Hierarchical Risk Assessment on the Construction Project of Base Transceiver Station

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ABSTRAK

Konstruksi stasiun pancarima basis menawarkan manfaat substansial, yang meliputi konektivitas ekonomi, perluasan inklusi digital, dan penguatan keberlanjutan bisnis. Namun demikian, hal itu juga menimbulkan spektrum risiko, khususnya di seluruh fase konstruksi. Fase-fase ini terdiri dari beberapa tahap yang saling terkait yang menghadirkan risiko berbeda yang dapat memengaruhi tujuan proyek. Kegagalan dalam menerapkan kontrol risiko yang memadai dapat mengakibatkan keterlambatan, pembengkakan biaya, ketidakpatuhan terhadap peraturan, kerusakan reputasi, atau bahkan kegagalan proyek secara total. Oleh karena itu, penilaian risiko yang ketat dan terstruktur sangat diperlukan untuk memandu pengambilan keputusan yang tepat dan memastikan keberhasilan pelaksanaan proyek konstruksi stasiun pancarima basis di seluruh siklus hidup proyek. Untuk mengatasi tantangan ini, penelitian ini menggunakan proses hierarki analitik sebagai kerangka kerja pengambilan keputusan untuk mengklasifikasikan dan memprioritaskan risiko proyek secara hierarkis. Analisis tersebut mengungkap bahwa risiko fisik memiliki bobot keseluruhan tertinggi, yang menggarisbawahi kerentanan operasional yang dihadapi selama fase konstruksi.

***Kata kunci**: penilaian risiko, stasiun pancarima basis, proses hierarki analitik*

ABSTRACT

The construction of base transceiver stations offers substantial benefits, including the promotion of economic connectivity, the expansion of digital inclusion, and the reinforcement of business continuity. Nevertheless, it also introduces a spectrum of risks, particularly throughout the construction phases. These phases comprise multiple interrelated stages, each of which presents distinct risks that can affect project goals. Failure to implement adequate risk controls may result in delays, cost overruns, regulatory non-compliance, reputational damage, or even complete project failure. Therefore, a rigorous and structured risk assessment is indispensable for guiding informed decision-making and ensuring the successful execution of base transceiver stations development project across the entire project lifecycle. To address this challenge, the study employed the analytical hierarchy process as a decision-making framework for classifying and prioritizing project risks in a hierarchical manner. The analysis reveals that physical risks hold the highest overall weight, underscoring the operational vulnerabilities faced during the construction phase.

***Keywords**: risk assessment, base transceiver stations, analytical hierarchy process*

1. PENDAHULUAN

Telecommunication infrastructure plays a critical role in driving economic growth and fostering digital transformation. In the modern era, digital economies, e-government services, online education, e-commerce, and remote working all depend heavily on reliable and extensive telecommunication networks. Access to telecommunications is no longer a luxury but a basic necessity that directly impacts productivity, economic equality, and social inclusion. Alongside this, technological advancements—such as the shift from 4G to 5G, the widespread adoption of smart devices, and the growing influence of the Internet of Things (IoT)—have intensified demand for high-speed, low-latency, and reliable telecommunication services. This puts constant pressure on service providers to expand network coverage, enhance capacity, and improve service quality [2]. A key component of this infrastructure expansion is the deployment of BTS, which function as the backbone of mobile communication systems. BTS serves as the critical interface between user devices and the core network. Its primary function is to maintain signal strength and ensure seamless communication within its coverage area for both voice and data services. Without robust BTS networks, especially in remote and high-density urban areas, operators cannot deliver stable or high-quality service. As a result, telecom operators continuously invest in expanding BTS to meet growing user demands and ensure network scalability [10]. Despite the significant benefits, BTS development poses considerable risks, particularly during key phases such as site acquisition, construction, equipment installation, and commissioning [3]. Each stage is susceptible to different risks affecting cost, time, quality, safety, and environmental sustainability [15]. Poor risk management can lead to project delays, cost overruns, regulatory penalties, and even project failure. Therefore, adopting a structured risk management approach is essential to ensure that BTS projects are delivered on time, within budget, and according to quality standards [4].

Effective risk management begins with comprehensive risk assessment, which involves identifying potential hazards, estimating their probability, and evaluating their impacts. These three core elements—identification, likelihood, and consequence—form the foundation of most risk assessment models. A thorough risk assessment enhances decision-making, improves resource allocation, and increases the predictability of project outcomes [7,8]. A widely recognized framework for risk classification in construction projects was introduced by Mustafa and Al-Bahar (1991) [9]. Their model categorizes risks into six major groups. The first are acts of God risks, referring to natural disasters such as earthquakes, floods, and storms that can severely disrupt project activities. The second, physical risks, involves potential damage to assets, structural failures, or on-site accidents. The third is financial and economic risks, including inflation, currency fluctuations, payment delays, and financial constraints that may undermine the project’s viability. The fourth category, political and environmental risks, addresses regulatory changes, political instability, and adverse environmental impacts. The fifth, design risks, emerges from errors, deficiencies in design documents, or mismatches between design specifications and field conditions. The sixth, job site-related risks, covers operational issues such as low labor productivity, equipment failures, logistical challenges, and unpredictable site conditions. This classification offers a structured lens through which project stakeholders can systematically identify and mitigate risks throughout the project lifecycle [9].

BTS infrastructure development, by its very nature, is a complex, multi-phased endeavor that exposes projects to an extensive array of risks. If not properly managed, these risks can jeopardize project success in terms of cost efficiency, timely completion, structural integrity, and operational reliability. One critical weakness of many current risk management practices is their descriptive nature; they often lack a structured mechanism to prioritize risks based on severity and likelihood. This limitation hinders their effectiveness in supporting project decision-making, especially under dynamic and uncertain conditions. Consequently, there is a pressing need for a more robust and decision-oriented risk assessment framework that blends both quantitative analysis and qualitative expert judgment. Such a framework would help project teams prioritize risks, guide resource allocation, and determine whether certain risks should be mitigated, transferred, accepted, or monitored [12]. At the core of this challenge lies the absence of an adaptive model capable of clarifying managerial responsibilities and offering tailored mitigation strategies that align with the specific nature of each risk and project phase. A variety of techniques are available for risk assessment in construction and infrastructure projects. Quantitative approaches such as Monte Carlo Simulation, Sensitivity Analysis, Fault Tree Analysis (FTA), and the Critical Path Method (CPM) provide valuable probabilistic insights. However, these methods often depend on precise historical data, which may be unavailable, unreliable, or difficult to quantify in complex, real-world projects [11]. Moreover, purely quantitative models are generally insufficient for capturing subjective insights, stakeholder preferences, and context-specific knowledge. To bridge this gap, the Analytical Hierarchy Process (AHP) offers a robust alternative. Developed by Thomas Saaty, AHP structures complex decision-making problems into a hierarchy, allowing stakeholders to break down the problem into manageable components. Participants then assign relative weights to criteria through pairwise comparisons, and the process aggregates these judgments to determine the priority ranking of alternatives [14]. A key advantage of AHP is its ability to integrate both qualitative and quantitative factors, making it particularly well-suited for risk assessment in infrastructure projects like BTS development, where data may be uncertain, and expert opinion is critical. By applying AHP, project managers can develop a risk hierarchy that reflects both the likelihood and the severity of various risks. This enables a more balanced and informed approach to risk prioritization. Instead of treating all risks equally, AHP helps decision-makers focus attention and resources on high-impact risks while developing proportionate strategies for less critical risks. Moreover, the hierarchical structure of AHP aligns well with the multi-layered nature of BTS development, which typically involves technical, financial, regulatory, environmental, and social considerations [16].

This study is conducted based on data from the BTS construction projects in Central Java Province and the Special Region of Yogyakarta, Indonesia, and emphasizes the importance of a structured and comprehensive risk assessment framework tailored to the unique challenges. The research specifically aims to answer how the relative contribution of each risk factor and sub-factor influences the overall risk profile during different project phases. Understanding this distribution is crucial, as it allows project teams to develop targeted mitigation plans, optimize resource allocation, and improve project outcomes. Additionally, the hierarchical weighting of risks offers a systematic basis for decision-making, ensuring that project stakeholders can address the most significant risks proactively while maintaining flexibility to adapt to changing conditions.

2. METHODS AND MATERIALS

This study is generally carried out through several key phases, as follows:

1. Literature Review, which is focused on identifying and assessing risks within the project scope, and exploring types of work that potentially generate risks — ranging from low to severe [11]. The literature was sourced from materials related to risk management, project reports, and other references concerning occupational health and safety (OHS) risk management. This was followed by discussions on the identified risk aspects with project personnel involved in the work and who have expertise in Occupational Health and Safety (OHS) to obtain the necessary data for conducting the study.
2. Primary Data Collection, which includes identifying potential risks through brainstorming and interviews with various parties involved in the project [6]. Risk factors were derived from the literature review, which were then assessed. Data obtained from questionnaire,

aimed at assigning weights to risk factors and conducting risk assessments to determine the project risk level. Determining the types, likelihood, and impact of hazards in the components of risk events, risk agents, the relationship between risk events and risk agents, and the relationship between preventive (proactive) actions and risk agents.

3. Risk Identification, which is carried out across the entire scope of EPC work, starting from the engineering phase to the implementation phase [12]. Risk identification in this study was carried out comprehensively across all phases of the Engineering, Procurement, and Construction (EPC) process. The process began from the initial engineering design stage and extended through procurement planning, material handling, and on-site construction implementation. The primary objective of this step was to systematically detect all potential events or conditions that could adversely affect the project objectives in terms of cost, schedule, quality, safety, and stakeholder expectations.
4. Risk Assessment, which is conducted to determine the risk levels, categorized as Low Risk, Medium Risk, and High Risk . Risk assessments were performed for all stages of the work. The approach used in this study was an empirical approach, based on statistical methods for analyzing questionnaire data, as well as mathematical and statistical methods integrated into a Decision Support System to address the problem [16].
5. Formulation of Risk Response and Monitoring, which is conducted after the risk levels were obtained from the assessment, response actions were formulated to eliminate or reduce the identified risks. Subsequently, monitoring of the implementation of the risk response program was carried out, along with the designation of responsible personnel. Risk response is the process of modifying or addressing a risk. Risk response is the process of developing options and determining actions to enhance opportunities and reduce threats to project objectives. Responses are directed at identified risks, and the choice of response is based on prior risk assessments [5].

Figure 1. Key phases of this study

3. RESULTS AND DISCUSSION

In the context of infrastructure development—particularly in complex and capital-intensive projects such as the construction of BTS—a systematic and structured approach to risk classification is critical for achieving effective and proactive risk management. Unlike routine operations, infrastructure projects are inherently exposed to a wide range of uncertainties stemming from technical complexities, environmental dynamics, regulatory frameworks, stakeholder interactions, and external socioeconomic conditions. The multifaceted nature of these projects demands that risks be not only identified, but also categorized in a way that enables stakeholders to trace their origin, understand their mechanism of impact, and develop appropriate response strategies.

3.1 Risk Identification

Classifying risks into logical and comprehensive categories enhances the overall clarity of risk analysis by providing a common language among stakeholders and ensuring consistency in evaluation. It enables project owners, contractors, consultants, and regulators to align their expectations, monitor risk exposure throughout the project lifecycle, and allocate resources effectively for mitigation. Each category of risk—whether it relates to design, execution, finance, environment, or force majeure—has unique implications for cost, time, safety, and quality, and therefore must be addressed using context-specific approaches. Furthermore, risk classification serves as a foundational step for prioritization and quantitative assessment, including methods such as the AHP.

Drawing upon the results of an extensive literature review as well as in-depth discussions with project professionals and domain experts, this study proposes a practical classification scheme to group risks into meaningful and operationally relevant categories. These classifications integrate theoretical insights from academic sources with empirical knowledge derived from field experience, making them both conceptually sound and pragmatically applicable. The categories reflect not only the internal dynamics of construction processes, but also the broader externalities that can disrupt project continuity and performance. Based on the outcomes of these consultations, two risk categories originally proposed by Mustafa and Al-Bahar (1991)—namely political and site-related risks—were excluded [9]. Political risk was considered irrelevant in this context, as all project locations were situated within the same geopolitical and regulatory jurisdiction, thereby minimizing policy volatility and legislative uncertainty. Site-related risks, meanwhile, were deemed to have already been mitigated during the preceding feasibility analysis stage. At that point, any proposed sites that lacked adequate social, environmental, or economic justification were excluded from further development, thereby narrowing the risk profile of the subsequent stages. This study classifies risks into the following factors:

1. Force Majeure; Referred to as "Act of God", is a term commonly used in the insurance industry to describe events that are unpredictable and beyond human control. These are usually natural events and are often referred to as natural phenomena. Common risks in this category include physical damage and personal injury caused by earthquakes, floods, fires, landslides, and other similar events. Force majeure is a standard clause in contracts and typically includes war, riots, natural disasters, and other occurrences that cannot be foreseen or anticipated in the scope of design and implementation.
2. Physical Risks; Typical risks in this category are associated with damage to property or assets owned or managed by the project owner. These risks include: damage to structures or property, damage to equipment and materials, workplace injuries and fatalities, and errors in work methods leading to losses or workplace accidents.
3. Financial and Economic Risks; Most risks in construction projects are financially related. Project financing is a potential economic risk for contractors. Insufficient funding from the owner or funding agency may cause delays and financing issues that can be unbearable for many contractors. The owner must have adequate funds to complete the work and must provide these funds in a manner and timeframe that allows the contractor to proceed. Another potential but less frequently discussed risk is the financial failure of subcontractors. Although rare, the consequences of such failures can be significant and must be considered.
4. Design Risks; Design-related risks typically include defective designs, ambiguous specifications and plans, errors and omissions in design, inaccurate geological and geotechnical investigations, and unclear scopes of work.

This study adopts the AHP method for risk assessment within the project scope. In the analysis for project risk assessment, the type of data used was qualitative data in Saaty's verbal scale. This qualitative data was used to determine the weight of risk likelihood criteria affecting the BTS construction. The qualitative data was then converted into quantitative form using Saaty's numerical scale. The converted data was derived from respondents' perceptions when comparing factors and sub-factors (in the pairwise comparison process) for identifying risks in

BTS construction. The analysis is considered acceptable if the resulting inconsistency ratio does not exceed 10%.

Table 1. Risk Identification of This Study

Hierarchy	Factors	Sub-Factors
First	Force Majeure	
Second		Earthquake
Second		Landslide
Second		Wind
Second		Lightning Strike
Second		Extreme weather
First	Physical	
Second		Methods
Second		Money
Second		Material
Second		Man
First	Design	
Second		Incomplete Scope of design
Second		Design miscalculation
Second		Improper specification
Second		Change of design
First	Economics	
Second		Inflation
Second		Volatility of exchange rate

3.2 Risk Assessment

In the context of risk prioritization for BTS construction, the AHP is employed to classify and weigh various risk categories based on their relative impact. The analysis identifies four major categories of risk: physical, design, economic, and force majeure. Among these, physical risks emerge as the most dominant, carrying a priority weight of 0.467, which indicates that nearly half of the overall project risk stems from physical factors. This category includes risks related to human resources or labor issues (weight: 0.136), material problems such as shortages or substandard quality (0.136), construction methods (0.060), and financial execution during implementation (0.136).

Figure 2. Risk factor hierarchy

Design-related risks represent the second most significant category, with a weight of 0.292. This includes risks due to incomplete or ambiguous specifications (0.120) and the impact of design changes made during project execution (0.087). These risks often lead to cost escalation, schedule delays, or the need for redesign, which can disrupt project continuity if not properly managed. Additionally, risks associated with incomplete design (0.035) and miscalculation (error) design (0.051) are also noted as contributing factors under design risks.

Economic risks account for 0.155 of the total risk weight. This category primarily focuses on macroeconomic conditions that affect project financing, including inflation (0.103) and interest rate fluctuations (0.052). While these factors are external to the project itself, they can significantly impact the contractor's ability to maintain profitability and meet contractual obligations.

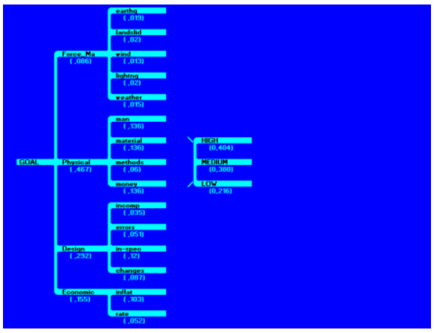

Figure 3. Risk assessment

Meanwhile, force majeure risks, also known as "Acts of God," have the smallest relative weight at 0.086. Despite their lower weight, these risks are important due to their unpredictable and uncontrollable nature. They include natural events such as earthquakes (0.019), landslides (0.020), wind (0.013), lightning (0.020), and extreme weather conditions (0.015). These risks are generally covered in contractual clauses and require contingency planning, even if their probability is low.

Table 2. Pairwise Comparison Between Factors, Sub Factors and Level of Risk

Factors		Sub Factors		Level of Risk		
				High	Medium	Low
Force Majeure	0,086					
		Earthquake	0.018			
				0.006	**0.008**	0.004
		Landslide	0.020			
				0.006	**0.009**	0.003
		Wind	0.013			
				0.005	**0.006**	0.002
		Lightning Strike	0.020			
				0.012	0.006	0.002
		Extreme Weather	0.015			
				0.009	0.003	0.003
Physical	0,467					
		Methods	0.136			
				0.043	**0.062**	0.031
		Money	0.136			
				0.043	**0.062**	0.031
		Materials	0.059			
				0.038	0.016	0.005
		Man	0.136			
				0.055	**0.065**	0.016
Design	0,292					
		Incomplete Scope of design	0.035			
				0.013	**0.016**	0.006
		Design miscalculation	0.051			
				0.029	0.015	0.007
		Improper specification	0.120			
				0.070	0.034	0.016
		Change of design	0.086			
				0.028	**0.036**	0.022
Economics	0,155					
		Inflation	0.103			
				0.029	0.014	**0.060**
		Volatility of exchange rate	0.052			
				0.027	0.017	0.008

Finally, the AHP model also categorizes the overall risk severity into three levels. High-severity risks hold the largest portion with a weight of 0.404, followed by medium-severity risks at 0.380, and low-severity risks at 0.216. This result indicates that more than 40% of the identified risks are considered high priority and require immediate attention and mitigation efforts. These findings provide a structured basis for decision-making in risk management, allowing project stakeholders to allocate resources efficiently and focus on the most critical risk factors in BTS project implementation.

The dominance of physical risks in the AHP result highlights a crucial insight: the majority of threats to successful BTS delivery stem from the operational and implementation phases, rather than from external environmental or macroeconomic influences. This finding is consistent with previous research emphasizing the centrality of internal execution challenges in infrastructure projects [5,6]. It underscores the need for project managers and contractors to invest more intensively in managing on-site execution variables, such as workforce safety, material logistics, equipment reliability, and method consistency. According to Aladayleh and Aladaileh (2024) [1], integrating Building Information Modeling (BIM) with AHP offers a robust framework for visualizing and quantifying these risks at the site level, allowing for proactive intervention.

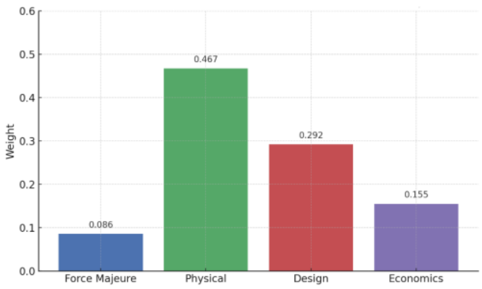

Figure 4. Risk factor weights

The equal weight assigned to labor, materials, and financial management within the physical risk category suggests that these three elements are interdependent and must be managed in an integrated manner. For instance, delays in material delivery can disrupt labor schedules, which may, in turn, increase labor costs and result in execution errors due to rushed completions—an issue also highlighted by Amalin and Handayeni (2017) in the context of BTS planning in urban areas [4]. This reinforces the importance of robust project control systems, including integrated scheduling, quality assurance protocols, and field-level safety monitoring, which are also recommended by Mustafa and Al-Bahar (1991) as part of a structured AHP-based risk management approach [9].

The relatively high ranking of design risks points to a systemic issue frequently encountered in fast-tracked infrastructure projects: insufficient detail and clarity during the early planning and design stages. Errors or incompleteness in design specifications not only constrain the construction team's ability to execute accurately but also generate costly redesigns and change orders [6,12]. This finding supports the argument for stronger front-end planning (FEP), cross-disciplinary coordination in design development, and thorough constructability reviews before mobilization. As shown in the study by Widyatmoko and Mauludiyanto (2015), applying multi-criteria methods such as AHP-TOPSIS in the planning of BTS towers leads to better alignment between technical and environmental feasibility, thus mitigating early-phase design risks [15].

From the economic perspective, while financial risks such as inflation and interest rate volatility may receive lower AHP weights, their long-term implications are significant—especially in multi-phase infrastructure settings. Inflation can rapidly escalate material and labor costs, reducing profit margins and possibly triggering contract renegotiations [2]. Similarly, volatility in interest rates affects borrowing costs in Public-Private Partnerships (PPP) and syndicated loans [3]. To address these, risk mitigation strategies such as hedging, escalation clauses, and contingency budgeting are recommended as part of a comprehensive 3E (Energy, Economy, Environment) framework [2].

Interestingly, the relatively low weight assigned to force majeure risks in the AHP results does not imply irrelevance, but rather reflects their low-frequency, high-impact nature. Natural disasters like earthquakes and landslides, while rare, can be catastrophic in consequence. Therefore, even if they score low in the AHP matrix, they should be managed through preventive structural design, resilience planning, and insurance coverage [7]. This aligns with the risk control philosophy presented by Sheikallavudeen and Sankar (2015), which advocates allocating proportional attention to hazards based on their impact, not merely their likelihood [13].

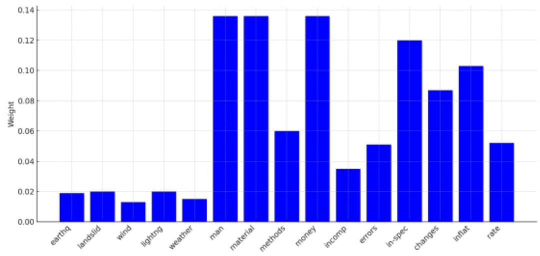

Figure 5. Sub factor weights

The severity ranking—with high-severity risks dominating with a score of 0.404—further affirms the urgency of proactive risk governance in BTS infrastructure delivery. A close score distribution between high (0.404) and medium risks (0.380) suggests that risk conditions are dynamic, necessitating adaptive project management strategies. Osei-Kyei et al. (2022) support this conclusion by highlighting the increasing relevance of real-time risk-tracking systems in complex construction projects, particularly under evolving regulatory, financial, and environmental conditions [11].

In summary, the AHP findings serve not only as a prioritization tool but also as a diagnostic framework that reveals structural vulnerabilities in telecommunication infrastructure projects. The integration of AHP into BTS risk management allows decision-makers to allocate resources strategically, structure mitigation strategies based on weighted priorities, and embed risk awareness across all project phases—from design and planning to execution and operation. As demonstrated by Nugroho (2020), prioritization using AHP supports more predictable and resilient infrastructure deployment, especially in regions with high service demand and site complexity [10].

In this study, risk management plays a pivotal role in ensuring that projects are implemented efficiently, safely, and within scope. Given the inherently complex and multi-phased nature of BTS infrastructure development—which typically involves the engineering, procurement, and construction (EPC) phases—early identification and appropriate response to risks become not only a best practice but also a strategic necessity [9,11]. As highlighted by Aladayleh and Aladaileh (2024), the use of structured risk assessment tools such as the AHP within a BIM-based environment enhances the precision of decision-making by ranking risk factors based on their impact and controllability [1].

By prioritizing the management of controllable internal risks, the BTS infrastructure development project will have a significantly higher potential to achieve its objectives in terms of time, cost, and quality. Conversely, while force majeure risks must still be monitored and considered, they should not be the primary focus in the allocation of risk management resources.

3.3 Risk Response

The risk response strategies identified in this study are structured around four major risk categories: force majeure, physical, design, and economic risks. Each category is addressed through tailored approaches depending on the controllability, predictability, and impact severity of the associated risks. Furthermore, clear designation of a Person in Charge (PIC) and alignment of each strategy with the project life cycle ensures accountability and timing efficiency [6,12]. Force majeure risks, by their very nature, fall outside the realm of human control. These include natural events such as earthquakes, landslides, strong winds, lightning strikes, and extreme weather conditions. Since such events cannot be prevented or predicted with accuracy, the response strategy focuses on risk acceptance combined with risk transfer, primarily through insurance. Risk insurance allows the project stakeholders to absorb the financial implications of such rare but high-impact occurrences without disrupting the project timeline or budget. For instance, comprehensive coverage against seismic activity or extreme weather ensures that, should such a disaster occur, the reconstruction or recovery costs are borne by the insurer rather than the project owner or contractor. The responsibility for arranging such insurance lies with the Project Director, and it is critical that these measures are undertaken in the pre-construction phase, well before any physical work begins on site.

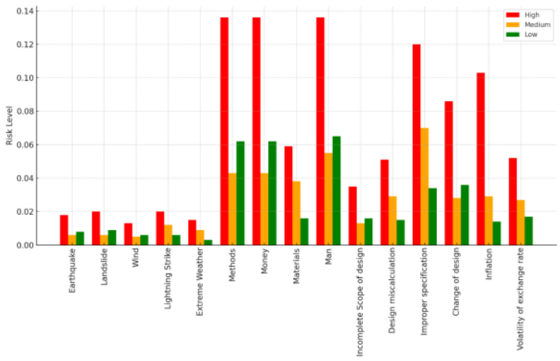

Figure 6. Risk level by sub factor

Table 3. Risk Response Formulation

Factor	Sub Factor	Risk Response	Risk Response	PIC	Schedule
Force Majeure	Earthquake	Risk acceptance	Risk insurance	Project Director	Pre-construction
	Landslide	Risk acceptance	Risk insurance	Project Director	Pre-construction
	Wind Strike	Risk acceptance	Risk insurance	Project Director	Pre-construction
	Lightning Strike	Risk acceptance	Risk insurance	Project Director	Pre-construction
	Extreme weather	Risk acceptance	Risk insurance	Project Director	Pre-construction
Physical	Methods	Risk mitigation	Standardized construction and safety procedures	Project Manager	Construction phase
	Money	Risk mitigation	Secure project financing	Project Manager	Construction phase
	Material	Risk mitigation	Provide reliable supply chain	Project Manager	Construction phase
	Man	Risk mitigation	Provide training and supervision	Project Manager	Construction phase
Design	Incomplete Scope of design	Risk mitigation	Early stakeholder involvement	Project Manager	Pre-construction
	Design miscalculation	Risk mitigation	Independent design review	Project Manager	Pre-construction
	Improper specification	Risk mitigation	Standardized specification coordination	Project Manager	Pre-construction
	Change of design	Risk mitigation	Implement change control standard	Project Manager	Pre-construction
Economics	Inflation	Risk mitigation	Price escalation clause	Project Director	Pre-construction
	Volatility of exchange rate	Risk mitigation	Currency risk hedging	Project Director	Construction phase

Force majeure risks, such as earthquakes, landslides, extreme weather, and lightning, fall outside human control. These low-probability, high-impact events require a strategy focused on risk acceptance and risk transfer, particularly through insurance mechanisms [13]. Comprehensive insurance coverage allows stakeholders to absorb financial implications without jeopardizing project continuity. As recommended by (Huang et al., 2024), pre-construction planning must incorporate disaster resilience and contractual safeguards, including insurance clauses for seismic or weather-related damage [7]. The Project Director is responsible for arranging such coverage before any physical work begins, as part of early-stage risk governance.

Physical risks, which include construction method variability, material and labor quality, and funding availability, are more predictable and thus manageable through effective planning and control. To address execution variability, standardized work sequences and safety protocols are emphasized, ensuring consistency across teams and locations [5]. The issue of financial disruption is handled through secured financing arrangements, including milestone-based disbursements or credit engagement. Material-related risks—such as supply delays or quality inconsistencies—are mitigated by maintaining a diversified supplier base and prioritizing local sourcing where possible. Human-related risks (labor competency, safety behavior, productivity) are tackled through training, certification, and continuous on-site supervision—with the Project Manager accountable during the construction phase, where these risks tend to escalate [15].

Design-related risks pose systemic challenges. Errors or omissions during the planning phase often cascade into construction delays, rework, or budget overruns [6,12]. To address these, stakeholder involvement during early design is critical to define a complete and actionable scope. For design miscalculations, independent design reviews—often conducted by external experts—are necessary to validate structural assumptions. Altamimi et al. (2024) emphasize that such verification procedures reduce uncertainty in technically complex infrastructure. Improper specification, frequently arising from disciplinary silos or failure to reference updated standards, is mitigated through interdisciplinary coordination involving civil, mechanical, and electrical teams. Meanwhile, potential design changes must be governed via controlled change management systems, which include formal documentation, approvals, and impact analysis [2]. These mitigation efforts fall under the Project Manager's purview and must be embedded in the pre-construction phase to prevent costly disruptions.

Economic risks, though sometimes underprioritized in AHP models, remain strategically significant, particularly in volatile economic contexts. Inflation is addressed through price escalation clauses, allowing for payment adjustments based on inflation indices. Similarly, exchange rate volatility—particularly the weakening of the Rupiah against major currencies—can jeopardize procurement costs for imported equipment. To this end, currency hedging, forward contracts, or multi-currency budgeting are applied [2,3]. Importantly, economic risk mitigation requires continuous monitoring during both pre-construction and construction phases, distinguishing it from more static risks like force majeure or design errors. The Project Director is tasked with maintaining financial flexibility and contractual fairness, ensuring that the project remains resilient to market shocks.

The integrated risk response framework emphasizes the alignment of mitigation strategies with risk types and lifecycle phases. As argued by Osei-Kyei et al. (2022), a responsive and dynamic risk management system is indispensable for maintaining project predictability, compliance, and delivery performance [11]. When coupled with AHP prioritization models [9,10], risk response becomes not only reactive but diagnostic and proactive, empowering BTS project stakeholders to allocate resources efficiently and sustain operational excellence. Overall, the structured responses outlined in the table offer a comprehensive framework for managing risk throughout the lifecycle of a BTS construction project. By aligning the nature of each risk with an appropriate response strategy, assigning clear responsibility, and integrating timing considerations, the risk management framework ensures that both preventable and unpredictable events are addressed in a proactive, measured, and effective manner.

4. CONCLUSIONS

This study highlights the critical importance of a comprehensive and structured approach to risk assessment in the development of BTS which must be developed with precision, efficiency, and resilience. However, such development is inherently complex and carries significant risks across multiple dimensions. These risks, if not properly identified, assessed, and mitigated, have the potential to compromise project objectives related to cost, schedule, quality, and safety. To address this challenge, the study employed the AHP as a decision-making framework for classifying and prioritizing project risks in a hierarchical manner. Through a combination of literature review and expert judgment, risks were categorized into four primary factors: physical, design, economic, and force majeure

The analysis reveals that physical risks hold the highest overall weight, underscoring the operational vulnerabilities faced during the construction phase. Sub-factors such as labor safety, material shortages, construction methods, and funding availability were found to be highly interdependent and sensitive to poor planning or execution. This implies that project teams must invest heavily in construction management controls, supply chain reliability, and workforce capacity building to effectively manage these risks. Design risks ranked second in importance, indicating persistent challenges related to incomplete specifications, design errors, and mid-project design changes. These risks often emerge during the early project phases but have long-term implications if not addressed proactively. Their prominence in the risk hierarchy suggests a need for stronger front-end planning, stakeholder collaboration, and rigorous peer review during the engineering design stage. Economic risks, while carrying lower relative weight, remain significant in light of inflationary pressures and currency exchange volatility. These factors can erode profit margins, disrupt procurement plans, and delay financing. Therefore, risk responses such as the incorporation of price escalation clauses, financial buffer planning, and currency hedging are essential tools for protecting the economic viability of the project. Meanwhile, force majeure risks—which include earthquakes, landslides, extreme weather, and lightning—though assigned the smallest weight in the hierarchy, represent low-probability but high-impact events. As such, these risks must be addressed through preventive strategies such as disaster-resilient engineering, site screening, and the inclusion of comprehensive all-risk insurance policies. These are typically implemented under risk acceptance frameworks, where risks are acknowledged but not avoided due to their inherent unpredictability.

A significant contribution of this study lies in the formulation of targeted risk response strategies that are aligned with the type of risk, the project phase in which they occur, and the personnel responsible for their management. The study categorizes risk responses into two main groups: risk mitigation, applied predominantly to physical and design risks that are within managerial control; and risk acceptance, adopted for economic and force majeure risks that are largely external. Each response is assigned to either the Project Manager or the Project Director, depending on the level of decision-making required, and is further classified by implementation timing—whether in the pre-construction phase or during active construction. This approach ensures a clear assignment of responsibilities and supports real-time responsiveness to emerging risk scenarios. Furthermore, the classification of risk severity into high, medium, and low levels provides an additional layer of prioritization. The study found that high-severity risks represent over 40% of total risk exposure, warranting immediate and continuous monitoring. The close distribution between high- and medium-level risks suggests that risk conditions can shift dynamically as the project evolves, highlighting the need for adaptive risk monitoring systems. Such systems should be integrated into project governance frameworks and supported by data-driven tools to allow flexible, scenario-based risk response planning.

REFERENCES

[1] K. J., Aladayleh, & M. J., Aladaileh, (2024). "Applying Analytical Hierarchy Process (AHP) to BIM-Based Risk Management for Optimal Performance in Construction Projects", *Buildings*, 14(11). https://doi.org/10.3390/buildings14113632

[2] M. B., Ali, A., Altamimi, S. A., Kazmi, Z. A., Khan, & S., Alyami, (2024). "Sustainable Growth in the Telecom Industry through Hybrid Renewable Energy Integration: A Technical, Energy, Economic and Environmental (3E) Analysis", *Sustainability*, 16(14). https://doi.org/10.3390/su16146180

[3] A., Altamimi, M. B., Ali, S. A., Kazmi, & Z. A., Khan, (2024). "Multi-Agent Reinforcement

Learning Optimization Framework for On-Grid Electric Vehicle Charging from Base Transceiver Stations Using Renewable Energy and Storage Systems", *Energies*, 17(14). https://doi.org/10.3390/en17143592

[4] R. E., Amalin, & K. D. M. E., Handayeni, (2017). "Kriteria Lokasi Pembangunan Tower BTS (Base Transceiver System) di Kota Kediri", *Jurnal Teknik ITS*, 6(1), pp. 67–70. https://doi.org/10.12962/j23373539.v6i1.22198

[5] I. B., Dunovic, M., Radujkovic, & M., Vukomanovic, (2016). "Internal and external risk based assesment and evaluation for the large infrastructure projects", *Journal of Civil Engineering and Management*, 22(5), pp. 673–682. https://doi.org/10.3846/13923730.2015.1128479

[6] J. S., Chou, P. C., Liao, & C. D., Yeh, (2021). "Risk Analysis and Management of Construction and Operations in Offshore Wind Power Project", *Sustainability*, 13(13). https://doi.org/10.3390/su13137473

[7] H., Huang, Q., Zhang, H., Xu, Z., Li, X., Tian, S., Fang, J., Zheng, E., Zhang, & D., Yang, (2024). "Risk Identification and Safety Evaluation of Offshore Wind Power Submarine Cable Construction", *Journal of Marine Science and Engineering*, 12(10). https://doi.org/10.3390/jmse12101718

[8] R. Y., Li, K. W., Chau, & F. F., Zeng, (2019). "Ranking of Risks for Existing and New Building Works", *Sustainability*, 11(10). https://doi.org/10.3390/su11102863

[9] M. A., Mustafa, & J. F., Al-Bahar, (1991). "Project Risk Assessment Using the Analytic Hierarchy Process", *IEEE Transactions on Engineering Management*, 38(1). https://doi.org/10.1109/17.65759

[10] W., Nugroho, (2020). "Study on determining priority of Base Transceiver Station (BTS) construction", *Advances in Business, Management and Entrepreneurship* 1st ed., pp. 167–171. CRC Press, Taylor and Francis Group. https://doi.org/10.1201/9781003131465-35

[11] R., Osei-Kyei, T., Narbaev, & G., Ampratwum, (2022). "A Scientometric Analysis of Studies on Risk Management in Construction Projects", *Buildings*, 12(9). https://doi.org/10.3390/buildings12091342

[12] A., Refsdal, B., Solhaug, & K., Stølen, (2015). "Risk identification", *SpringerBriefs in Computer Science*, pp. 61–80. Cyber-Risk Management. https://doi.org/10.1007/978-3-319-23570-7_7

[13] S., Sheikallavudeen, & S., Sankar, (2015). "Hazard Identification, Risk Assessment and Risk Control in Foundry", *International Journal of Industrial Engineering (IJIE)*, 2(2), pp. 61–80. https://doi.org/10.14445/23499362/IJIE-V2I3P101

[14] A., Tereso, C., Santos, & J., Faria, (2025). "Risk Management Practices in the Purchasing System of an Automotive Company", *Systems*, 13(6). https://doi.org/10.3390/systems13060444

[15] Widyatmoko, & A., Mauludiyanto, (2015). "Perencanaan Jumlah dan Lokasi Menara Base Transceiver Station (BTS) Baru pada Telekomunikasi Seluler di Kabupaten Lumajang Menggunakan Metode Analytical Hierarchy Process-TOPSIS (AHP-TOPSIS)", *Jurnal Teknik ITS*, 4(1), pp. 71–76.

[16] Q., Zhang, H., Huang, H., Xu, Z., Li, X., Tian, S., Fang, J., Wang, C., Xie, & D., Yang, (2024). "A Hierarchical Analysis Method for Evaluating the Risk Factors of Pile Foundation Construction for Offshore Wind Power", *Sustainability*, 16(18), 7906. https://doi.org/10.3390/su16187906