard, the Korea Transport Institute (KOTI), which is under the Prime Minister's Office, is currently conducting a case study in order to come up with a practical methodology for DMU techniques application. As the outcome of this process, KOTI has developed suitable DMU techniques for Korea and applied them to the past case on that basis. With definition of uncertainties on transportation infrastructure, KOTI is planning to present implications and limitations, and explain the efforts that should be implemented in order to apply them in Korea in the future.

Key Words: *DMU techniques for Transportation Infrastructure Feasibility Study, Future direction of DMU application in Korea, Case study result for DMU techniques in Korea*

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1. Introduction

Today's society has shown rapid changes, increasingly deep uncertainties and competing priorities in a variety of perspectives. In this state, the methodology of assuming future values and evaluation of transport investment project feasibility by only analysts has its limitations. There are limits in assuming deep uncertainties in rapid changes dependent on analysts. If analysts assume future consequences and make decisions on whether to implement a project or not, it would provoke many other difficulties causing conflicts with stakeholders.

In order to resolve this problem, although various analysis methods such as sensitivity analysis, stochastic analysis and scenario analysis, etc. has been introduced, there are still restrictions remaining in assessment of an unbiased future and uncertainties: Sensitivity analysis is used to review the project performances on a certain part of variables. Biased assumption is applied on stochastic analysis without the perception of a precise probability distribution and scenario analysis is based on a biased assumption at the stage of building scenarios.

One of the methodologies we introduced in this paper to overcome such restrictions is 'Decision Making under Uncertainty' (DMU). DMU does not allow any biased assumption on future expressing variables except for upper and lower limits. DMU suggests vulnerabilities and trade-offs from the reviewed result and based on that, it reviews the total number of combinations of input variables and draws the best result.

2. How to Consider Deep Uncertainty in Decision Making Process

Current feasibility systems for transport investment need to replace its decision making process using B/C, AHP etc. with the methodology which can include the deep uncertainty such as DMU. This study is the first step to examine the availability of DMU application on transport facilities feasibility study in South Korea based on the current investing assessment system.

For example, we tested a trial application of DMU in terms of a transport SOC investment decision making system in South Korea. We began by analyzing future uncertainties in the transportation industry. We searched various future uncertainties, from social phenomena such as population aging to innovative technologies such as the introduction of autonomous vehicles, in the transport field. We also analyzed effects on current methodology with a transport investment feasibility decision making process, particularly on the variables applied to economic analysis and set restrictions of input variables.

In this study, restrictions have been set for 47 variables with LHS (Latin Hypercube Sampling) simulation implemented. The simulation result was analyzed with Scenario Discovery methods to find out vulnerabilities and analyzed interrelationships between variables.

Thereafter, we executed a virtual test with both methodologies; current decision making process and DMU. This study as the virtual test with real stakes is still under progress. The next step should be a re-configuration of the current economic analysis system.

3. Methodology

In order to make a strategic decision while maintaining the methodology currently applied as in Figure 1, The DMU methodology structured by KOTI(hereinafter, KDMU) sets the objective to include future uncertainties in a decision making process. Certainly, even today, there have been multiple attempts to reflect uncertainties in order to avoid ineffective decision-making processes from future uncertainties by undergoing sensitivity analysis, scenario analysis, stochastic approach, etc. However, every methodology happens in the framework of analysis and is limited by the absence of the decision maker and interested parties in a process of understanding and taking responsibilities for the future uncertainties.

For example, in South Korea, as shown in Figure 1, numerous problems arose from traditional assumptions currently applied by the organization, such as a 38% cost variation in the initial planning and design, 18.4% and 10% cost and construction period variations, respectively, in the construction stage, and an inaccurate forecast of the traffic rate of 19,976 (pcu/day) to an actual value of 9,750 (pcu/day).

Figure 1. Comparison between KDMU Method and Present Decision Making Process

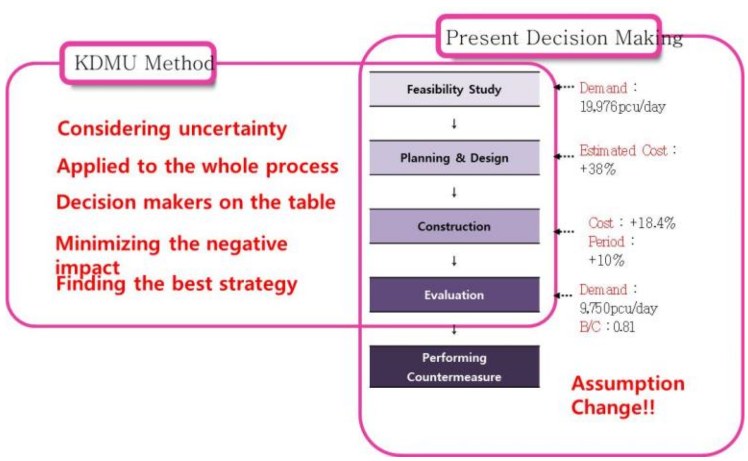
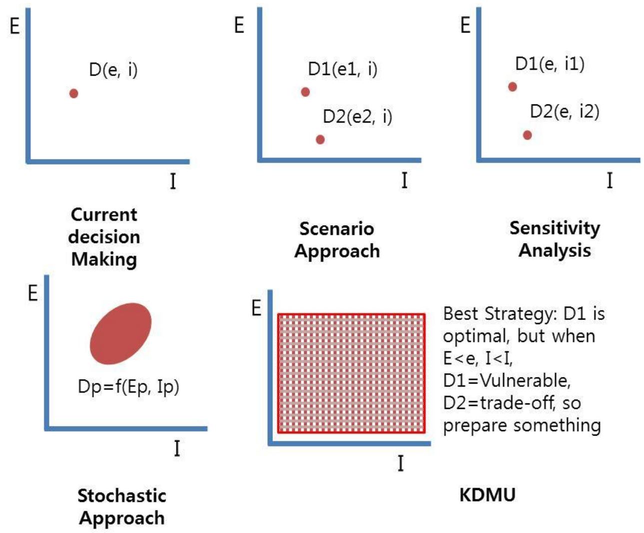
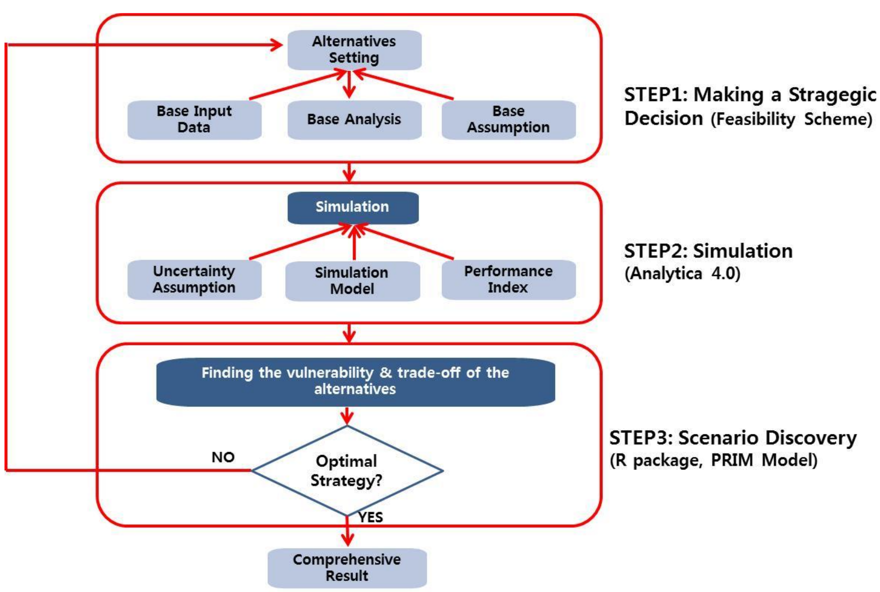


Figure 2. Concept Explanation on KDMU



This paragraph systematized KDMU's analysis process presented in Figure 3. This kind of analysis system is formed according to the specific field during case analysis. Basically, KDMU does not require a huge alteration in preparation as it does not substitute the currently applied decision-making standards. Instead, the currently performed decision-making system is converted into a feedback system, and several procedures are added, namely, the simulation to reflect uncertainties during the analysis, a process that converts the above-mentioned simulation into a simpler conclusion, and lastly a process that generates the most optimized strategy.

Figure 3. Study Framework



As KDMU has not been previously applied in South Korea, this study examines the scope that the suggested methodology applies. KDMU's goal is to reflect future uncertainties and requires constant resource inputs and it does not apply to short-term businesses that do not have a considerable amount of future uncertainties. Moreover, this methodology is used in the following cases when the relevant projects' validity is severely affected by external factors or when the project is severely impacted by external factors.

4. Methodology Development

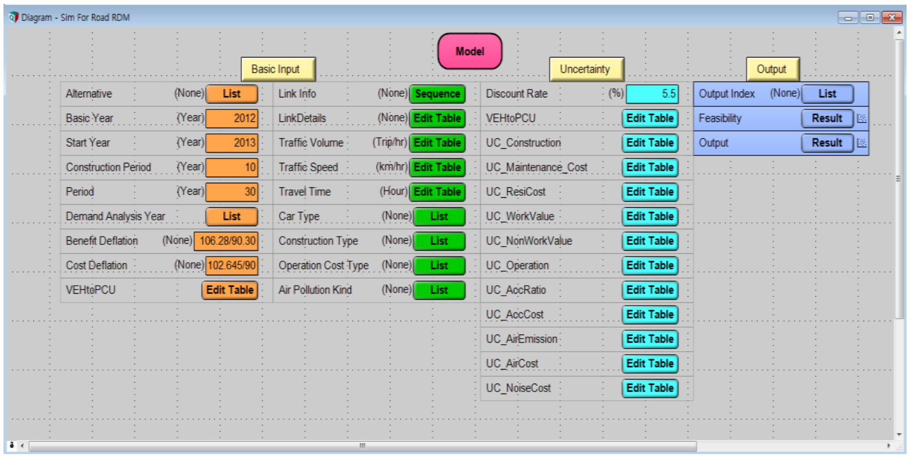
(1) Simulation Model

This study developed a program that can be used even if the target project is changed for future applications. This paragraph explains a model that is structured by the developed program so as to aid readers to better understand and use the model without difficulties.

The model for a simulation consists of several orders. Firstly, an input screen of the developed model for analysis is shown in Figure 4. It enables users to type in basic information such as an alternative, duration of the business, and the year of the analysis. Moreover, users can also type in a coefficient to unify standard years, PCU coefficients, results of traffic demands, and a list to categorize input variations. Currently, all the data is recorded according to the standard suggested by「Preliminary feasibility guideline for road and railway businesses (fifth edition)」provided by the Ministry of Finance in Korea.

In order to input boundary values of uncertainty, there is a section to define uncertainties. Finally, the result of the simulation can be drawn by choosing B/C, NPV, and IRR.

Figure 4. User Interface of Simulation Model



(2) Scenario Discriminant Model

In order to discern a weakness of an original alternative and to analyze a correlation between variables and alternatives, R program's 'sdtoolkit' package is used. This package is developed to enable analysts to utilize Fisher's Patient Rule Induction Method (PRIM).

PRIM consists of 4 stages, namely, candidate group selection, analysis of a selected group, understanding and regrouping of an analysis, and feedback. During the candidate group selection process, analysts can choose the candidate group based on the groups' Coverage and Density indices. Even though, a group with higher scores on both indices should be the most optimized group, an analyst needs to consider that the two indices are in a Trade-off relationship and choose accordingly. Therefore, depending on each case, analysts need to select reasonable groups instead of one optimized group. There is no certain standard in choosing the number of groups up until now.

If the group selection is completed, an analysis is performed to identify the variables that determine a candidate group and relevant indices. During this process, an analyst needs to scrutinize whether the chosen main variables are relevant and whether the main variables imply an important meaning. Through scrutiny, analysts can choose an analysis object group.

In the next step, interpretation is attempted on those analysis object groups based on various aspects such as an external environment, expertise, etc. If regrouping is needed on the results that are excluded from this process, the same process is repeated. Through this process, a provisional result can be interpreted and lastly, based on the interpretation, going back to the first step, the above-mentioned process is repeated until the appropriate conclusion is drawn when feedback is needed.

(3) Assumption of Uncertainty

In order to carry out a simulation that reflects on uncertainty, this study sets the parameters for 47 variables as shown in Table 1 and assumed the Uniform Distribution. Also, LHS (Latin Hyper Cube Sampling) is used to conduct 1,000 simulations.

Table 1. Assumption of Uncertainty

Uncertainty factors	Lower bound	Average value	Upper bound
Discount rate (%)	5.1	5.5	5.92
Construction cost	80%	-	120%
Road maintenance cost	80%	-	120%
Depreciation cost	80%	-	120%
Value of transit time during business hours (Car) (KRW)	16,897	18,626	20,461
Value of transit time during business hours (Bus) (KRW)	9,920	10,228	10,556
Value of transit time during business hours (Truck) (KRW)	15,009	16,571	18,230
Value of transit time during nonbusiness hours (Cars) (KRW)	5,528	6,091	6,689
Value of transit time during nonbusiness hours (Bus) (KRW)	2,786	3,036	3,301
Value of transit time during nonbusiness hours (Truck) (KRW)	3,431	3,729	4,045
Gasoline cost (KRW/l)	584.77	642.30	703.37
Diesel cost (KRW/l)	571.25	631.60	695.65
Engine oil cost (Car) (KRW/km)	4.71	4.98	5.27
Engine oil cost (Small bus) (KRW/km)	4.56	4.76	4.98
Engine oil cost (Large bus) (KRW/km)	8.70	9.21	9.75
Engine oil cost (Small freight car) (KRW/km)	5.46	5.76	6.08
Engine oil cost (Medium freight car) (KRW/km)	6.58	6.95	7.34
Engine oil cost (Large freight car) (KRW/km)	7.66	8.08	8.52
Tire cost (Car) (KRW/km)	5.00	5.52	6.07
Tire cost (Small bus) (KRW/km)	4.86	5.51	6.20
Tire cost (Large bus) (KRW/km)	11.96	13.66	15.46
Tire cost (Small freight car) (KRW/km)	5.64	6.20	6.80

Tire cost (Medium freight car) (KRW/km)	15.71	17.21	18.80
Tire cost (Large freight car) (KRW/km)	18.67	20.60	22.64
Car maintenance cost (Car) (KRW/km)	18.48	19.95	21.51
Car maintenance cost (Small bus) (KRW/km)	16.61	18.05	19.58
Car maintenance cost (Large bus) (KRW/km)	31.43	34.46	37.67
Car maintenance cost (Small freight car) (KRW/km)	21.15	22.63	24.21
Car maintenance cost (Medium freight car) (KRW/km)	46.19	49.80	53.63
Car maintenance cost (Large freight car) (KRW/km)	46.36	48.24	50.23
Depreciation cost (Car) (KRW/km)	127.56	141.74	156.86
Depreciation cost (Small bus) (KRW/km)	187.83	223.66	261.63
Depreciation cost (Large bus) (KRW/km)	123.75	143.05	163.55
Depreciation cost (Small freight car) (KRW/km)	105.31	118.55	132.61
Depreciation cost (Medium freight car) (KRW/km)	172.99	194.70	217.69
Depreciation cost (Large freight car) (KRW/km)	149.52	155.11	161.05
Mortality accident cost (KRW 10,000/Person)	48,258	52,741	57,501
Injuries accident cost (KRW 10,000/Person)	1,965	2,156	2,359
Air pollution cost (Car) (KRW/km)	19.17	19.95	20.75
Air pollution cost (Small bus) (KRW/km)	17.35	18.05	18.78
Air pollution cost (Medium bus) (KRW/km)	17.35	18.05	18.78
Air pollution cost (Large freight car) (KRW/km)	33.12	34.46	35.85
Air pollution cost (Small freight car) (KRW/km)	21.75	22.63	23.54
Air pollution cost (Medium freight car) (KRW/km)	47.87	49.80	51.80
Air pollution cost (Large freight car) (KRW/km)	45.66	48.24	50.90
Noise pollution cost (Urban) (KRW/dB.m.year)	3,598	3,739	3,886
Noise pollution cost (Province) (KRW/dB.m.year)	1,553	1,614	1,678

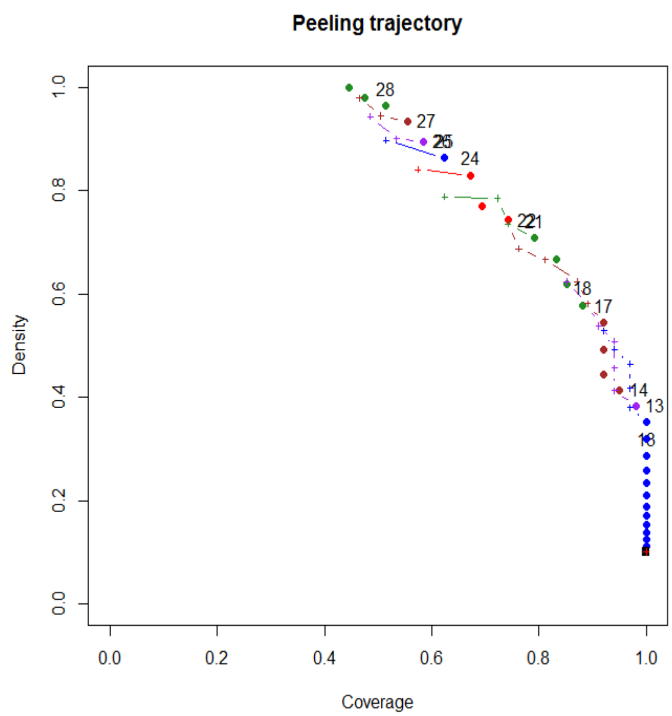
5. Case Study Result

This paragraph summarizes the implementation of the methodology in an actual preliminary feasibility plan for roadways. A target for this implementation is a business with an original preliminary feasibility plan. The target project is a newly-organized local road project that stretches 7.36 km and costs more than KRW 200 billion which is entirely subsidized by the government. Duration of the project is for 10 years starting from the day the construction starts and the main objective of the project is to resolve chronic traffic congestion. The actual name of the project is left out of this report as it is a currently undergoing project.

(1) Analysis Result

Based on the simulation result, the last step of KDMU which is to set the standard point to draw the scenario is determined at a point where B/C is less than 1. Figure 5 is a graph of the simulation result on Coverage and Density indices. An analyst needs to select an appropriate group from this graph and this study examines every groups' statistic indices and the drawn conclusion. Group number 21 is selected as the subject of analysis and the example of the following result is as shown in Table 2.

Figure 5. Example of Group Identification



Dataset Statistics in Table 2 refers to the result of the entered simulation. Global mean is the value calculated from dividing a Total number of interesting points that satisfies a standard point by the Total number of points.

Ensemble box sequence statistics refers to the main statistics for several groups. A group is selected in Table 2 to help gain a better understanding. Coverage refers to the rate that satisfies a standard point among observed values belong to the group. Density is the rate of observed values that satisfies a standard point from the total observed values and support is the rate of observed values that belong to the group from the total observed values.

Table 2. Case Study Result Summary

<table>
<tr><td colspan="6">Dataset Statistics</td></tr>
<tr><td colspan="4">Total number of points</td><td colspan="2">1000</td></tr>
<tr><td colspan="4">Total number of interesting points</td><td colspan="2">101</td></tr>
<tr><td colspan="4">Global mean</td><td colspan="2">0.101</td></tr>
<tr><td colspan="4">Total input dimensions</td><td colspan="2">47</td></tr>
<tr><td colspan="6">Ensemble box sequence statistics</td></tr>
<tr><td colspan="2">Total number of boxes</td><td colspan="4">1</td></tr>
<tr><td colspan="2">Ensemble coverage</td><td>0.7921</td><td colspan="3">80 out of 101interesting points captured</td></tr>
<tr><td colspan="2">Ensemble density</td><td>0.7080</td><td colspan="3">80 out of 113 captured points are interesting</td></tr>
<tr><td colspan="2">Ensemble support</td><td>0.113</td><td colspan="3">113 out of 1000 total points are captured</td></tr>
<tr><td colspan="6">Report on individual boxes</td></tr>
<tr><td colspan="6">Box 1</td></tr>
<tr><td colspan="4">Density</td><td colspan="2">0.7080</td></tr>
<tr><td colspan="4">Coverage</td><td colspan="2">0.7921</td></tr>
<tr><td colspan="4">Support</td><td colspan="2">0.113</td></tr>
<tr><td rowspan="5">Box definition</td><td>Dimension name</td><td>Bound</td><td>Density</td><td>Coverage</td><td>Support</td></tr>
<tr><td>Construction cost (baseline proportion)</td><td>> 1.1294</td><td>0.1010</td><td>1.0000</td><td>1.000</td></tr>
<tr><td>Value of transit time (Truck) (baseline proportion)</td><td>< 1.0521</td><td>0.5284</td><td>0.9208</td><td>0.176</td></tr>
<tr><td>Discount rate (%)</td><td>> 5.1282</td><td>0.6232</td><td>0.8515</td><td>0.138</td></tr>
<tr><td>Maintenance cost (baseline proportion)</td><td>> 0.8286</td><td>0.6667</td><td>0.8119</td><td>0.123</td></tr>
</table>

(2) Analysis Result Case Interpretation

According to the analysis, a scenario that exposes weak points occurs when the construction cost increased to 12.9%, the value of transit time of truck drivers does not exceed 5.2%, the discount rate does not go lower than 5.12%, and the maintenance cost does not drop below 82.8%. This result can be shown in a simple form as the following to decision makers as evidence.

> The given alternative is not profitable unless the value of transit time of truck drivers does not exceed 5%, the discount rate does not go below 5.12%, the construction cost increases to 12%, and the maintenance cost does not drop below 82.8%.

Table 3 shows a decision making process example using the analysis result. As shown in this case, it is now easier to discuss weak points based on quantitative data which had been considered to be difficult to discuss on a concrete level and also provides an opportunity to find a much more effective alternative to the future uncertainty.

Table 3. Interpretation on the case study result

Categories	Possibilities	Discussion
Value of transit time of truck drivers	The value of transit time of truck drivers will not exceed 5% with the advent of autonomous trucks.	Given alternative is profitable based on the current assumptions, but is fragile if future uncertainty is included. An alternative to resolve construction costs and maintenance costs needs to be examined.
Discount rate	There might be a drop in discount rates but it seems unreasonable to go below 5.12%	
Construction cost	An increase in construction costs more than 12% is prevalent, so there is a high chance of this occurring	
Maintenance cost	Even with the advent of new technology to deal with maintenance costs, it is very unlikely that the cost will go below 82.8%	

6. Discussion

The objective of KDMU is to show uncertainty by maintaining the current structure while suggesting an easy-to-understand scenario of a correlation between weaknesses and alternatives that might occur in the future through simulations. The systemic economic analysis for feasibility assessment is based on demands to show various convenience items and costs in a linearly manner and in this process, a variable such as a social rate of discount can have a huge impact on the results. In a case of a single assumption, this does not pose a threat, but in a system that reflects variances in each of the items can be limited to reflect its objective which is to show various uncertainties.

Table 4. Implications and Limitations on KDMU

Linear Scale Effect of current structure	- Limitation: Existing validity structure is a linear structure that is sensitive to baseline parameters such as social discounts. - Solution: Identify both positive and negative sides of uncertainties in terms of cost and convenience, then promote studies on how to adjust the scale on main factors.
Inconvenience on uncertainties	- Limitation: During the process of selecting or considering uncertainties, it might develop into a convenience of policy. - Solution: Each year, establish guidelines on the scope or variables of uncertainties through research facilities with public confidence.
Detailed plan to promote participation of interested parties	- Limitation: Concrete plan to promote the participation of interested parties is not in the scope of KDMU. - Solution: Establish a method to promote the participation of decision makers on the basis of KDMU.
Activation of initial application	- Limitation: Activation of an initial application and expansion is limited as it implements a different paradigm to an existing one. - Solution: Through institutions with public confidence, provide regular training, seminars and informational packages that can be used immediately.

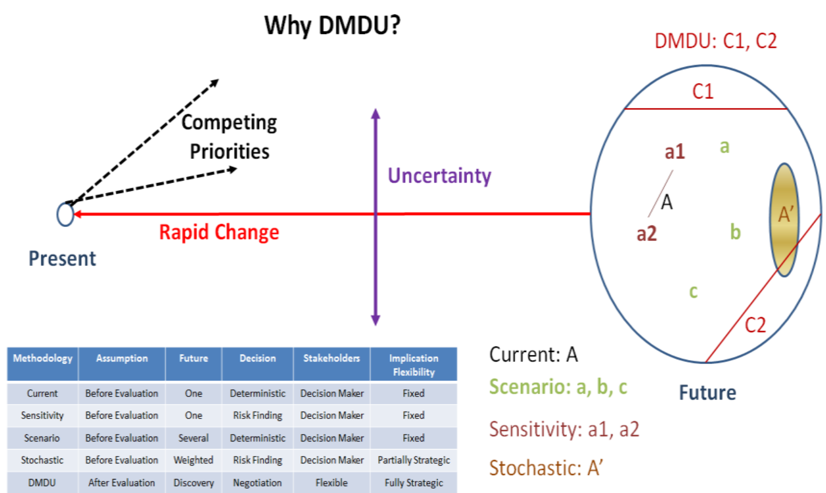
The KDMU developed in this study is significant in that it is the first methodology that applied the DMU method in the South Korean traffic investment evaluation. Based on this study, Table 5 and Figure 6 display a result that conceptually compared sensitivity analysis, scenario analysis and stochastic analysis that are applied to show uncertainties other than DMU.

Table 5. Comparison between methodologies

Category	Assumption point	Future	Decision making	Interested parties	Flexibility of application
Present	Before analysis	Fixed	Decisive	Analyst, Decision maker	Fixed
Sensitivity	Before analysis	Fixed	Unconstitutional	Analyst, Decision	Fixed

analysis				maker	
Scenario analysis	Before analysis	Limited	Fixed	Analyst, Decision maker	Fixed
Stochastic analysis	Before analysis	Weighted	Unconstitutional	Analyst, Decision maker	Partly strategically
KDMU	After analysis	Heuristic	Negotiative	Applied flexibly	Strategically

Figure 6. Comparison of methodologies' concept



7. Conclusion

This study examined feasibility of the investment evaluation methodology using RDM in order to resolve issues arisen from the currently applied deterministic investment evaluation methodology. Firstly, future uncertainties are drawn that are included in the process of carrying out economic feasibility, and RDM analysis is applied to these factors. Although there is a limitation to include various future uncertain changes of environments since only quantitative cost and convenience are considered in the economic analysis, it is significant that the applicability of the RDM methodology on the actually applied investment evaluation methodology is examined and meaningful results are drawn from it.

(1) Application Plan of the RDM Methodology

① Complement the existing comprehensive evaluation method using the RDM methodology

There may be many variations followed by future uncertainty factors when economic feasibility determines whether to continue with a business project plan. Even when the B/C value exceeds 1.0 and secures the business validity, there may be cases when the validity is lost because of variations as the project proceeds. On the other hand, even when the B/C value does not exceed 1.0, there are cases when a business actually turns out to be profitable. Considering these points, there needs to be an extensive discussion during the feasibility evaluation stage and a new investment assessment methodology that takes future uncertainties into account needs to be developed.

During the economic analysis that considers uncertainties, it is estimated that the comprehensive evaluation method that is carried out as a short-ranged preliminary validity evaluation can consider uncertainties. However, this methodology is based on the deterministic decision making process so it cannot suffice as a fundamental alternative. Therefore, in a long term, a development of fundamental evaluation methodology that can consider future uncertainties is necessary. The RDM methodology’s decision making process is based on the Agree-on-Decision method and it is safe to say that this decision making process is a result of consensus and additional processes to draw consensus on analysis results need to be prepared.

② Priority selection on projects with similar sizes and characteristics using the RDM methodology

Up until now, investment is made in the most economically feasible plans, but future uncertainties need to be considered when choosing the most optimized project among various projects. When carrying out economic feasibility with future uncertainties taken into account, the amount of involvement differs depending on the size and characteristics of projects, so it is necessary to consider vulnerabilities to future uncertainties during the alternative selection process. Moreover, the analysis result of these project weaknesses can be useful when the nation’s Transport Ministry proceeds with a preliminary validity test on projects.

③ Validity evaluation that takes future uncertainties into account

The RDM methodology is expected to be useful in determining the validity of traffic related businesses. Especially, considering that traffic related projects are usually long-term projects that range from 10 to 20 years, they are more susceptible to future uncertainties.

The national institution's traffic networking plan categorizes all the projects included in the next 20 years as short-, medium- and long-term projects. Future uncertainties are greater with middle- and long-term projects so it is estimated that the effectiveness can be greatly improved if constant monitoring and maintenance is accompanied on those projects.

Furthermore, it is also expected that the RDM methodology can improve objectivity when coming up with plans to evaluate a comprehensive feasibility test. By including the amount of future uncertainties in the evaluation category, it is estimated that a more active reaction on future variations is possible.

(2) Improvement plan to adopt the RDM methodology

① The addition of a decision-making process based on Agree-on-Decision

The existing decision making process is based on the already determined values of the rate of benefit to cost or AHP, of which the interested parties are often left out from the decision making. Therefore, Agree-on-Assumption has a limitation that it is difficult to lead a mutual agreement. Even though carrying out economic feasibility using the RDM method includes a suggestion of standard result values, also included are a range of various future uncertainties that can affect final decisions on which project to choose. Therefore, when applying the RDM values, a mutual agreement between interested parties is necessary in order to discuss all the possible cases. In the long run, with some improvements in the existing decision-making process, a conversion from deciding project feasibility on a single project into multiple candidate projects system requires discussion on investment and period.

② Categorizing and differentiating projects followed by the RDM analysis results

The most important factor when deciding whether a project is feasible or not using DMU methodology is discussion on the projects with the benefit-cost ratio close to 1.0. This is because there are cases dependent on future uncertainties, projects that are selected even without securing economic feasibility and vice versa.

In traffic investment businesses, there are many cases that resulted in expensive social costs as the actual benefit did not meet the expectations. Considering this point, it seems that there needs to be a special care for projects that do not guarantee feasibility. Even now, when proceeding with a comprehensive evaluation during a preliminary validity test, a special care is taken for cases when it is difficult to decide whether the project is feasible or not by categorizing them in a gray area. However, the gray area is subject to change depending on who analyzes them so it is differentiated from the future uncertainties. As evidenced from past experience, the fact that the project's feasibility can be greatly affected by future uncertainties, a plan to categorize and differentiate the management of projects that have large future variations is expected to be an effective management plan.

③ Reflection of guidelines on RDM based evaluation technique

Representative guidelines related to the Traffic investment evaluation technique include 「A standard guideline on preliminary projects for roads and railways」and 「Traffic infrastructure evaluation guideline」 provided by Korea Government.

This study suggests that if the guideline is revised to include the KDMU model when carrying out economic analysis, it is possible to include many more diverse uncertainties that are not suggested by a traditional analysis result. Moreover, it is recommended to lead a mutual agreement among the interested parties when an economic analysis concludes that the value of B/C is close to 1.0.

Also, it seems necessary to include a degree of susceptibility to future uncertainties while conducting a comprehensive evaluation.

④ Conducting an international study to establish the RDM methodology in traffic fields

As mentioned earlier, international organizations such as the World Bank are working on the DMU methodology in the energy field and the water resources field, but not many cases are found when the DMU method is applied in the transportation field.

This study based on actual national projects that have been done in the past and carried out a case analysis to examine applicability of the DMU method, concludes that it is possible to apply the DMU method in the transportation field when conducting an investment evaluation that includes future uncertainties. However, there needs more studies to establish investment evaluation techniques that include sustainability and uncertainties of technology development on the international scale, and a cooperation with international organizations is needed to establish an evaluation methodology that satisfies the international standards.

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