Infrastructure Project Selection Automation Using Non-Structural Fuzzy Decision Support System II

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INFRASTRUCTURE PROJECT SELECTION AUTOMATION USING NON-STRUCTURAL FUZZY DECISION SUPPORT SYSTEM II

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In this study, we develop a web-based Decision-Making Tool (DMT) based on a four-year research project in building the proper multiple criteria Decision-Making Framework (DMF) for infrastructure project selection automation. Several challenges in selecting and prioritizing infrastructure projects include poor front-end planning, lack of project funding, improper investment, unsustainable development, regulatory barriers, and poor coordination among stakeholders. The Non-Structural Fuzzy Decision Support System II (NSFDSS-II) is chosen as the main method applied in the proposed DMF since it could resolve complex multi-criteria problems, even without sufficient information provided. When developing the DMT, Agile software development method is used since the development cycle can be run in a light and fast manner with iterative and incremental processes. The DMT is successfully developed by using PHP, HTML, and JavaScript which implement the proposed NSFDSS-II method. We further tested the decision results from the DMT by using eight real past infrastructure projects from relevant infrastructure agencies in Indonesia, such as the Ministry of Public Works and Housing (MPWH), the Ministry of Transportation, and the Local Government. The DMT outcomes were compared with the actual implementation status and evaluated by an independent expert. It was found that the decision results from the developed DMT are in accordance with the real implementation status of evaluated projects. The DMT is recommended to be used for infrastructure project selection automation. However, despite of its fast and accurate result, the DMT should be tested on larger number of infrastructure projects in the future

Keywords: agile method, artificial intelligence, decision-making tool, NFSDSS-II, projects selection automation

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1. Introduction

During his first term in office (2014–2019), President Joko Widodo has put much stress on Indonesia's infrastructure development. He understands that the overall national development of a country depends on its infrastructure development. Therefore, as listed in the National Strategic Projects list [1], there are 245 projects and two programs with a total estimated investment of IDR 4,197 T (USD 309 B). These strategic projects cover 15 sectors, which consist of 74 road projects, 54 dam projects, 30 area development projects, 23 railway projects, 12 energy projects, ten port projects, nine water management projects, eight airport projects, seven irrigation projects, six smelter projects, four technology projects, three housing projects, three cross-border post projects, one agriculture or marine project, and one sea embankment project. With the increasing number of infrastructure projects, it is hoped to stimulate Indonesia's economic growth.

However, many challenges are impeding the progress of these initiatives. Poor front-end planning, lack of project funding, improper investment allocation, unsustainable development, regulatory barriers, and poor coordination among stakeholders are a few examples. Among these challenges, previous publications have shown that the adequate front-end planning (FEP) phase plays a crucial role in forming better project performance [2, 3]. Several issues associated with poor infrastructure performance, including lack of analysis regarding the problems and alternatives, unclear infrastructure effects, lack of coordination, underestimated costs, and overestimated benefits [4–6] are related to the poor FEP.

To facilitate the right infrastructure investment decision constraint by a limited budget, a Decision-Making Framework (DMF) that integrates multiple decision parameters is needed. We have developed a DMF model in the last four years, collaborating with many stakeholders and ministries in the Indonesian government. Here, we highlight the importance of an epistemic context-based DMF consisting of three epistemic context dimensions namely knower context, knowing context, and knowledge context. Four different Artificial Intelligence (AI) methods for infrastructure projects selection were implemented and evaluated to choose the best model for the DMF. Interested readers are encouraged to read our previous publications [7–10].

This study further takes the project results by building a Decision-Making Tool (DMT) based on the epistemic context-based DMF model. Hence, the importance and contribution of this paper are:

– building a new DMT based on the proposed epistemic context-based DMF for infrastructure project selection;

– investigating the DMT power by evaluating the results with eight real past projects assessed by an expert in the domain;

– bridging the development of science to industry through technology transfer so that it can provide practical benefits for infrastructure decision makers.

2. Literature review and problem statement

Various Decision-Making Frameworks (DMF) have been developed and introduced in the literature in helping related stakeholders to decide the best infrastructure project to be implemented. They applied different algorithms within specific domain. In [11], for example, presented an integrated rough group multicriteria decision-making model for railway infrastructure project prioritization and evaluation. Firstly, they applied the Full Consistency Method (FUCOM) to evaluate the selection criteria and then followed by the Multi-Attributive Ideal-Real Comparative Analysis (MAIRCA) to prioritize alternative projects. They implemented the proposed framework to a case study in Serbian Railways to find the best rail infrastructure project. They found that the utility of the proposed decision-making method is evident, but its acceptance by management might be a concern. The rough FUCOM-MAIRCA model employs many Mathematics and Statistics concepts that may not easily understood by the decision-makers. Hence, the utilization of this method as a part of a decision support system or decision-making tool will make it more acceptable to management [11].

The authors of [12] introduced another complex framework that composes of a fuzzy hybrid multi-criteria method and a fuzzy bi-objective mathematical programming model in project portfolio selection problem. Both fuzzy Analytical Hierarchy Process (AHP) and fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) were combined to evaluate the projects before moving to the fuzzy mathematical model that tries to maximizing Net Present Value (NPV) of profit and portfolio score. Based on the experimental results using an Iranian company as a case-study, the authors found that multiple modes approach could give better results than using only one mode (i.e., maximum NPV). The shortcoming of the proposed framework is the complex Mathematical formulations introduced by the hybrid method.

Similarly, [13] also conducted a multi-criteria analysis using four different methods, namely AHP, fuzzy AHP, TOPSIS, and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), for road infrastructure projects in north-eastern Poland area. They found that the use of those methods requires precise quantitative data and multiple specialists' involvement as well as more specialized software. They also pointed out that despite the growing number of publications on the multi-criteria decision-making (MCDM) topic, the introduction of more complicated algorithms may present certain limitations to their practical application. Many introduced framework in the literature could work best in the specialized environment and case prepared during the experimental phase, but could not be used in the practical application due to its complexity.

In a more specific domain, the authors of [14] introduced a novel hybrid decision-making method for wind energy project selection. The proposed method combines the hesitant Interval-Valued Intuitionistic Fuzzy (IVIF) Decision Making Trial and Evaluation Laboratory (DEMATEL) and Multi-Objective Optimization on the basis of Ratio Analysis (MOORA). They identified several important criteria to make investment decision on wind energy projects. However, they did not consider general issues that could affect the wind energy investments, especially with and between different country groups. In [15], there are four multi-criteria decision-making (MCDM) techniques applied, viz. TOPSIS, ELECTRE III, VIKOR, and PROMETHEE, to aid decision makers in prioritizing post-disaster reconstruction projects. Although, the proposed method may give a good prioritization result, this is a very domain-specific problem that may give different results when implemented to different locations or when involving different disasters' characteristics.

Lastly, [16] investigated the decision power of fuzzy TOPSIS, fuzzy VIKOR, and fuzzy Grey Relational Analysis (GRA) for sustainability evaluation of urban mobility projects. They found that the best alternative is selected using veto of those three methods rather than using single MCDM method. But as in other studies that proposed hybrid and ensemble methods, the proposed method tends to be more complex and could hinder it to be implemented in the real-world application.

Most of the research focused on the key challenges and DMF developed to solve problem in their specific domain. Very few of them took further step in creating a Decision-Making Tool (DMT) based on the developed DMF. Hence, the applicability of the introduced DMF is very limited which become the main problem trying to be solved in this study. In [7] we explored different techniques to build a proper multiple criteria DMF for infrastructure project selection. Infrastructure project selection criteria was identified through a systematic review of literature in [8]. Features and characteristics of the DMF was identified in [9]. The results were synthesized to develop an epistemic context-based DMF for infrastructure project selection equipped with the weighting of each selection criteria [10]. Meanwhile, in this study we focus on developing a web-based DMT based on the proposed DMF for practical uses in the construction industry.

3. The aim and objectives of the study

The aim of the study is to develop a Decision-Making Tool (DMT) based on the proposed Decision-Making Framework (DMF) using the Non-Structural Fuzzy Decision Support System II (NSFDSS-II). This will make it possible to assist decision makers in selecting infrastructure projects to be implemented in a fast and transparent manner. Thus, this tool will be useful for the government to allocate limited investment funds in the right infrastructure projects.

To achieve this aim, the following objectives are accomplished:

– to systematically learn and develop the proposed DMF that applies NSFDSS-II for infrastructure projects selection;

– to experimentally create a web-based DMT that implements the proposed DMF;

– to effectively evaluate the DMT prioritization outcomes by using eight real past infrastructure projects in Indonesia.

4. Materials and methods of research

4. 1. Data sources

In our previous research, we have tried to develop an epistemic context-based DMF for infrastructure project selection and prioritization [10]. The method used in developing the DMF is a mixed-method approach consisting of semi-structured expert interviews, questionnaire surveys, and pairwise comparisons. Semi-structured expert interviews were conducted to find out the infrastructure project selection practice and criteria in the Indonesian context. The expert respondents are (1) practitioners who work in ministries, infrastructure consultant agencies, and academics; (2) at least have five years of experience; (3) have a Master's degree in construction-related disciplines; and (4) have been involved in project planning. There are ten questions asked to twenty expert respondents that took place from December 2018 to March 2019. The interview results are summarized in Table 1.

Table 1

Interview questions and responses

No.	Interview questions	Key responses
A	Current practices	
1	How does FEP occur and carry out in your organization?	In stages; no standard guidance; the cycle is not closed; need to be improved
2	What is your current practice in making decisions related to infrastructure project selection and prioritization?	Based on needs; judgmental process; provide alternatives; based on government policies, macro national policies; conduct FGDs; WPS (strategic development regions)
3	Is there any procedure, technique, tool, other available to help you make decisions/select project proposals?	Comparison; readiness criteria; prioritization; data availability; need new tool to integrate all projects
4	Is the decision-making process more judgmental or rational?	Rational
5	How effective is the current decision-making process?	Getting better than before; a comprehensive process
B	Challenges	
6	What are the challenges in the decision-making process of infrastructure project selection?	No standard framework and tool; limited funding sources; lack of coordination; sectoral ego; weak socialization; lack of program synchronization; change in proposals; not knowing the field; geographic challenges; local authority issues; community objections and interferences; lack of planning integration; readiness criteria is sectoral; no indicators for integrated strategic planning; human resource problems; directive programs; cultural dilemma; demand for quick planning; political intervention; decentralization trap; poor regulations; subjectivity problems
7	How do these challenges affect the decision-making process?	Poor planning; investor withdrawal; high risk investment; replanning, reprogramming; inappropriate allocation; complicated bureaucracy; rejection from community
8	What are the weaknesses of government decision-making?	Too many directive programs; no perfect model; lack of innovations; politically driven; focused on financing
9	How should the decision-making process ideally be carried out and improved?	Integration; provide tool to select and prioritize project proposals; closed cycle; scientifically proven; transparent and accountable DMF; actual consideration basis; easy to be understood and implemented; cross-sectors
C	Selection criteria	
10	What are the criteria for selecting and prioritizing infrastructure projects?	Needs; urgency; conformity; funding; risks; innovation; political influence; readiness criteria; financial; planning integration; existing utilities; local government issues; project feasibility; technology; sustainability

Source: [10]

The second data collection stage is a questionnaire with the aim of refining the identified selection criteria using a larger number of respondents. Questionnaires were distributed from July to November 2019 and received 302 responses. However, after the preliminary analysis, there were only 104 valid responses to be analyzed using Exploratory Factor Analysis (EFA). EFA was employed to explore the critical project selection criteria [10]. Using SPSS software, it was found that the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was 0.891, which falls into a great acceptability level, while the Bartlett's test of sphericity shows 0.000 significance value which is less than 0.05 and hence the data are suitable for factor analysis [10]. Table 2 presents the EFA results, which grouped 19 criteria into five component groups.

The EFA results were then used to develop the DMF using the NSFDSS-II technique. The advantage of this technique is that it allows for the determination of criteria weightings via pairwise comparisons. In a nutshell, it compares the relative importance, preference, or probability of two variables [17]. The more criteria there are, the more pairwise comparisons are performed. [18] contend that when many criteria are involved, pairwise comparisons may produce inconsistent results. Other researchers advised keeping the number of criteria under ten [17, 19, 20]. Given the weighting exercise's practicability and credibility, the 19 selection criteria that were previously identified from EFA were grouped based on the nature of their aspects and similarities to ten key selection criteria: strategic fit, readiness criteria, innovative planning, risks and politics, contract and governance, funding and financing, team and stakeholder coordination, private sector and community involvement, local government issues, and sustainability and environmental issues [10].

Meanwhile, determining the weight of the ten key criteria is done by applying the MCDM technique. There are four MCDM techniques considered in this study:

– NSFDSS-II (Non-Structural Fuzzy Decision Support System II): the NSFDSS technique's successor, which was proposed in 2002. It could resolve complex multi-criteria problems, even without sufficient information provided [21]. It becomes the primary method in this study;

– NSFDSS-I (Non-Structural Fuzzy Decision Support System I): the MCDM technique developed in [22] and is the predecessor technique of NSFDSS-II. Several studies utilizing this technique include [23–26];

– Fuzzy SAW (Fuzzy Simple Additive Weighting): MCDM technique that combines aspects of fuzzy logic with a simple additive weighting (SAW) method. Some studies using this technique include [27, 28];

– AHP OS (Analytical Hierarchy Process Online System): AHP is one of the commonly used techniques for solving decision-making problems [29, 30]. It can analyze qualitative problems through a quantitative method [31]. AHP OS is a free web-based AHP solution, which was explored in the first phase of this study.

Table 2

Results of EFA

Component	Criteria	Factor Loading
1	Land acquisition	0.997
	Funding and financing	0.97
	Design readiness	0.954
	Team member and stakeholders	0.817
	Contract and procurement system	0.762
	Operational and maintenance readiness	0.53
2	Policies	0.829
	Local government issues	0.826
	Good governance	0.807
	Technology readiness	0.68
	Private sector and community involvement	0.673
	Planning integration	0.542
3	The needs	0.898
	Urgency	0.87
	Conformity	0.835
	Sustainability and environmental issues	0.67
4	Risks	0.818
	Politics	0.671
5	Innovation	0.832

Source: [10]

As reported in previous publications [7, 10], out of those four methods, NSFDSS-II was chosen as the basic method for developing the proposed DMF model for infrastructure projects selection due to its reliability and stability. It follows three operating principles consisting of decomposition, comparative judgment, and synthesis of priorities [21, 24]. As opposed to NSFDSS-I, it allows the decision makers to define the importance of assessment parameters (P) within the system as well as the criteria (C) under various assessment parameters. In this study, three assessment parameters were identified for infrastructure project selection in Indonesia, namely time effectiveness (P1), cost effectiveness (P2), and project complexity (P3). A two-round pairwise comparisons were conducted to obtain data input for NSFDSS-II on January and February 2020. Eight experts were involved to provide their judgments on the weight of key selection criteria. These eight experts meet the study requirements, namely practitioners in the construction sector with a minimum of 10 years work experience and a minimum managerial position, have a construction-related educational background with a master degree level, are members of a construction-related organization and have a professional certification, and have been involved in infrastructure project planning and/or execution.

4. 2. Research method

In this study, our focus is to build a web-based DMT for infrastructure projects selection automation. This is crucial to bridge the findings from the previous study to provide practical benefits to the industry, in this context, infrastructure decision makers in relevant ministries in Indonesia. Let's use the Agile software development method to build the DMT. The Agile method has several characteristics, such as having an iterative and incremental development process, being delivered in a light and fast development cycle, and being adaptive to the customer's needs [32]. It becomes the most used method by software industry practitioners [33]. It also becomes an umbrella for newer software development methods that share the same characteristics, such as Scrum, eXtreme Programming, Dynamic Software Development Method, and Feature-Driven Development [34, 35]. Fig. 1 shows the research phases and their corresponding outcomes.

Firstly, in the 'planning' stage, we systematically reviewed and learnt the proposed DMF developed by using NSFDSS-II method. The key author invited and intensively discussed the DMF with two other authors who have software engineer and informatics background. We then 'designed' the user interface of the DMT by putting more focus on the functionalities and correctness of calculation for implemented NFSDSS-II of the proposed DMF. In the next stage, we 'developed' the DMT following the agreed design in the previous stage. We used several web technologies in developing the DMT, including PHP server-side scripting language, JavaScript client-side scripting language, and HTML markup language. The created DMT flows and user interface are described in the following section. In the 'test' stage, we tested the DMT by using eight real past infrastructure projects as data materials together with their own characteristics. The outcomes were evaluated by an independent expert during initial 'release' followed by getting some 'feedbacks' for further development.

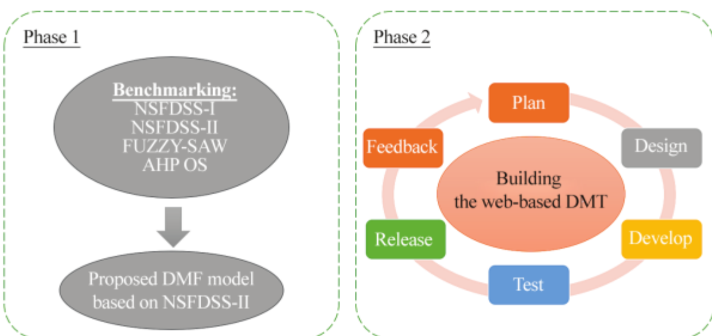


Fig. 1. Research phases and their outcomes

5. Results of the developed Decision-Making Tool based on the Proposed DMF with NSFDSS-II method

5. 1. Proposed DMF with NSFDSS-II for infrastructure projects selection

In developing the DMF for infrastructure project selection and prioritization, we apply an MCDM technique, namely NSFDSS-II to determine the weight of each key selection criterion. It is a systematic and scientific method that can decompose a complex problem into a hierarchy of subproblems [10]. The results are the calculation of key selection criteria contribution as presented in Table 3, where C refers to the selection criteria and P refers to the assessment parameters.

In view of the above findings, a four-stage DMF for infrastructure project selection and prioritization is proposed as presented in Fig. 2. It starts with identifying input data, which includes infrastructure project proposals and project selection criteria. The project selection criteria data is analyzed using NSFDS-II principles in the second stage. The third stage is project evaluation, in which decision makers provide their judgments on each project alternative and calculate the final scores based on the weights of the ten key criteria. As a result, a list of infrastructure project priorities is generated, with higher-scoring proposals deemed more important than those lower-scoring proposals [10].

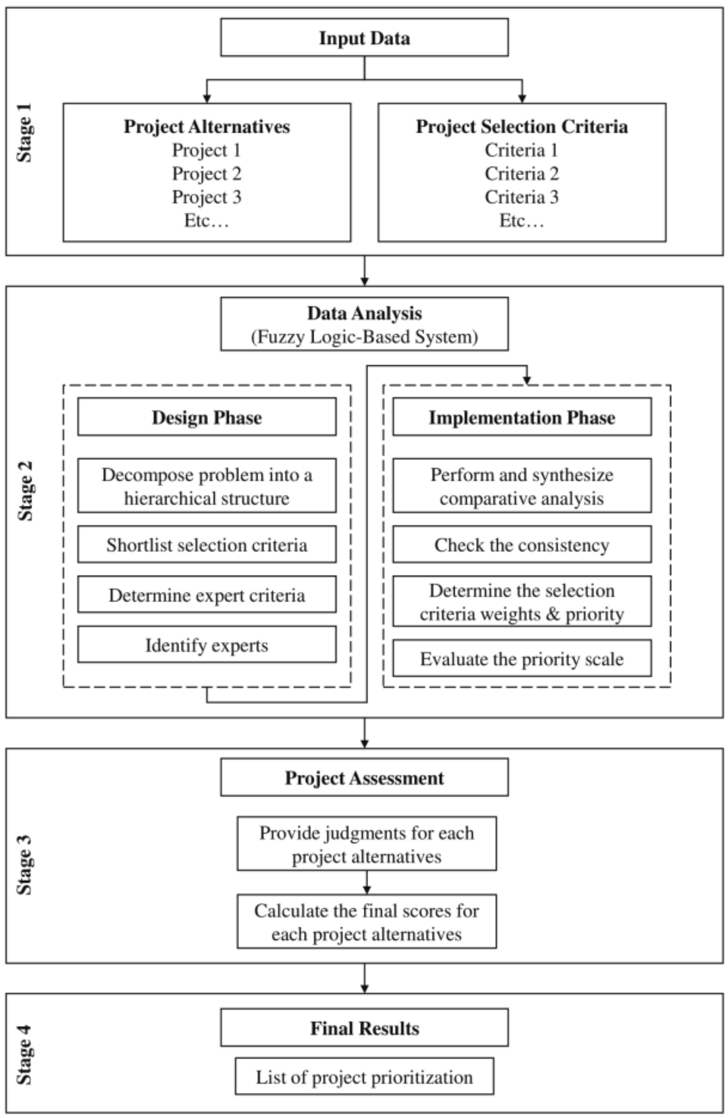


Fig. 2. Proposed DMF (source: [10])

Table 3

Weight determination for key selection criteria

Ci/Pi	P1	P2	P3	Sum
Strategic fit (C1)	11.17 %	3.46 %	0.83 %	15.45 %
Readiness criteria (C2)	5.37 %	3.12 %	1.12 %	9.62 %
Innovative planning (C3)	5.37 %	3.12 %	0.92 %	9.41 %
Risks and politics (C4)	11.17 %	3.46 %	0.92 %	15.54 %
Contract and governance (C5)	5.37 %	2.27 %	0.60 %	8.25 %
Funding and financing (C6)	6.01 %	4.23 %	0.67 %	10.91 %
Team and stakeholder coordination (C7)	6.01 %	1.60 %	0.60 %	8.21 %
Private sector & community involvement (C8)	7.45 %	3.46 %	0.67 %	11.58 %
Local government issues (C9)	2.79 %	0.60 %	0.20 %	3.59 %
Sustainability and environmental issues (C10)	4.23 %	2.54 %	0.67 %	7.44 %
Total	64.94 %	27.86 %	7.21 %	100 %

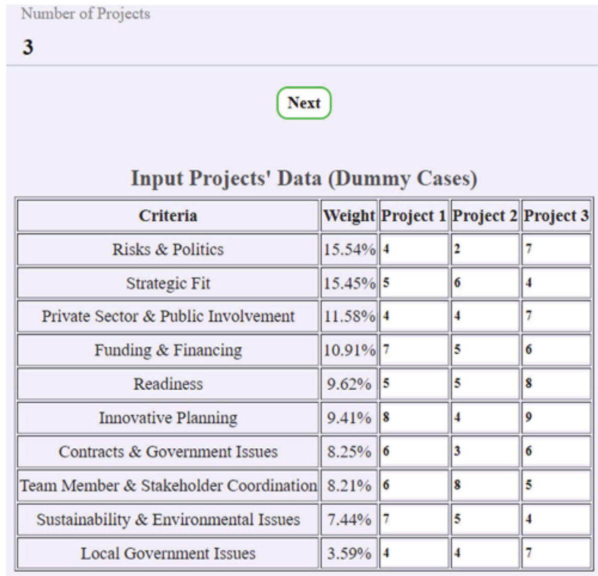
Source: [10]

5. 2. Web-based DMT that implements the proposed DMF

In this paper, we follow up the DMF development in our previous research by developing a web-based DMT. In the landing page of the created DMT, firstly the user could input the number of projects being considered in the decision-making process. In this dummy example, three projects are being considered. After the user clicks on the Next button, a table will be generated automatically according to the number of projects being considered. The user then could enter the respective scores of each criterion for each project being considered. There are ten criteria for infrastructure projects selection in Indonesia, namely Risks & Politics, Strategic Fit, Private Sector & Public Involvement, Funding & Financing, Readiness, Innovative Planning, Contracts & Government Issues, Team Member & Stakeholder Coordination, Sustainability & Environmental Issues, and Local Government Issues [10]. The user could input the score on a scale of 1 (less preferred or less dominant) to 10 (most preferred or dominant) for each criterion and project, as shown in Fig. 3.

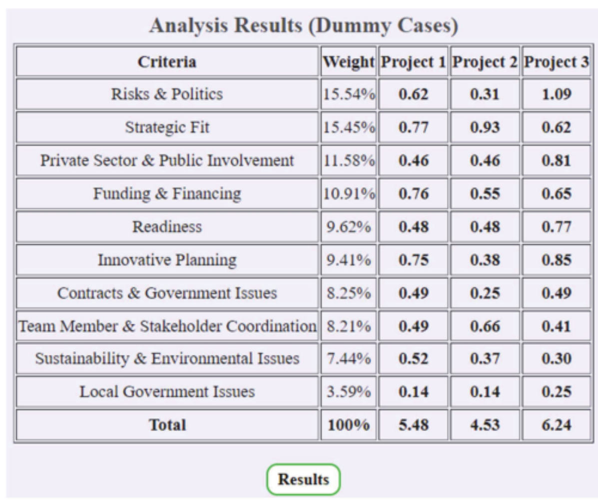
The data analysis results will then be automatically calculated according to the proposed DMF model. This calculation is the result of multiplying the weight with the score criteria for each project. For instance, in the dummy project 1 the criteria «Risks & Politics» have a weight of 15.54 % and is given a score of 4, so the result is 15.54 %×4=0.62. The higher the value obtained means that the project is more prioritized. The results are shown to the user in a tabular form, as can be seen in Fig. 4.

After the user clicks on the Results button, the implemented NSFDSS-II will be triggered. When NSFDSS-II calculation process finished, the priority list will be shown together with the ranking results, highlighting the three highest-ranked projects. In the last part of the web-based DMT, a radar graph is shown to the user. The radar graph could help the user and decision-makers get an insight into each project's performance being considered relative to each criterion used in this study.



Criteria	Weight	Project 1	Project 2	Project 3
Risks & Politics	15.54%	4	2	7
Strategic Fit	15.45%	5	6	4
Private Sector & Public Involvement	11.58%	4	4	7
Funding & Financing	10.91%	7	5	6
Readiness	9.62%	5	5	8
Innovative Planning	9.41%	8	4	9
Contracts & Government Issues	8.25%	6	3	6
Team Member & Stakeholder Coordination	8.21%	6	8	5
Sustainability & Environmental Issues	7.44%	7	5	4
Local Government Issues	3.59%	4	4	7

Fig. 3. The projects' data input process (for dummy cases)



Criteria	Weight	Project 1	Project 2	Project 3
Risks & Politics	15.54%	0.62	0.31	1.09
Strategic Fit	15.45%	0.77	0.93	0.62
Private Sector & Public Involvement	11.58%	0.46	0.46	0.81
Funding & Financing	10.91%	0.76	0.55	0.65
Readiness	9.62%	0.48	0.48	0.77
Innovative Planning	9.41%	0.75	0.38	0.85
Contracts & Government Issues	8.25%	0.49	0.25	0.49
Team Member & Stakeholder Coordination	8.21%	0.49	0.66	0.41
Sustainability & Environmental Issues	7.44%	0.52	0.37	0.30
Local Government Issues	3.59%	0.14	0.14	0.25
Total	**100%**	**5.48**	**4.53**	**6.24**

Fig. 4. The data analysis results page (for dummy cases)

5. 3. DMT prioritization outcomes by using eight real past infrastructure projects in Indonesia

To test the built web-based DMT, eight real past projects from relevant infrastructure agencies, such as the Ministry of Public Works and Housing (MPWH), the Ministry of Transportation, and the Local Government, will be experimented with and evaluated. The data was taken from KPPIP book report as provided in the reference [36]. Table 4 shows the details of those eight project proposals which were submitted for the 2019 fiscal year.

An expert respondent from the Ministry of Public Works and Housing (MPWH) was asked to provide an assessment of those eight past infrastructure project proposals. The expert met the criteria in this study, namely a practitioner with a minimum of 15 years work experience and a minimum managerial position, has a construction-related educational background with a master degree level, is a member of a construction-related organization and has a professional certification, has awareness of Indonesia's infrastructure development, and has been involved in infrastructure project planning and/or execution. Next, the expert was provided documents relating to the detailed status of those projects. Then, the expert was asked to give his judgment scores on a scale of 1 to 10, as shown in Table 5.

Using the expert's judgment scores, we compare the results of infrastructure project selection and prioritization between the web-based DMT results and the actual status of those projects' implementation. The web-based DMT results are given in Fig. 5, 6. According to Fig. 5, the most recommended projects are Project #1 (MRT Phase 2), Project #3 (Existing Refinery Revitalization), Project #5 (Jakarta Sewerage System Zone 1 & 6), and Project #7 (Kisaran – Tebing Tinggi Toll Road). Meanwhile, Project #8 (Yogyakarta – Bawen Toll Road) and Project #4 (Palembang – Tanjung Api-Api Toll Road) are the two least preferred projects be chosen. Fig. 6 shows the radar graph for all those eight infrastructure projects. Using this radar graph, decision makers can easily determine the strength and weaknesses of each considered project for each criterion and take the best decision related to the project selection.

Priority List

Project 1 – Rank: 1
Project 2 – Rank: 5
Project 3 – Rank: 2
Project 4 – Rank: 8
Project 5 – Rank: 4
Project 6 – Rank: 6
Project 7 – Rank: 3
Project 8 – Rank: 7
Project 1 – 18.02, 18.02, 13.52, 11.05, 4.22, 9.59, 5.96, 9.59, 5.38, 4.65
Project 2 – 15.63, 18.15, 13.61, 5.55, 4.87, 12.61, 4.20, 11.09, 10.08, 4.20
Project 3 – 18.42, 13.82, 15.15, 12.93, 7.13, 5.65, 9.81, 9.81, 3.27, 3.71
Project 4 – 14.05, 11.17, 12.43, 15.68, 5.23, 5.05, 11.89, 11.89, 8.11, 4.50
Project 5 – 16.85, 14.37, 10.66, 11.75, 4.48, 11.59, 6.34, 10.20, 9.27, 4.48
Project 6 – 18.96, 16.17, 12.00, 5.74, 11.65, 4.87, 4.35, 11.48, 10.43, 4.35
Project 7 – 19.17, 11.90, 12.52, 13.45, 7.42, 4.33, 10.20, 10.20, 6.96, 3.86
Project 8 – 21.99, 16.65, 16.49, 5.85, 5.14, 8.33, 4.43, 11.70, 7.98, 4.43

Fig. 5. Priority list and ranking for eight real past projects

Table 4

Project profiles

#	Project Name	Amount	Funding Scheme	Location	Responsibility	Start Year	End Year
1	MRT (Phase 2)	Rp 22.5 T	National State Budget & Jakarta Budget with overseas loan	Jakarta	PT. MRT	2019	2024
2	Inland Waterways Cikarang – Bekasi	Rp 3.4 T	PPP	West Java	PT. Pelindo II	2019	2021
3	Existing Refinery Revitalization	Rp 246.22 T	Assignment to SOE	East Java, West Java & East Kalimantan	PT. Pertamina	2019	2021
4	Palembang – Tanjung Api-Api Toll Road	Rp 14.2 T	Assignment to SOE	South Sumatera	Toll Road Governing Body, MPWH	2019	2021
5	Jakarta Sewerage System (Zona 1 & 6)	Rp 70 T	National State Budget with overseas loan	Jakarta	Jakarta Provincial Government	2019	2022
6	West Semarang Water Supply System	Rp 1,191 B	PPP	East Java	PDAM Kota Semarang	2019	2021
7	Kisaran – Tebing Tinggi Toll Road	Rp 13.4 T	Assignment to SOE	North Sumatera	Toll Road Governing Body, MPWH	2019	2021
8	Yogyakarta – Bawen Toll Road	Rp 12.14 T	PPP	Yogyakarta & East Java	Toll Road Governing Body, MPWH	2019	2021

Table 5

Expert's judgment scores for eight past projects

Criteria	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6	Project 7	Project 8
Contracts & governance issues	5	3	8	8	5	3	8	3
Funding & financing	7	3	8	8	7	3	8	3
Innovative planning	7	8	4	3	8	3	3	5
Local gov issues	9	7	7	7	8	7	7	7
Private sector & public involvement	8	7	9	6	6	6	7	8
Readiness criteria	3	3	5	3	3	7	5	3
Risks & politics	8	6	8	5	7	7	8	8
Strategic fit	8	7	6	4	6	6	5	5
Sustainability & env issues	5	8	3	6	8	8	6	6
Team member & stakeholder coordination	8	8	8	8	8	8	8	8

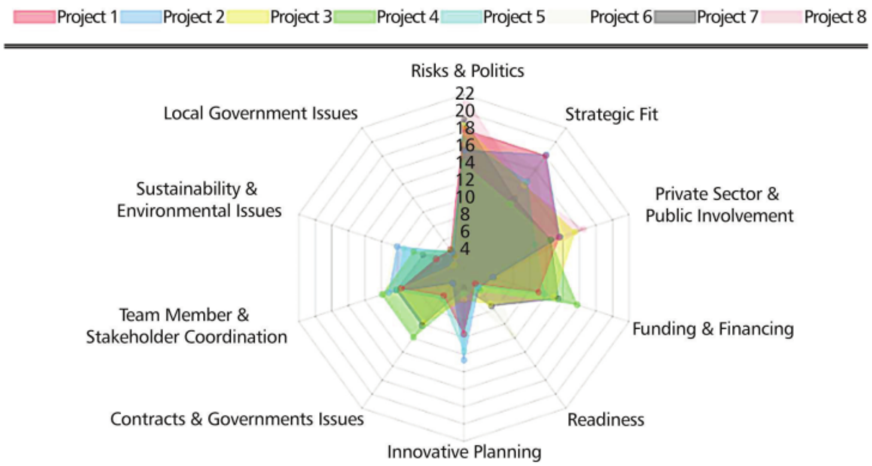


Fig. 6. Radar graph for eight real past projects

Furthermore, the web-based DMT results were compared with the actual status of those eight projects implemented in 2020. The verification results are shown in Table 6.

Table 6

Verification results of the eight infrastructure projects

Project Name	DMT Rank	Actual Status
MRT (Phase 2)	1	Selected for implementation
Existing Refinery Revitalization	2	Selected for implementation
Jakarta Sewerage System (Zona 1 & 6)	3	Selected for implementation
Kisaran – Tebing Tinggi Toll Road	4	Selected for implementation
Inland Waterways Cikarang – Bekasi	5	Selected for implementation
West Semarang Water Supply System	6	Selected for implementation
Yogyakarta – Bawen Toll Road	7	Postponed
Palembang – Tanjung Api-Api Toll Road	8	Postponed

As shown in Table 6, the two least preferred projects from the web-based DMT results were postponed for implementation in the following fiscal year. This means that the prioritization results from DMT is in line with the actual implementation status of those eight infrastructure projects in Indonesia.

6. Discussion of the results of developing the new web-based Decision-Making Tool for infrastructure project selection

In this study, we have systematically reviewed the epistemic context-based DMF for infrastructure project selection and prioritization. The DMF was developed using a mixed-method approach involving different parties and identifying key selection criteria in the infrastructure project problem as shown in Table 2. 19 selection criteria were grouped based on the nature of their aspects and similarities to ten key selection criteria, namely strategic fit, readiness criteria, innovative planning, risks and politics, contract and governance, funding and financing, team and stakeholder coordination, private sector and community involvement, local government issues, and sustainability and environmental issues. Four different MCDM techniques were evaluated and the NSFDSS-II was chosen due to its reliability and stability. Table 3 presents the final weights of ten key selection criteria which were calculated using two-round pairwise comparisons of NSFDSS-II.

Based on the NSFDSS-II analysis, there are top three key selection criteria for infrastructure project selection in Indonesia, namely risks and politics (with a weight of 15.54 %), strategic fit (with a weight of 15.45 %), and private sector and community involvement (with a weight of 11.58 %) which representing 42.57 % of the overall weight of the criteria. C4 (risks and politics) appears to be the most important criterion due to the fact that infrastructure projects are typically large and complex projects with high levels of risk including political risks, legal risks, and market risks. These are common challenges in Indonesia's infrastructure development. The second most important selection criterion is C1 (strategic fit). It is concerned with the evaluation of an infrastructure project proposal that provides a strategic purpose to a country's socioeconomic development. It has four components of needs, urgency, conformity, and policies. Meanwhile, two external forces that may influence project success are the private sector and community involvement (C8). The Indonesian government has encouraged private sector and community involvement, particularly in terms of private sector investment. A four-stage DMF was then proposed for infrastructure project selection and prioritization. As shown in Fig. 2, the proposed DMF provides a systematic and adaptive framework which can be modified for use in other contexts and situations [10].

From the literature review, we also identified the common problem that most developed DMF only worked in a very specific domain and use cases. Therefore, we created a web-based DMT based on the developed DMF for practical uses. The DMT was built using Agile method and different web technologies, including PHP, JavaScript, and HTML. NSFDSS-II was also implemented in the DMT as the main algorithm in determining the infrastructure projects' ranking. We further evaluated the prediction accuracy of the created DMT by using eight real past infrastructure projects in Indonesia. The selection and prioritization results are shown in Fig. 5 and Table 6. According to the DMT outcomes, the most recommended projects are Project #1 (MRT Phase 2), Project #3 (Existing Refinery Revitalization), Project #5 (Jakarta Sewerage System Zone 1 & 6), and Project #7 (Kisaran – Tebing Tinggi Toll Road). These outcomes similar to the actual implementation status of those infrastructure projects. Using the created DMT, decision makers also could identify the strength or weaknesses of each project based on the selection criteria as shown in Fig. 6.

According to the implementation and evaluation results, the developed web-based DMT was successfully built and produced the consistent prioritization results. It is important to note that this is the first running prototype of the DMT for infrastructure projects selection automation which was built based on the proposed DMF. Therefore, it can serve as a technology transfer from the acceptable concept within the science (the proposed DMF) to the practical usage of the concept in the real industry, in this case the infrastructure decision makers.

The web-based DMT provides a reliable and faster prioritization decision making than using manual and conventional approach. It can be accessed directly by related stakeholders and decision makers using the internet, easier to be managed, and supports transparency in the decision-making process. However, several features also can be improved in the future development of the DMT, such as adding restriction to access different parts of DMT based on the user's privileges and ability to be more responsive when the DMT is opened in different devices with different monitor sizes.

The limitation of this current study is on the testing scope. In this study, only eight real past infrastructure projects are used in the testing and evaluation phases. Although the proposed DMF and DMT can give prioritization outcome with high accuracy result for those eight real past projects, they have not been tested on a larger scale decision-making process. On the other hand, different experts and stakeholders could have different opinion on the criteria weighting, hence the ability to change the weight of each criterion within the DMT could boost the effectiveness and acceptance of this tool.

This study confirms that NSFDSS-II as a decision-making technique applied in the DMT can successfully be used in helping the proper decision-making process by related stakeholders. However, future studies to compare the prioritization and selection results with other MCDM methods, such as PROMETHEE [31], TOPSIS [37], and VIKOR [38] can be done. The implementation of social capital concept [39] in the decision-making process, especially in more general cases, also can be considered in the future. Moreover, the combination of expert knowledge with information on the deviation of both determined and actual parameters of previous projects as proposed in [40] is interesting to be implemented in the future.

7. Conclusions

1. The proposed DMF has been systematically reviewed and learnt to transfer the concept to the practical uses in the industry. It was determined that the proposed DMF with NFSDSS-II method is best applied as a web-based DMT that provides scalability, reliability, and transparency in the decision-making process.

2. The web-based Decision-Making Tool (DMT) has been successfully built by using PHP server-side scripting language, HTML mark-up language, and JavaScript client-side scripting language. The DMT was developed based on the proposed Decision-Making Framework (DMF) that uses ten selection criteria and the Non-Structural Fuzzy Decision Support System II (NSFDSS-II) as the main algorithm.

3. The web-based DMT was tested and evaluated by using eight real past infrastructure projects from several agencies, such as the Ministry of Public Works and Housing (MPWH), the Ministry of Transportation, and the Local Government in Indonesia. From the experimental results, we found that the web-based DMT could give relevant and suitable results compared to the actual status of those eight projects in the following fiscal year.

Conflict of Interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data Availability

Data will be made available on reasonable request.

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