Analysis of Implementation Method Selection Based on the Analytical Hierarchy Process (AHP) for the Development of Integrated Utility Network Infrastructure in Denpasar City

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Abstract. Urban infrastructure development, particularly integrated utility network systems, faces increasing complexity in cities like Denpasar due to spatial limitations, the diversity of utility types, and the need for inter-agency coordination. This study aims to identify the most suitable construction method using the Analytical Hierarchy Process (AHP), a structured decision-making approach capable of handling multiple criteria. The evaluation considers seven key criteria: technical feasibility, cost, time efficiency, environmental impact, social impact, safety, and risk. Three alternative construction methods (conventional, tunneling, and clean construction) were compared. Data were collected through expert interviews and stakeholder questionnaires in the infrastructure and construction sectors of Denpasar City. The results indicate that the most influential criteria are technical aspects (weight: 0.301), time (0.228), and social impact (0.212). The most critical sub-criteria include compatibility with field conditions (0.153), impacts on public activities (0.120), and community disruption (0.118). Among the alternatives, clean construction emerged as the most preferred method with the highest priority weight (2.662), due to its ability to minimize disruption, enhance occupational safety, and reduce environmental impact. This study provides a structured framework to support decision-making in urban infrastructure projects and highlights the advantages of clean construction for integrated utility systems in dense urban environments

Keywords: Analytical Hierarchy Process, Clean Construction, Urban Development, Utility Network

1 Introduction

The development of utility infrastructure in densely populated urban areas faces complex challenges, particularly related to limited space, disruptions to community activities, and the need to protect existing infrastructure. Denpasar City, as the capital of Bali Province, has experienced an increasing demand for an Integrated Utility Network System (IUNS) that is modern, efficient, and minimally disruptive. However, in practice, the selection of construction methods for IUNS projects often relies on

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conventional approaches without a systematic consideration of technical, environmental, social, or occupational risk factors (Maulana et al., 2024).

Ideally, the selection of construction methods should be carried out through a multi-criteria evaluation process that objectively and measurably considers various aspects. Unfortunately, in reality, many technical decisions on-site are still subjective, influenced by personal experience or data limitations (Handoko et al., 2019). This gap highlights the need for a scientific and systematic approach to support decision-making in complex infrastructure projects such as IUNS (Walean et al., 2012).

Several previous studies have investigated the selection of construction technologies using multi-criteria approaches. For instance, (Arabi & Gharehhassanloo, 2018) applied the Analytical Hierarchy Process (AHP) alongside network analysis to determine the optimal water transmission pipeline path in the densely populated Tehran metropolitan region. Meanwhile, (Basit et al., 2021) emphasized the importance of expert involvement in rationally weighing criteria within the context of project risk. In Indonesia, the application of AHP in infrastructure projects remains limited to general case studies and has not yet specifically addressed IUNS projects in complex, high-density urban settings (Tanubrata & Lukman, 2019).

The Analytical Hierarchy Process (AHP) is a widely used multi-criteria decision-making method that effectively simplifies complex problems into a hierarchical structure and allows for weighting based on expert preferences (Saaty, 1989). One of AHP's strengths lies in its ability to measure the consistency of judgments, thereby enhancing the reliability of decision outcomes (Ishizaka & Labib, 2011).

Based on this background, the objective of this study is to analyze the optimal construction method for the implementation of IUNS in Denpasar City using the AHP method (Arabi & Gharehhassanloo, 2018). This study considers not only cost and time factors but also technical, social, environmental, safety, and risk aspects, involving a total of 20 sub-criteria. Thus, the research is expected to offer practical contributions to project decision-making and enrich the academic literature on AHP applications in the context of utility infrastructure development in densely populated urban areas.

2 Methodology

This study employs a quantitative approach using the multi-criteria decision-making method, Analytical Hierarchy Process (AHP). This approach was chosen to provide a systematic analytical framework for evaluating alternative construction implementation methods based on various relevant criteria.

The object of the study is the development project of the Integrated Utility Network Facility (IUNS) in Denpasar City, Bali Province. The focus of the research is to select the most appropriate construction method for densely populated urban areas. Three construction method alternatives analyzed are: (1) conventional/open trench method, (2) bore tunneling method, and (3) Clean Construction method.

The evaluation is based on six main criteria: (1) technical aspects, (2) cost, (3) time, (4) environmental impact, (5) social impact, and (6) safety and risk. Each main criterion includes several sub-criteria, totaling 20 sub-criteria in all, which were determined through literature review and preliminary expert interviews.

Primary data were collected through questionnaires and in-depth interviews with 30 respondents who are experts and practitioners in the construction and infrastructure sectors, including design consultants, executing contractors, academics, and officials from the Department of Public Works and Spatial Planning, PDAM, and other relevant agencies. The number of respondents was determined based on the need to represent key stakeholders and to ensure the validity of assessments in AHP. Secondary data were obtained from project documents, previous studies, and relevant technical regulations issued by government institutions.

The AHP analysis steps include: (1) Developing a decision hierarchy structure consisting of the main goal, criteria, sub-criteria, and alternative methods. (2) Constructing pairwise comparison matrices among elements using Saaty's scale (1–9). (3) Calculating priority weights for each element through matrix normalization and eigenvector calculation. (4) Testing the consistency ratio (CR) to ensure logical consistency of respondent assessments. A CR value ≤ 0.1 is considered consistent. (5) Synthesizing the final values by combining the weights of criteria and alternatives to determine the best implementation method based on the highest priority score.

3 Result and Discussion

3.1 Result

AHP Hierarchy of Construction Methods The AHP hierarchy in selecting construction methods simplifies complex variables into a multilevel structure, consisting of the goal at the first level, criteria at the second level, and sub-criteria at the third level. Each level represents variables based on actual behavioral and structural characteristics in the field (Saaty, 1989). The hierarchical structure based on confirmed variables is presented in Figure 1.

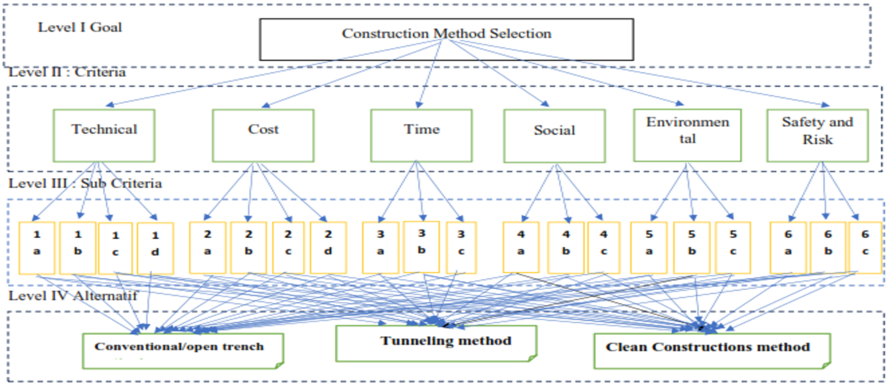

Figure 1. AHP Hierarchy of Construction Methods

Creating a pairwise comparison matrix. Based on the questionnaire data that has been collected and processed using the geometric mean, the pairwise comparison matrix for the criteria level is obtained as shown in the following table.

Table 1. Pairwise Comparison Matrix Criteria

Criteria	Technical	Cost	Time	Enviromental	Social	Safety and risk
Technical	1	3	2	2	2	3
Cost	0.333	1	0.500	0.500	0.333	2
Time	0.500	2	1	2	1	2
Enviromental	0.500	2	0.500	1	0.500	2
Social	0.500	3	1	2	1	3
Safety and risk	0.333	0.500	0.500	0.500	0.333	1

Calculation of priority weight and consistency. A similar process is applied at the sub-criteria level, covering technical, cost, time, environmental, social, safety, and risk aspects. Once all pairwise comparison matrices are obtained, normalization is performed to calculate the eigenvalues, which serve as the basis for determining the weights and priority rankings of each criterion and sub-criterion. The results of the weights and priorities for the criteria, cost sub-criteria, quality sub-criteria, and time sub-criteria are presented in Table 2, Table 3, Table 4, Table 5, Table 6, Table 7, and Table 8.

Table 2. Criteria Weight And Priority

Ranking	Criteria	*Eigen*	Average	Weight (%)
1	Technical	1.808	0.301	30.126
2	Cost	1.275	0.212	21.248
3	Time	1.111	0.185	18.517
4	Enviromental	0.798	0.133	13.306
5	Social	0.564	0.094	9.400
6	Safety and risk	0.444	0.074	7.393
	Amount	6.000	1.000	100.000

The pairwise comparison results indicate that the technical aspect has the highest priority weight at 30.16%, followed by the social aspect at 21.25%, and the time aspect at 18.52%.

Table 3. Weight and Priority of Technical Sub-Criteria

Ranking	Sub-Criteria	*Eigen*	Average	Weight (%)
1	Ease of Construction	2.028	0.507	50.693
2	Suitability to Field Conditions	0.904	0.226	22.596
3	Method Reliability	0.650	0.162	16.250
4	Availability of Equipment and Technology	0.418	0.105	10.462
	Amount	4.000	1.000	100.000

Based on the priority scale of the technical aspect sub-criteria, the most determining factor with the highest weight is the sub-criterion "Suitability with field conditions" with a weight of 50.693%, followed by the sub-criterion “Ease of construction” with a weight of 22.596%, and the sub-criterion “Method reliability” with a weight of 16.250%.

Table 4. Weight and Priority of Cost Sub-Criteria

Ranking	Sub-Criteria	*Eigen*	Average	Weight (%)
1	Initial Implementation Cost	1.692	0.423	42.304
2	Maintenance Cost	1.567	0.392	39.179
3	Efficiency in Resource Use	0.501	0.125	12.529
4	Social/External Costs	0.240	0.060	5.988
	Amount	4.000	1.000	100.000

Based on the priority scale of the cost aspect sub-criteria, the most influential is the social/external cost sub-criterion with a weight of 42.304%, followed by initial implementation cost at 39.179%, and maintenance cost at 12.529%.

Table 5. Weight and Priority of Time Sub-Criteria

Ranking	Sub-Criteria	*Eigen*	Average	Weight (%)
1	Implementation Duration	1.73	0.458	45.769
2	Scheduling Ease	1.248	0.416	41.603
3	Influence on Other Activities	0.379	0.126	12.628
	Amount	3.000	1.000	100.000

Based on the priority scale of time-related sub-criteria, the most influential is implementation duration with a weight of 45.769%, followed by impact on other activities at 41.603%, and scheduling ease at 12.628%.

Table 6. Weight and Priority of Environmental Sub-Criteria

Ranking	Sub-Criteria	*Eigen*	Average	Weight (%)
1	Environmental Impact	1.944	0.648	64.799
2	Construction Waste Management	0.689	0.230	22.981
3	Energy Consumption	0.367	0.122	12.219
	Amount	3.000	1.000	100.000

Based on the priority scale of environmental sub-criteria, the most influential is impact on the surrounding environment with a weight of 64.799%, followed by construction waste management at 22.981%, and energy use at 12.219%.

Table 7. Weight and Priority of Social Sub-Criteria

Ranking	Sub-Criteria	*Eigen*	Average	Weight (%)
1	Impact on Society	1.671	0.557	55.714
2	Public Acceptance	0.961	0.320	32.024
3	Public and Worker Safety	0.368	0.123	12.262
	Amount	3.000	1.000	100.000

Based on the priority scale of social sub-criteria, the most influential is impact on the community with a weight of 55.714%, followed by public acceptance at 32.024%, and occupational and public safety at 12.262%.

Table 8. Weight and Priority of Safety and Risk Sub-Criteria

Ranking	Sub-Criteria	*Eigen*	Average	Weight (%)
1	Workplace Accident Risk	1.373	0.458	45.767
2	Risk to Existing Utilities	1.248	0.416	41.601
3	Risk Mitigation Capability	0.379	0.126	12.623
	Amount	3.000	1.000	100.000

Based on the priority scale of safety and risk sub-criteria, the most influential is the risk of damage to existing utilities with a weight of 45.767%, followed by the risk of work accidents at 41.601%, and ease of risk mitigation at 12.263%.

Consistency ratio testing (CR). After the weights and priorities of each criterion and sub-criterion element have been determined, the next step is to perform a consistency test for each element to assess the level of consistency. The results of the consistency test are presented in Table 9.

Table 9. Consistency Test of Criteria and Sub-Criteria Matrix

		Sub-criteria					
Variable	Criteria	Technical	Cost	Time	Environ mental	Social	Safety and risk
n	6	4	4	3	3	3	3
RI	1.24	0.90	0.90	0.58	0.58	0.58	0.58
λ maks	6.177	4.099	4.099	3.011	3.005	3.023	3.011
CI	0.035	0.033	0.033	0.005	0.003	0.012	0.006
CR	2.85 %	3.67 %	3.69%	0.92%	0.44%	2.02%	0.95%
Consistency	OK	OK	OK	OK	OK	OK	OK

From Table 9, it can be seen that all weighting calculations have met the consistency test requirement, with consistency ratios less than 10%. From Table 10, it can be seen that the priority order of the criteria is as follows: the technical aspect criterion with a weight of 0.301, followed by the time aspect criterion with a weight of 0.228, the social aspect criterion with a weight of 0.212, the environmental aspect criterion with a weight of 0.133, the cost aspect criterion with a weight of 0.094, and the safety and risk aspect criterion with a weight of 0.074. The sub-criteria with the highest priority are suitability to field conditions (0.153), followed by impact on other activities (0.120), impact on the community (0.118), environmental impact (0.086), and duration of implementation (0.085). After obtaining the global priorities, the overall weight of each alternative can be calculated by summing all the global priority values for each construction method. The results are presented in Table 11.

Table 10. Final Local Weights of the Criteria and Sub-Criteria

Criteria dan sub-criteria	Global Weight	Total Wieght	Rangking Criteria	Sub-criteria
Technical		0.301	1	
Ease of Construction	0.068			7
Suitability to Field Conditions	0.153			1
Method Reliability	0.049			8
Availability of Equipment &Technology	0.032			12
Cost		0.098	5	
Initial Implementation Cost	0.037			10
Maintenance Cost	0.012			18
Efficiency in Resource Use	0.006			20
Social/External Costs	0.040			9
Time		0.228	2	
Implementation Duration	0.085			5
Scheduling Ease	0.023			16
Influence on Other Activities	0.120			2
Environmental		0.113	4	
Environmental Impact	0.086			4
Construction Waste Management	0.031			14
Energy Consumption	0.016			17
Social		0.212	3	
Impact on Society	0.018			3
Public Acceptance	0.068			6
Public and Worker Safety	0.026			15
Safety and risk		0.074	6	
Workplace Accident Risk	0.031			13
Risk to Existing Utilities	0.034			11
Risk Mitigation Capability	0.009			19

Determining the best alternative. Once the global priorities are obtained, the overall weight of each alternative can be calculated by summing all the global priorities for each construction method. The results are shown in Table 12.

Table 11. Global Weight Results of Each Alternative

Alternative method weights	Alternative method weights (%) Tunneling	Conventional	Clean constr
Technical			
Ease of Construction	0.057	0.016	0.154
Suitability to Field Conditions	0.117	0.062	0.328
Method Reliability	0.070	0.016	0.076
Availability of Equipment &Technology	0.007	0.064	0.033
Cost			
Initial Implementation Cost	0.043	0.228	0.121
Maintenance Cost	0.091	0.009	0.025
Efficiency in Resource Use	0.041	0.006	0.013
Social/External Costs	0.235	0.038	0.150
Time			
Implementation Duration	0.216	0.069	0.172
Scheduling Ease	0.079	0.017	0.030

Alternative method weights	Alternative method weights (%)		
	Tunneling	Conventional	Clean constr
Influence on Other Activities	0.236	0.041	0.139
Environmental			
Environmental Impact	0.216	0.064	0.368
Construction Waste Management	0.135	0.021	0.074
Energy Consumption	0.072	0.011	0.040
Social			
Impact on Society	0.303	0.061	0.193
Public Acceptance	0.124	0.054	0.142
Public and Worker Safety	0.057	0.012	0.053
Safety and risk			
Workplace Accident Risk	0.239	0.034	0.143
Risk to Existing Utilities	0.080	0.088	0.290
Risk Mitigation Capability	0.030	0.017	0.079
Amount	2.448	0.930	2.622

Table 12. Overall Alternative Weight

Alternative	Weight	Priority
Clean Construction method	2.622	I
Bore tunneling method	2.448	II
Conventional/open trench method	0.930	III

3.2 Discussion

The research shows that the Clean Construction method received the highest priority score in selecting the implementation method for the Integrated Utility Network System (IUNS) in Denpasar City. This indicates a shift in preference toward modern, environmentally friendly construction approaches that cause minimal disruption to daily urban activities. The method's dominance in the AHP assessment is supported by high weights in sub-criteria such as minimal traffic disruption, worksite safety, and low social impact—all critical in dense urban environments.

These findings align with previous studies. (Huang, 2018) highlighted the preference for low-excavation and well-controlled construction methods in metropolitan cities, while (Basit et al., 2021) emphasized the importance of expert involvement in socially and risk-based decision-making, a key aspect of this research (Wismantoro, 2022).

Additionally, the study supports the multi-criteria evaluation approach of AHP as discussed by (Ishizaka & Labib, 2011), which simplifies technical and social complexities in infrastructure projects through a logical decision hierarchy.

Interestingly, while Bore Tunneling excels technically and in safety, its high cost makes it less competitive than Clean Construction. Conversely, the Conventional/Open Trench method received the lowest score due to its significant social and environmental impact and higher safety risks, especially in densely populated areas—supporting findings by (Maulana et al., 2024).

Theoretically, the study reinforces (Saaty, 1989) the Analytical Hierarchy Process (AHP) is a useful tool in urban infrastructure decision-making, capable of integrating technical, social, and environmental dimensions while allowing multi-stakeholder participation (Eliatun & Tjitradi, 2021).

Practical implications are substantial. The findings guide local governments and construction industry stakeholders in planning IUNS projects in urban areas. Selecting the right construction method can reduce social conflict, expedite project execution, and improve safety and environmental quality. The results can also serve as a reference for developing technical regulations that promote sustainable construction methods in Indonesia.

4 Conclusion

Based on the results and discussion above. it can be concluded that: The selection of the construction method for the Integrated Utility Network Development in Denpasar City is primarily influenced by technical aspects (weight: 0.301), followed by time (0.228), social (0.212), environmental (0.133), cost (0.094), and safety and risk (0.074). The most decisive sub-criteria are compatibility with field conditions (0.153), impact on other activities (0.120), impact on the community (0.118), environmental impact (0.086), and construction duration (0.085). Based on the AHP analysis, the clean construction method is identified as the most optimal alternative, with the highest priority weight (2.662), due to its advantages in minimizing disruption, enhancing safety, and reducing environmental impact.

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