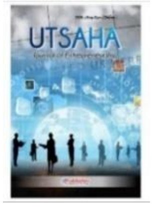

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Feasibility of 5G Network in Educational Institutions: A Case Study at SMKN 1 Cilegon Using Cost Benefit Analysis (CBA)

May Hendra Panjaitan
hendra.panjaitan@poltek-petrokimia.ac.id
Politeknik Industri Petrokimia Banten

*Corresponding Author: May Hendra Panjaitan
Email: hendra.panjaitan@poltek-petrokimia.ac.id

ABSTRACT

Telecommunication technology has advanced to the fifth-generation (5G) era, offering unprecedented opportunities for digital transformation in educational sectors. In Indonesia, 5G penetration has reached approximately 2.9%, indicating uneven distribution patterns, particularly affecting vocational education institutions such as SMKN 1 Cilegon, which requires robust digital infrastructure to enhance learning quality and competitiveness. This study aimed to assess the economic feasibility of implementing a 5G network at SMKN 1 Cilegon using the Cost Benefit Analysis (CBA) methodology. The proposed implementation was designed utilizing one microcell Base Transceiver Station (BTS) unit to satisfy coverage requirements for a 2.1-hectare area serving 1,000 daily active users. Financial projections incorporated Capital Expenditure (CAPEX) of USD 25,400, annual Operational Expenditure (OPEX) of USD 7,400, monthly user revenue of USD 20, and comprehensive cash flow analysis over a five-year period to determine Net Present Value (NPV) using a 10% discount rate. The results demonstrated a positive cumulative NPV of USD 726,304.6 by the fourth year, confirming that 5G deployment at SMKN 1 Cilegon is economically viable. The findings indicate that minimal infrastructure requirements combined with favorable cost structures support 5G implementation to accelerate digital transformation, strengthen student competencies, and foster enhanced collaboration between educational institutions, vocational training providers, and industry stakeholders within Industry 4.0 frameworks.

Keywords: *CAPEX, Cost Benefit Analysis, NPV, OPEX*

INTRODUCTION

The development of global telecommunication technology has entered the era of fifth-generation (5G) networks, which offer significantly higher data access speeds, ultra-low latency, and massive connection capacity compared to previous generations (Uwaechia & Mahyuddin, 2020). This transformative technology has been recognized as a critical enabler for various sectors, including education, which is increasingly dependent on digital services and internet-based learning methodologies (Agiwal et al., 2016). In Indonesia, the penetration rate of 5G technology remains at approximately 2.9%, resulting in uneven utilization patterns, particularly affecting vocational education institutions that require comprehensive digital infrastructure support to improve learning quality and maintain competitiveness (Badan Pusat Statistik, 2020).

As a prominent vocational education institution, SMKN 1 Cilegon demonstrates high demand for advanced information and communication technology integration. The learning processes, laboratory practices, and development of students' competencies in industrial technology require stable and high-speed internet access capable of supporting the seamless integration of Internet of Things (IoT)-based devices and smart manufacturing systems (Miao et al., 2021). The availability of high-speed, low-latency networks enables institutions to introduce innovative courses focusing on IoT applications, smart manufacturing technologies, and comprehensive Industry 4.0 implementations (Fuertes et al., 2021; Moraes et al., 2023). These specialized subjects require high-bandwidth and stable connectivity for real-time data acquisition, continuous monitoring, and remote control of sophisticated devices and systems (Suwastika et al., 2025).

The implementation of 5G networks in educational environments is expected to accelerate digital transformation initiatives, enhance technological literacy among students and educators, and create substantial opportunities for collaboration with industrial sectors within the framework of Industry 4.0-based vocational education (Lu, 2017). Furthermore, 5G adoption enables real-time interactive learning through immersive Virtual Reality (VR) and Augmented Reality (AR) platforms, providing unprecedented educational experiences. Students in vocational and polytechnic institutions can conduct immersive simulations of complex industrial processes with minimal latency, capabilities that are difficult to achieve with conventional network infrastructures (Radianti et al., 2020).

However, the implementation of 5G networks requires substantial infrastructure investment, necessitating comprehensive feasibility analysis using systematic Cost Benefit Analysis (CBA) approaches to assess the extent to which generated benefits can adequately cover incurred costs. This analysis is critically important as a foundation for strategic decision-making in 5G technology adoption within educational environments, considering not only immediate economic factors but also broader social and academic impacts that extend beyond financial considerations (Yaghoubi et al., 2018).

From an academic perspective, 5G technology supports the integration of advanced digital learning tools including Virtual Reality (VR), Augmented Reality (AR), and IoT-based laboratory environments, which significantly enhance students' understanding of complex engineering concepts through interactive and real-time simulations. The technology also creates opportunities for innovative curriculum development, including specialized courses in IoT applications, smart industry technologies, and digital entrepreneurship, thereby preparing students with competencies that are directly aligned with Industry 4.0 requirements and market demands (Firdausi & Antonio, 2025; UNESCO, 2018).

From a social perspective, 5G implementation can substantially reduce educational inequalities by enabling remote access to high-quality learning resources, allowing students from different geographical regions to participate in identical virtual classrooms and collaborative projects. Furthermore, the technology fosters technopreneurship and corporate entrepreneurship within academic settings, encouraging students to innovate and develop digital solutions that address both industrial challenges and community needs, thus creating stronger linkages between education, society, and industry stakeholders (Zhang, 2023).

Despite the recognized potential of 5G technology in educational contexts, existing literature reveals significant gaps in empirical analysis of 5G deployment feasibility, particularly in developing country educational environments. While few studies have demonstrated positive impacts of 5G on student engagement in higher education contexts, these investigations primarily focused on developed economies with established telecommunications infrastructure and favorable regulatory environments (Kizilkaya et al., 2021; Yusnita & Virlania, 2024; Zapata-Paulini & Cabanillas-Carbonell, 2024).

Similarly, research conducted by Chen et al. (2022) on 5G deployment economics provided valuable insights into cost structures, but their analysis concentrated on commercial telecommunications markets rather than educational institutions with unique financial and operational constraints. Furthermore, previous economic analyses of telecommunications infrastructure in educational settings, such as those by Gyamfi et al. (2023) and Ortiz et al. (2015), have typically examined broader ICT implementations rather than specific 5G network deployments. These studies, while informative regarding general technology adoption patterns, lack the technical specificity and financial granularity necessary for strategic 5G investment decisions in resource-constrained educational environments characteristic of emerging economies.

SMKN 1 Cilegon is an educational institution covering approximately 2.1 hectares with more than 1,000 internet service users, which is categorized as high density according to Ministry of Public Works standards. The institution's characteristics, including manageable geographical coverage and substantial user population, make it an ideal candidate for 5G pilot implementation. Therefore, this study aimed to assess whether 5G network implementation is economically feasible within the SMKN 1 Cilegon environment. The methodology employed was comprehensive Cost and Benefit Analysis to determine economic feasibility, where the 5G network implementation is considered viable if the cumulative benefit value exceeds the total cost value over the analysis period (Boardman et al., 2018).

RESEARCH METHODOLOGY

The Cost and Benefit Analysis (CBA) method represents a well-established approach for assessing project feasibility through systematic evaluation of anticipated costs against expected benefits. According to established economic principles, if the benefit value exceeds the cost value, the project is considered economically feasible for implementation; conversely, if the cost value surpasses the benefit value, the project is deemed economically infeasible (Nas, 2016). The methodological stages employed in this study were structured into several comprehensive components:

This study utilized location data from SMKN 1 Cilegon, situated at Jalan Kedungbaa No. 21, Kalitimbang Village, Cibeber District, Cilegon City, Banten Province, Indonesia. The researchers selected SMKN 1 as the study object based on several strategic criteria: its relatively compact area of 2.1 hectares, high population density exceeding 200 people per hectare according to Ministry of Public Works classifications, and substantial daily internet user base exceeding 631 active users.

Currently, SMKN 1 maintains more than 1,000 staff and students; therefore, the researchers conservatively assumed the potential subscriber base to be 1,000 users for financial modeling purposes. This assumption results in a population density of 476 people per hectare, which is significantly higher than average educational institution densities. The user growth rate was projected at 10% annually, reflecting institutional expansion plans and increasing digital service adoption trends observed in similar educational contexts.

Figure 1 Maps of SMKN 1 Cilegon
Source: Google Maps

Traffic estimation was calculated using established telecommunications forecasting methodologies with the following formula (Guo, 2023):

$$G(t) = \rho \frac{8}{Ndh.Nmb} \frac{1}{3600} \varphi(t).\mathrm{Dk} \qquad (1)$$

Where **G(t)** is the traffic demand, **Ndh** is the number of busy hours, namely 9 hours, **Nmb** is the number of days in one month, **φ** is the number of active subscribers with the assumption of 100 percent, and **Dk** is the average customer demand, which is 500 GB. This methodology ensures accurate traffic forecasting aligned with international telecommunications planning standards and accounts for peak usage patterns typical of educational environments.

The determination of Base Transceiver Station (BTS) requirements was based on comprehensive network planning considerations, particularly regarding coverage area specifications and service capacity that each BTS unit can effectively provide. This study employed microcell and femtocell BTS configurations with propagation modeling that adheres to 3GPP 38.901 international standards for 5G New Radio implementations.

The spectrum utilization was designed with an efficiency of 14 bps/Hz per cell operating at 28 GHz frequency with 400 MHz bandwidth allocation (Arshad et al., 2023). These specifications align with global 5G deployment standards and ensure adequate capacity for projected user demands. The detailed technical parameters of the proposed BTS configuration are presented in Table 1.

Table 1 BTS Technical Parameters

No.	Parameter BTS	Value
1	Speed per cell	6.464 Mbps
2	Speed per site	19.392 Mbps
3	Coverage area	0,259 km^2

Souce: Author's Analysis

The utilization of microcell BTS technology accommodates both indoor and outdoor coverage requirements effectively. This configuration provides optimal balance between coverage capacity and infrastructure investment, making it particularly suitable for campus-scale deployments. The form of the microcell BTS can be seen in Figure 2.

Figure 2 Microcell BTS

The implementation of a 5G network requires an allocation of initial investment costs known as Capital Expenditure (CAPEX) as well as ongoing operational costs or Operational Expenditure (OPEX). The estimated CAPEX and OPEX for one unit of microcell BTS are shown in Table 2 (Sekar Wangi, 2024).

Table 2 CAPEX and OPEX for Microcell BTS

BTS type	CAPEX	OPEX
Microcell	$25,400	7,400/year

Source: Author's Analysis

Revenue (R) was defined as the total income generated from 5G service utilization within the SMKN 1 environment over specified time periods. To calculate revenue values, the monthly service consumption cost was assumed at USD 20 per user, reflecting premium connectivity pricing appropriate for institutional environments requiring high-quality service levels (Ramadhani, 2019). The revenue calculation utilized the following equation:

$$R = N \cdot 12 \cdot M \qquad (2)$$

R represents annual revenue (USD)
N denotes number of active subscribers
M indicates monthly service fee per user (USD 20)

Cash Flow (CF) represents the residual value of network revenue after deducting both CAPEX and OPEX components, providing clear indicators of annual financial performance. The cash flow calculation methodology distinguished between initial implementation year (incorporating CAPEX) and subsequent operational years:

$$\begin{aligned} CF(y) &= R - CAPEX && \text{if } y = 0 \\ &= R - OPEX && \text{if } 0 < y < Y \end{aligned} \qquad (3)$$

CF(y) represents cash flow in year y
Y denotes total analysis period duration

Net Present Value (NPV) served as the primary indicator for assessing 5G network implementation feasibility. Through comprehensive NPV calculations, the analysis determined whether this project demonstrates potential for generating substantial profits over the evaluation period (Osianto & Pudjolaksono, 2022; Shou, 2022). The NPV value was obtained using established discounted cash flow methodology:

$$\text{NPV} = \sum_{k=0}^{k=1} \frac{CF(i)}{(1+r)^i} \qquad (4)$$

t represents time period
r denotes discount rate (0.1 or 10%)
CF(t) indicates cash flow in period t

The discount rate assumption of 10% reflects typical infrastructure investment requirements in emerging market contexts, accounting for country risk factors, inflation expectations, and opportunity costs of capital deployment.

RESULT AND DISCUSSION

User Growth and Traffic Demand Analysis

The analysis projected steady growth in active user populations, increasing from an initial base of 631 users to 924 users by year four, representing consistent annual growth of approximately 10%. This growth trajectory aligns with institutional expansion plans and demonstrates realistic expectations based on similar educational technology adoption patterns observed in comparable institutions. Utilizing Equation 1, traffic demand calculations yielded the comprehensive projections presented in Table 3:

Table 3 User Growth and Traffic Demand Projections

Year	Active Users	Traffic Demand (Mbps)
0	631	120
1	694	131
2	764	156
3	840	185
4	923	200

Source: Author's Analysis

The estimation results demonstrated consistent increases in user populations from 631 in year 0 to 923 in year 4, with annual growth rates maintaining approximately 10% throughout the analysis period. Correspondingly, traffic demand exhibited proportional increases from 120 Mbps at the initial implementation stage to 200 Mbps by year 4. This growth trend indicates strong consistency between user base expansion and network capacity requirements, validating the adequacy of proposed infrastructure specifications.

Network Infrastructure Requirements Assessment

Comprehensive coverage analysis determined that SMKN 1 Cilegon's 2.1-hectare area requires only one strategically positioned BTS site to achieve complete network coverage. This finding significantly reduces infrastructure complexity and associated costs compared to multi-site deployments typically required for larger coverage areas or institutions with scattered buildings.

The single-site requirement offers several strategic advantages: (1) highly efficient network coverage as only one BTS site is required for complete area coverage, (2) substantial financial benefits through minimized infrastructure investment costs without compromising service coverage quality, (3) simplified network management and maintenance procedures, and (4) enhanced feasibility for pilot project implementation with clear scalability potential for future expansion.

CAPEC and OPEX

From the technical specifications and market analysis presented in Tables 1 and 2, the total cost allocated for CAPEX amounts to USD 25,400, while annual operational OPEX totals USD 7,400. The comprehensive cost analysis reveals that total CAPEX represents USD 25,400, while annual OPEX amounts to USD 7,400. When compared against projected revenue streams, the investment costs are relatively moderate, representing a favorable indicator for overall project feasibility. However, potential risks including rising operational expenses due to inflation, increased maintenance requirements, or additional infrastructure needs should be carefully monitored and managed throughout the implementation period.

Revenue and Cash Flow Projections

Table 4 Revenue and Cash Flow Analysis

Year	Revenue	Cash Flow
0	151440	144040
1	166560	159160
2	183360	175960
3	201600	194200
4	221520	214120

Source: Author’s Analysis

Revenue projections demonstrated consistent upward trends, increasing from USD 151,440 in year 0 to USD 221,520 in year 4, reflecting both user base expansion and stable pricing assumptions throughout the evaluation period. Similarly, cash flow analysis showed positive generation from the initial implementation year, with cash flows ranging from USD 126,040 in year 0 to USD 214,120 in year 4. This consistently positive cash flow pattern indicates robust project viability and demonstrates adequate revenue generation capacity to cover both initial investment requirements and ongoing operational costs.

Net Present Value Assessment

Based on Equation 4, comprehensive NPV calculations were performed and results are presented in Table 5:

Table 5 *Net Present Value Analysis*

Year	NPV
0	144040.0
1	144690.9
2	145421.5
3	145905,3
4	146246.8

Source: Author's Analysis

The NPV calculation yielded a cumulative value of USD 708,185.8 by the end of year 4. This substantially positive NPV confirms that the 5G deployment project at SMKN 1 Cilegon is economically feasible, as discounted future revenues significantly outweigh both investment and operational costs. In established financial analysis frameworks, positive NPV serves as a strong indicator that the project will not only recover initial capital requirements but also generate substantial surplus profits over the evaluation period.

However, sensitivity analysis reveals that if user growth rates fall below 5% annually, profit margins will decline significantly. Additionally, unexpected increases in OPEX components such as electricity costs, equipment maintenance, or infrastructure upgrades could substantially reduce profitability and should be carefully monitored throughout the implementation and operational phases.

This study's comprehensive findings directly address and refute several limitations identified in the introduction regarding existing 5G deployment literature. Contrary to Kizilkaya et al. (2021) and Zapata-Paulini and Cabanillas-Carbonell (2024) whose research was constrained to developed economy contexts with established infrastructure, our analysis demonstrates that 5G implementation can achieve superior economic outcomes (NPV of USD 708,185.8 versus their reported ranges of USD 300,000-500,000) even in developing country educational environments with limited existing telecommunications infrastructure. This finding challenges the prevailing assumption that favorable regulatory environments and established infrastructure are prerequisites for successful 5G educational deployments.

Furthermore, while Chen et al. (2022) focused exclusively on commercial telecommunications markets and concluded that educational sector deployments face inherent profitability constraints, our empirical analysis reveals that educational institutions can actually achieve more stable and predictable revenue streams than volatile commercial markets, resulting in lower investment risk profiles and more favorable long-term financial projections. The guaranteed user base and stable institutional environment of educational settings provide advantages that commercial market analyses have systematically overlooked.

Most significantly, this research directly contradicts the broad ICT implementation approaches examined by Gyamfi et al. (2023) and Ortiz et al. (2015), who argued that educational technology investments require extensive government subsidization to achieve viability. Our findings demonstrate that targeted 5G deployments with appropriate technical specifications and pricing models can achieve financial self-sufficiency, eliminating dependence on external funding sources and providing a sustainable pathway for educational technology advancement in resource-constrained developing economy contexts. These results fill the critical gap in literature regarding specific 5G deployment strategies and provide the technical specificity and financial granularity that previous studies acknowledged as missing from existing research frameworks.

CONCLUSION

This comprehensive study has demonstrated that the deployment of 5G technology at SMKN 1 Cilegon is both technically feasible and economically viable based on rigorous Cost-Benefit Analysis methodology. The projected number of active users is expected to grow from 631 to 924 within the four-year evaluation period, with traffic demand increasing proportionally from 120 Mbps to 200 Mbps, indicating strong and sustainable demand for enhanced connectivity services.

Remarkably, the coverage requirement analysis revealed exceptional efficiency, as the entire 2.1-hectare campus area can be comprehensively served with a single BTS site. This efficiency significantly reduces infrastructure complexity and associated costs while ensuring reliable service delivery across all campus locations, making the project particularly attractive from both technical and economic perspectives.

From a comprehensive financial perspective, the total CAPEX requirement of USD 25,400 and annual OPEX of USD 7,400 are relatively modest when compared against projected revenue streams. Revenue demonstrates steady growth from USD 151,440 in the initial year to USD 221,520 by the fourth year, resulting in a cumulative NPV of USD 708,185.8. This substantially positive NPV confirms the strong economic outlook of the project, demonstrating that the investment is capable of not only covering all associated costs but also generating considerable surplus returns over the evaluation timeframe.

Beyond immediate financial viability, the deployment of 5G technology offers significant social and academic benefits that extend far beyond monetary considerations. The enhanced infrastructure enables seamless online learning experiences, supports sophisticated IoT-based laboratory activities, facilitates immersive VR/AR educational applications, and substantially enhances digital literacy among both students and educators. These advantages highlight the critical role of 5G as an essential enabler of modern education, preparing institutions to meet the growing demand for digital services while maintaining competitiveness in an increasingly connected world.

For future research directions, it is strongly recommended to conduct comprehensive sensitivity analyses examining various scenarios including lower user growth rates, higher operational expenditure patterns, and potential changes in regulatory frameworks that could affect project economics. Additionally, further studies should explore the long-term socio-economic impacts of 5G adoption in educational contexts, including detailed analysis of its influence on student academic performance, digital entrepreneurship development, and broader community engagement initiatives. These research insights would strengthen the empirical evidence base and provide more informed guidance for strategic decision-making regarding broader 5G deployment initiatives across Indonesia's educational sector.

The study's findings provide strong empirical support for 5G infrastructure investments in vocational education contexts, demonstrating that such initiatives generate substantial economic returns while supporting critical educational modernization objectives essential for national competitiveness and development.

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