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Quantitative Risk Analysis for Financial Feasibility of Cellular Tower Construction Using Value at Risk Method

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Abstract

The cellular tower industry faces growing financial challenges due to declining lease prices and rising capital expenditures (CAPEX), often leading to poor investment metrics such as Net Present Value, Internal Rate of Return, and Payback Period. Despite this, providers frequently proceed with projects based on qualitative justifications like urgency or future contract potential without quantifying key financial risks. This study introduces a quantitative framework using Value at Risk (VAR) and Monte Carlo simulation to assess project feasibility under uncertainty. Real-world data are used to model three primary risks: additional construction work, land lease extensions, and uncertain colocation revenue. The simulation shows that while individual risks can lead to unfeasible outcomes, long-term scenarios incorporating colocation and extended leases improve overall viability. The risk-adjusted metrics remain within feasible thresholds under most conditions. This approach provides a structured, data-driven tool for tower providers to improve investment decisions and manage financial risk.

Keywords
Probabilistic Model, Discounted Cashflow, Monte Carlo, Value at Risk, Cellular Tower Construction, Risk Analysis, Cost Benefit Analysis

1. Introduction
The telecommunications tower industry is vital in enabling wireless communication by providing essential infrastructure for mobile network coverage. As demand for data and connectivity continues to rise, Tower Providers must rapidly expand their infrastructure to support technological advancements and growing user needs. These companies focus on constructing, owning, and managing towers that support telecommunication networks. However, they are increasingly facing financial challenges due to two key factors: declining lease prices from mobile network operators (Figure 1) and rising construction costs. This combination often results in inflated capital expenditure (CAPEX) and weak financial performance, with key indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PBP) frequently falling below acceptable thresholds.

Despite these conditions, Tower Providers are often compelled to proceed with projects that do not meet financial feasibility standards. Such decisions are commonly based on qualitative justifications, such as meeting client deadlines or anticipating future contracts, rather than on thorough financial evaluations. This practice exposes companies to heightened financial risks and undermines long-term investment sustainability.

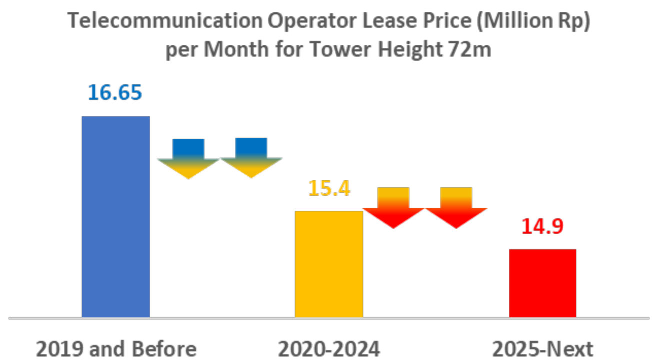

Figure 1. Declining Operator Lease Prices

In the context of risks associated with telecommunication tower projects, several studies from countries such as Ghana, Australia, and Ethiopia highlight the importance of identifying financial and operational risks (Adams, 2016; Mekonnen, 2019; Tetteh, 2012). These studies indicate that while operational and regulatory risks often receive attention, financial risk management tends to be overlooked during the early stages of construction. Although some research recommends the use of quantitative risk analysis, the majority still rely on qualitative assessments or deterministic methods, lacking models that account for uncertainty(Ardiantono et al., 2019).

The research gap (depicted in Figure 2) lies in the limited application of quantitative methods, particularly Value at Risk (VAR), in evaluating the financial performance of tower providers. While some studies have utilized investment feasibility analysis and Monte Carlo simulation for project risk assessment, an integrated framework combining Monte Carlo and VAR remains scarce(Ershad and Rahadian, 2022). This study aims to address that gap by developing a probabilistic model that integrates both methods to better capture financial uncertainty and support decision-making for tower providers.

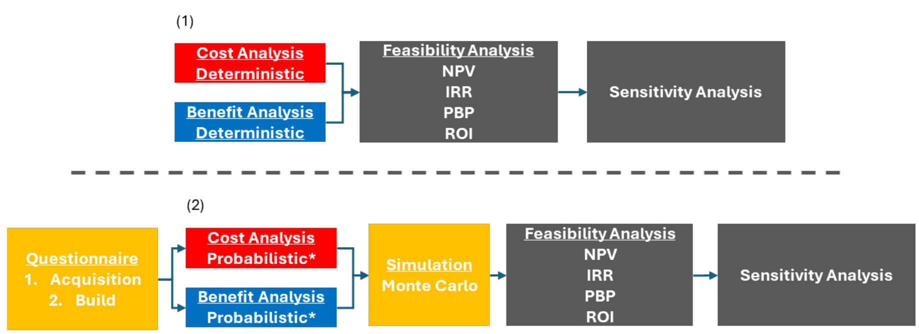

Figure 2. Method used for Financial Analysis on Cellular Tower in recent research

This research is motivated by the need to improve the quality of investment decision-making in the telecommunications infrastructure sector. By introducing a risk-based financial evaluation method, particularly the application of Value at Risk (VAR), the study aims to offer a more structured and data-driven approach to investment analysis. VR enables decision-makers to incorporate uncertainty into their financial models, predict potential losses, and plan scenarios that support more informed and balanced investment strategies.

In this context, the core problem addressed by this study is the lack of quantitative risk modeling in evaluating tower investments. It seeks to explore how financial uncertainty can be effectively quantified and how the use of Value at Risk can enhance the robustness of investment decisions, allowing Tower Providers to better manage risk while pursuing long-term profitability.

1.1 Objectives

This paper intends to assess the risk and uncertainty that could affect the value of expenditure and revenue of Cellular Tower, especially during the construction phase. It also seeks to calculate and evaluate the financial feasibility of investing in Cellular Towers, both before and after incorporating risk factors using quantitative methods, including Value at Risk. Furthermore, the study explores scenarios and conditions under which the tower construction business remains financially viable.

2. Literature Review

Literature Review consists of three main parts: Risk Profiles, Financial Metrics, and Probability Distribution

A. Risk Profiles

In late 2024, a risk assessment was conducted by one of Indonesia's biggest tower provider companies as part of compliance with BUMN Regulation Per-02/2023, which mandates formal risk management planning. The resulting 2025 risk profile identified and categorized risks based on likelihood and impact, forming a matrix that highlights both inherent and residual risks.

Three risks were particularly relevant to investment feasibility: uncertainty in future colocation orders (affecting revenue), lease renewal cost increases (impacting future CAPEX), and variability in operational models (influencing current CAPEX). According to the risk profile, these three categories have high probability occurrences and impact. These findings underscore the importance of integrating risk quantification methods such as Value at Risk (VAR) to support more data-driven and anticipatory financial decision-making in infrastructure projects.

B. Financial Metrics

Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PBP) are foundational metrics in capital budgeting used to evaluate investment feasibility. In the context of tower providers, these metrics are particularly critical due to the capital-intensive nature of telecommunication infrastructure. Projects with strong NPV and IRR values signal long-term profitability, and the PBP metric becomes especially important to measure investments quickly due to competitive market dynamics or investor expectations.

Net Present Value (NPV) is a core financial metric used to assess the profitability of an investment by calculating the present value of future cash flows minus the initial investment cost. The standard formula is:

$$NPV = \frac{R_t}{(1+i)^t}$$

$NPV = net\ present\ value$
$R_t = net\ cash\ flow\ at\ time\ t$
$i = discount\ rate$
$t = time\ of\ the\ cash\ flow$

Rooted in the time value of money principle, NPV accounts for the decreasing value of money over time. A project is considered financially feasible if the NPV is greater than zero. For tower providers, NPV is vital for evaluating long-term profitability, especially given that tower revenues, derived from tenant leases, are spread over several years. However, uncertainty in tenant acquisition and operating costs can lead to deviations from projected NPVs, emphasizing the need for risk-based evaluation.

Internal Rate of Return (IRR) is the discount rate that makes the NPV of a project equal to zero. It reflects the project's expected rate of return:

$$0 = NPV = \sum_{t=1}^{T} \frac{C_t}{(1+IRR)^t} - C_0$$

$C_t = net\ cash\ inflow\ during\ the\ period\ t$
$C_0 = total\ initial\ investment\ costs$
$IRR = the\ internal\ rate\ of\ return$
$t = the\ number\ of\ time\ periods$

The IRR is often used to compare investment opportunities. If the IRR exceeds the company's required rate of return or cost of capital, the investment is considered attractive. In the tower industry, IRR is used to assess project returns against internal benchmarks or external funding costs. However, IRR assumes reinvestment at the same rate, which can be unrealistic, particularly in volatile infrastructure markets. Additionally, IRR may provide misleading signals in non-conventional cash flow patterns, which are common in large-scale tower projects. For this research, Value IRR used is 9.47% based on one of the tower company's WACTR.

PBP calculates how long it takes for an investment to recover its initial cost from net cash inflows:

$$\begin{aligned}&Cummulative\ Cash\ Flow\\ &\quad = (Net\ Cash\ Flow\ Year\ 1 + Net\ Cash\ Flow\ year\ 2 + \cdots + Net\ Cash\ Flow\ year\ N)\end{aligned}$$

PBP is widely used for its simplicity and focus on liquidity and risk. In the telecommunication tower sector, where large upfront CAPEX and long-term revenue horizons are common, PBP is useful to gauge the short-term recovery of investments. However, it ignores cash flows beyond the payback point and does not consider the time value of money, making it less comprehensive than NPV or IRR.

3. Methods

This research adopts a structured analytical framework that integrates both qualitative and quantitative approaches to assess the financial feasibility and risk exposure in the construction of telecommunication towers. The methodological flow consists of three main stages: risk identification, risk modeling, and financial feasibility simulation, as depicted in Figure 3.

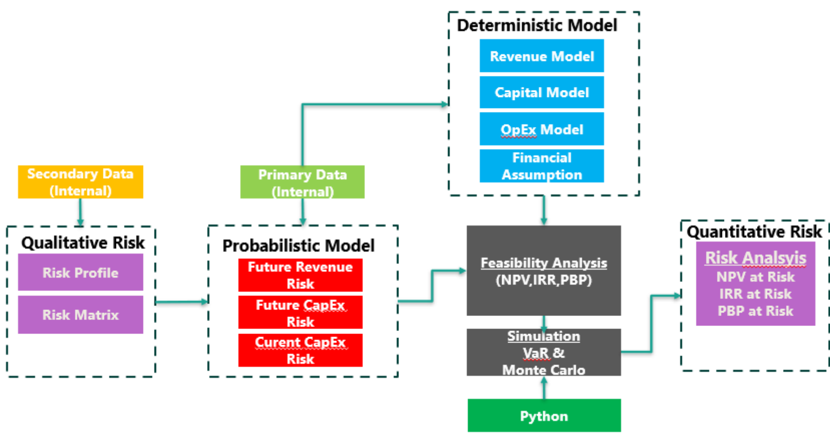

Figure 3. The Conceptual Model

A. Data Collection and Risk Identification
The study begins with the collection of both primary and secondary internal data. Secondary data, such as historical project reports and internal assessments, are used to construct a Qualitative Risk profile. On the other hand, identified key uncertainties related to capital expenditure (CAPEX), operating expenditure (OPEX), and revenue streams will be addressed using primary raw data.

B. Risk Modeling
Based on the identified qualitative risks, a Probabilistic Model is developed to represent three primary risk components: Additional Work as Current CAPEX risk, Land Lease Extension as future CAPEX risk, and Colocation as future Revenue risk. The model used for this research is a probability distribution.
In parallel, a Deterministic Model is constructed using financial assumptions and project parameters. This model includes the Revenue Model, Capital Model, OPEX Model, and Financial Assumptions.

C. Feasibility Analysis and Simulation
The outputs of both deterministic and probabilistic models feed into a Feasibility Analysis, which evaluates the project using standard financial metrics such as NPV, IRR, and PBP.

D. To incorporate uncertainty, a Monte Carlo Simulation is conducted using Python, allowing for repeated sampling of variable outcomes based on risk distributions. This leads to the development of a Quantitative Risk profile, where key financial indicators are transformed into risk-adjusted metrics: NPV at Risk, IRR at

Risk, and PBP at Risk. These outputs help determine the project's financial resilience under various risk scenarios.

4. Data Collection

Data Collection consists of three main parts: site profile, financial models, and risk models.

A. Site Profile

The planned site is depicted in Table 1. The primary data collected for this study highlights several contextual characteristics of tower construction projects in the Central Java (Jawa Tengah) region. Most project orders are in suburban areas, which present distinct operational challenges and opportunities compared to urban centers. The land acquisition process is relatively challenging, as communities tend to be more informed about telecommunication projects, leading to potential public resistance and interference from local organizations.

On the other hand, construction progress in Central Java is generally faster than projected, supported by good road infrastructure and direct land-based logistics. However, electricity availability, while present in most areas, sometimes fails to meet the required power specifications, potentially affecting operational readiness.

Table 1. General Site Profile

Description	**Category**
Locations	Central Java
Settlement Pattern	Sub-urban
Tower Height	72 m
Portfolio	Built to Suite (B2S)
Tower Type	Self-Supporting Tower (SST)
Land Type	Greenfield
BTS Type	Outdoor
Power Type	PLN
Power	10.6 – 11 KVA
Lease Durations	10-11 Years (First Cycle)

B. Financial Models

For the assumptions, We will be using data based on a set of general assumptions relevant to the financial and operational aspects of the project. Key parameters include interest rates, inflation, tax rates, and operational days/months/years, which are typically referenced from industry standards, government regulations, or institutional benchmarks. Capital investment and operational cost estimates are derived from market analysis and feasibility studies. These assumptions serve as the foundation for financial modeling and help ensure consistency and realism in evaluating the project's viability (Table 2).

Table 2.Cashflow Model with deterministic approach

Description	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Total Revenue	**134**	**179**	**180**	**180**	**181**	**182**	**182**	**183**	**184**	**184**	**46**
Revenue 1st Tenant	134	179	180	180	181	182	182	183	184	184	46
Revenue 2nd Tenant -> Risk											
Tax Final	**13**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**5**
Total	**121**	**161**	**162**	**162**	**163**	**163**	**164**	**165**	**165**	**166**	**42**
Total Expenses	**10**	**13**	**14**	**14**	**15**	**15**	**16**	**16**	**17**	**17**	**4**
OM, Insurance, Retribusi	7	10	10	11	11	11	12	12	13	13	3
G&A + Marketing	3	4	4	4	4	4	4	4	4	4	1
EBITDA	**111**	**148**	**148**	**148**	**148**	**148**	**148**	**149**	**149**	**149**	**37**
EBITDA margin	**83%**	**83%**	**82%**	**82%**	**82%**	**82%**	**81%**	**81%**	**81%**	**81%**	**81%**
Depreciation	73.29	97.72	97.72	97.72	97.72	97.72	97.72	97.72	97.72	97.72	24.43
EBIT	38	50	50	50	50	51	51	51	51	51	13
Tax	-	-	-	-	-	-	-	-	-	-	-
NOPAT	**38**	**50**	**50**	**50**	**50**	**51**	**51**	**51**	**51**	**51**	**13**
NOPAT margin	**28%**	**28%**	**28%**	**28%**	**28%**	**28%**	**28%**	**28%**	**28%**	**28%**	**28%**
Add : Depreciation & Amortization	73	98	98	98	98	98	98	98	98	98	24
CAPEX	(977)	-	-	-	-	-	-	-	-	-	-
Anchor & Colo	(977)	-	-	-	-	-	-	-	-	-	-
Additional Work -> Risk											
Land Lease (Extension)-> Risk	-	-	-	-	-	-	-	-	-	-	-
Net Cash Flow	(866)	148	148	148	148	148	148	149	149	149	37
Free Cash Flow	(866)	148	148	148	148	148	148	149	149	149	37
Payback Period	1	2	3	4	5	6	7	8	9	9.08	-
Discounted Cash Flow	(866)	135	123	113	103	94	86	79	72	66	15

For Revenue. the first operator has a fixed lease agreement, generating IDR 14.9 million per month or IDR 178.8 million annually (while in the first-year calculated start from RFI Month). This includes a base lease and O&M fee. A second tenant is projected but not yet confirmed, with a potential monthly revenue of IDR 11.65 million or IDR 139.8 million annually. And as the purpose of this research, the second operator is still uncertain, which will be one of the risk factors.

For Expenses, Monthly operational costs for each tenant include O&M (IDR 324,000), retribution fees (IDR 451,252), and insurance (IDR 58,663). Retribution refers to local government charges for specific permits or services, while insurance provides financial protection against defined risks as agreed in the policy. Electricity (PLN) is not included in this scenario.

For Capex, the initial investment cost for the project is IDR 1,065,469,773, incurred in year 0. This amount covers all standard expenditures during the pre-construction phase, including site acquisition (SIS & SITAC), regulatory permits (PBG & SLF), civil, mechanical, electrical (CME) works, power connections, land lease, and material procurement. This value does not yet account for any potential additional works, which may arise due to site-specific challenges or project scope adjustments. This uncertainty will be one of the risk factors in this research. And as the risk profile, the extended lease will be added to one of the risk factors.

Calculation NPV, IRR, and PBP result from deterministic approach are IDR 21 million, 10.04%, and 9.08 Years. All these results are feasible.

C. Risk Model

This study applies a structured uncertainty modelling approach to quantify potential risks that may affect project outcomes. The modelling process consists of four key steps. First, Exploratory Data Analysis (EDA) is conducted to understand the characteristics of each risk variable using visual tools such as histograms and Kernel Density Estimation (KDE). Second, a Goodness-of-Fit test is performed using the Kolmogorov-Smirnov (K-S) method to compare multiple distribution models and evaluate which best represents the observed data. Third, the most suitable statistical distribution is selected based on the test results. Finally, simulation is conducted using the chosen distribution to generate probabilistic outcomes, which are then compared to actual historical patterns for validation. All processes are depicted in Figure 4.

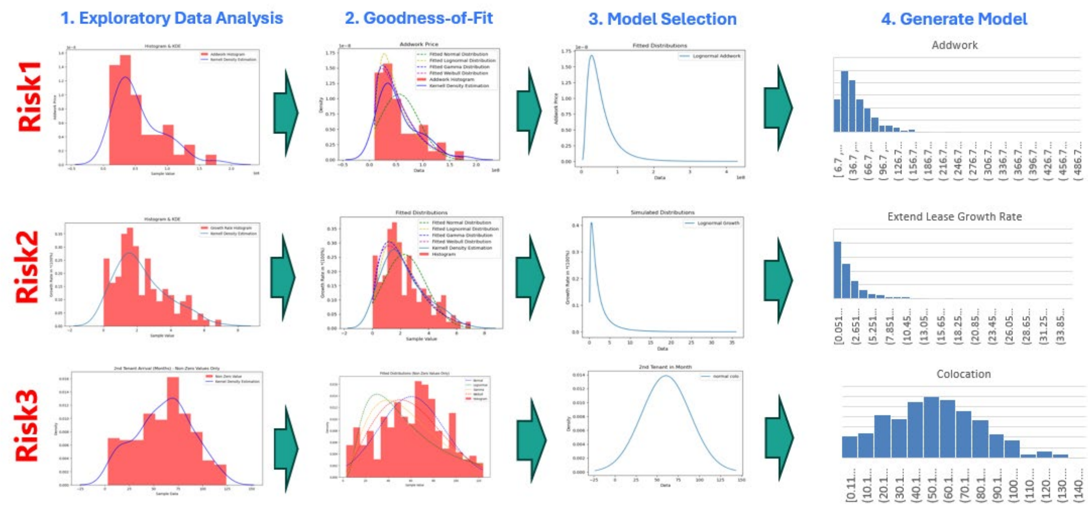

Figure 4. Quantitative Risk Modelling Process

In this study, three types of risk were identified and modelled: Additional Work (Risk 1), Extended Lease (Risk 2), and Colocation (Risk 3). The data for Risk 1, related to additional work or scope changes, was gathered from internal records of past infrastructure projects that experienced unplanned tasks or modifications. These records include cost fluctuations and work volume changes, which served as the basis for modelling the uncertainty in additional work requirements. Risk 2, which involves the possibility of extending the lease period, used data collected from previous project timelines where delays led to the need for extended site occupancy. This included examining historical patterns in lease extension durations and associated cost increments, enabling a growth-based distribution fit. Lastly, Risk 3, associated with the entry of a second operator or colocation, was modelled using market and operational data on typical entry intervals of additional tenants in shared infrastructure setups. This data allowed for the estimation of timing uncertainty, which is critical in forecasting revenue and planning site utilization. By modeling these risks quantitatively, it can be used as input for Monte Carlo and Value at Risk simulations as the risk factors. The summary parameter of the risk model depicted in Table 3.

Table 3. Parameters Summary

Risk Category	Uncertainty Factor	Distribution Model	Parameter	Remark	Affect
1	Additional Works	Lognormal	$\mu = 17.6156$ $\sigma = 0.6610$	Samples: 50++ Site Durations: Latest 1 Year	Current Capex
2	Future Land Lease	Lognormal	$\mu = 0.4738$ $\sigma = 1.0372$	Samples: 120++ Site Duration: Latest 10 Year	Future Capex
3	Colocation	Normal	$\mu = 53.63$ $\sigma = 33.08$	Samples: 250++ Site Durations: Latest 10 Year	Future Revenue

5. Results and Discussion

The simulation was conducted using a combination of Python (via Jupyter Notebook) and Excel. Python served three main functions: (1) generating random input data based on predefined risk distributions using libraries such as numpy and pandas, (2) executing Monte Carlo simulations and Value at Risk (VAR) calculations through iterative modeling, and (3) visualizing results using matplotlib.

The simulation outputs were linked to a structured Excel model containing financial assumptions, CAPEX, revenue, and OPEX components. Each iteration modified specific input cells in the Excel-based DCF model, dynamically updating outputs (NPV, IRR, PBP) to reflect financial performance under uncertainty. This integrated approach enabled automated scenario analysis and visual presentation of risk outcomes.

5.1 Numerical Results

The simulation results, depicted in Table 4, highlight the financial viability of tower construction projects even under full risk exposure. The average NPV of IDR 747 million and a risk-adjusted NPV (NPV at Risk) of IDR 531 million both fall within the “feasible” category, indicating positive value creation even in adverse scenarios. Similarly, the average Internal IRR is 20.13%, with the risk-adjusted IRR (IRR at Risk) at 15.94%, both exceeding typical hurdle rates. The PBP shows an average of 7.83 years, while the risk-adjusted PBP (PBP at Risk) is 10.77 years—both still within acceptable investment horizons.

Table 4. Simulation Results

Description	Value	Category
Avg. NPV	IDR 747 million	Feasible
NPV at Risk	IDR 531 million	Feasible
Avg. IRR	20.13%	Feasible
IRR at Risk	15.94%	Feasible
Avg. PBP	7.83 years	Feasible
PBP at Risk	10.77 years	Feasible

These findings reinforce the importance of a holistic financial risk analysis when evaluating tower investments. The model captures the complexity and interdependence inherent in the industry by simulating the interplay of three interrelated risks. The resulting distributions offer actionable insights for stakeholders, project managers, and investors, providing a quantifiable understanding of expected returns and downside risks. This approach supports more informed and resilient decision-making in capital-intensive infrastructure projects.

5.2 Graphical Results

The scenario used in the simulation presents the most comprehensive and realistic case by combining all three financial risks, capturing the full spectrum of potential project outcomes across NPV, IRR, and PBP (Depicted in Figure 5). The first histogram shows a slightly left-skewed NPV distribution, with an average of IDR 747 million and a 95% VAR of IDR 531 million, indicating resilience even under worst-case conditions. This is largely due to extended lease durations and continued tenant commitment, which sustain revenue flow and balance increased CAPEX.

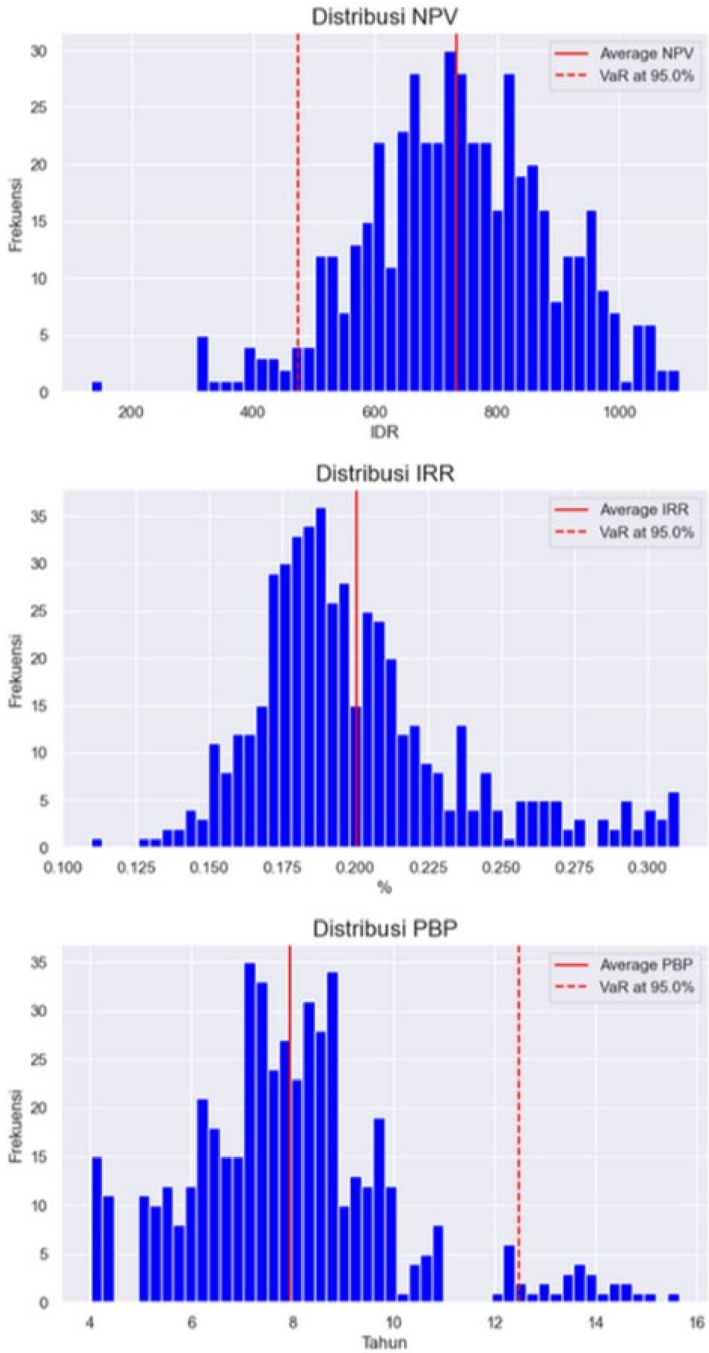

Figure 5. Histogram Representation for each metrics

The IRR distribution clusters between 10% and 18%, with an average of 20.13% and a VAR of 15.94%, both above typical hurdle rates—signaling strong investment appeal even under pressure. Meanwhile, PBP averages 7.83 years with a VAR of 10.77 years. These results emphasize that, under current industry dynamics, project viability requires a horizon beyond 10 years, ideally extending to 15–20 years.

Overall, this full-risk simulation underscores the importance of a holistic financial risk analysis. By capturing the interdependencies among financial risks, it equips stakeholders with a more robust, data-driven basis for investment decisions in the tower provider industry.

5.3 Proposed Improvements

Based on the simulation results and financial risk analysis, several mitigation strategies are proposed to enhance the viability and resilience of telecommunication tower investment projects:

1. Optimization of CAPEX through Design Innovation and Technology Adoption
   One key financial pressure point is the high initial CAPEX, particularly in physical infrastructure components such as CME and PLN. To mitigate this, tower providers should explore cost-reduction opportunities through modular design, value engineering, and the adoption of newer, more cost-efficient technologies. Streamlining procurement and standardizing designs can further contribute to lowering baseline CAPEX, reducing the risk of budget overruns.
2. Implementing Long-Term Lease Agreements from the Outset
   To minimize the uncertainty and financial impact associated with mid-project land lease renewals, often occurring at year 10, it is advisable to secure land leases for a full 20-year period during the initial construction phase. This proactive measure not only ensures continuity but also stabilizes cash flow and strengthens the project's long-term viability by eliminating renegotiation risks and cost escalations.
3. Selective Site Development Based on Colocation Potential
   In regions with low colocation potential, particularly in densely saturated areas of Java, where tenant acquisition is limited, the financial return per tower is significantly lower. To mitigate revenue risk, tower development should prioritize locations with higher colocation prospects, such as outer islands, where tenant demand is often unmet and the marginal return from additional tenants is more substantial. A more selective and data-driven site evaluation framework will help avoid underperforming investments.

6. Conclusion

The simulation indicates that additional work during the construction phase results in financially unfeasible outcomes. However, when colocation and land lease extension are factored in, the financial parameters become feasible. This highlights that the tower business relies heavily on long-term continuity, at least 20 years, to maintain profitability. All three risk categories analyzed have a high probability of occurrence and must be considered essential in the financial feasibility analysis.

Risk mitigation strategies should be implemented, such as reducing standard CAPEX costs for physical components (CME & PLN) through improved designs or technological advancements. Land lease agreements should be set for 20 years from the beginning to avoid renegotiation risks at year ten. Furthermore, tower development should be prioritized in areas with high co-location potential, as income from a single operator in Java is significantly lower than in other regions.

While colocation potential in Java remains high (>80%), the declining number of operators, from five operators in 2021 to just three operators in 2025, may reduce future colocation demand. Additionally, growing resistance from local communities and social groups poses a threat to project efficiency and cost control. As land lease prices continue to rise, a tipping point may be reached where lease renewal costs equal or exceed new build costs, making tower operations financially unviable even with reconstruction.

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Biographies

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