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Analysis of Factors Affecting Cost Efficiency and Project Completion Time on the Serang-Panimbang Toll Road

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Abstract: *The implementation of innovative construction methods is essential to improve cost efficiency and project completion in infrastructure development. This study analyzes the influence of top management, human resources, engineering, and external factors on project cost efficiency, as well as the effect of project cost efficiency on project completion time in the Serang–Panimbang Toll Road Project through the implementation of the Halfslab method. A quantitative approach with a descriptive design was employed using census sampling involving 58 respondents directly involved in the project. Data were collected through questionnaires and analyzed using Structural Equation Modeling–Partial Least Squares (SEM-PLS). The results indicate that top management ($\beta = 0.273$; $p < 0.001$), human resources ($\beta = 0.344$; $p < 0.001$), engineering ($\beta = 0.272$; $p = 0.001$), and external factors ($\beta = 0.292$; $p = 0.005$) have positive and significant effects on project cost efficiency. Furthermore, project cost efficiency positively and significantly affects project completion time ($\beta = 0.540$; $p < 0.001$). Human resources were identified as the most influential factor in improving cost efficiency. These findings demonstrate that the successful implementation of the Halfslab method depends on effective managerial support, competent human resources, appropriate engineering practices, and proper management of external factors to achieve cost-efficient and timely project completion.*

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INTRODUCTION

Construction projects play a strategic role in supporting infrastructure development in Indonesia, both in the public and private sectors. Effective construction management is essential to ensure that projects are completed on time, within budget, and in accordance with established quality standards. In an increasingly competitive construction environment, cost efficiency, optimal resource utilization, and timely project completion have become important indicators of project success. Nevertheless, construction projects frequently face various problems, including cost overruns, delays, inefficient resource utilization, and difficulties in controlling project implementation. These conditions indicate the importance of selecting appropriate construction methods and managing the factors that influence project performance.

One of the infrastructure projects currently being developed is the Serang–Panimbang Toll Road, which has an important role in improving connectivity and supporting economic activities in the Banten region. The Serang–Panimbang Toll Road consists of several construction packages with relatively ambitious completion targets. In Section III, Phase 2, the construction project involves significant structural work, particularly elevated concrete structures. The implementation of this project therefore requires effective management of time, cost, resources, and technical aspects to achieve the predetermined project objectives.

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In response to the demand for more efficient construction implementation, an innovation was introduced through a design and construction method change from the conventional Fullslab system to the Halfslab Precast system. The application of the Halfslab method provides several potential advantages, including the use of precast components, reduced on-site formwork, easier installation, and the potential to reduce construction time and costs. However, the implementation of this method also creates new technical and managerial requirements because changes occur in joint details, erection procedures, reinforcement installation, and in-situ concrete casting. Consequently, the success of the Halfslab method cannot be determined solely by the technical design but is also influenced by managerial, human resource, and external factors.

From a construction management perspective, top management support is important in determining the success of project implementation because management is responsible for strategic decision-making, resource allocation, coordination, and policy direction. Ahmed et al. (2016) demonstrated that top management support has a positive relationship with project success, while Ngwai et al. (2019) showed that project management practices influence construction cost control. These findings indicate that managerial support and project management practices are important in controlling project performance, particularly in relation to cost and resource utilization.

Human resources are also an important factor in construction project performance. The implementation of the Halfslab Precast method requires workers and project personnel who possess adequate technical competence, experience, and understanding of precast installation procedures. Primantari et al. (2025) emphasized the important role of human resource management in improving time and cost efficiency in construction projects. In addition, technical factors such as design accuracy, construction methods, material quality, and implementation procedures can affect the effectiveness of construction innovations. Research by Ramadhan & Kurniasari (2024) demonstrates that Value Engineering can contribute to construction cost savings, while Sugiono & Winarno (2023) indicate that the implementation of construction innovation is influenced by the technical capabilities and experience of project implementers.

In addition to internal factors, construction projects are also influenced by external conditions. Weather, material availability and prices, site accessibility, and other external conditions may disrupt project activities and subsequently affect project performance. Rogalska et al. (2008) highlighted the relationship between time and cost in construction project scheduling, while Wijaya (2021) examined the influence of external factors on construction project overhead costs. Suryawinata (2024) also identified external conditions, including material prices, government policies, and project site conditions, as factors that can influence construction cost control. These studies demonstrate that project performance is influenced by a combination of internal and external factors rather than by a single determinant.

Although previous studies have examined project management, human resources, technical factors, external factors, cost efficiency, and project time, most studies have focused on these factors separately or within conventional construction project contexts. Previous research has not adequately explained how top management, human resources, engineering factors, and external factors simultaneously influence project performance in the specific implementation of the Halfslab Precast method. Furthermore, research that integrates these factors into a single empirical model and examines their relationship with project completion time in a major toll road infrastructure project remains limited. The existing literature therefore leaves a research gap concerning the integrated analysis of managerial, human resource, technical, and external factors in the implementation of Halfslab Precast, particularly in the context of the Serang–Panimbang Toll Road.

The research gap is further strengthened by the fact that the change from Fullslab to Halfslab is not merely a technical design modification but also represents a construction management innovation that may affect resource utilization, project cost, work productivity, and completion time. Therefore, analyzing the Halfslab method only from a technical perspective is insufficient to explain its overall effectiveness. An integrated approach is required to identify the factors that contribute to project performance and to understand the relationship between project completion time and cost efficiency.

The novelty of this study lies in developing an integrated analytical model that examines the influence of top management, human resources, engineering, and external factors in the implementation of the Halfslab Precast method on the Serang–Panimbang Toll Road. Unlike previous studies that tend to examine cost efficiency, project management, technical innovation, or external factors separately, this study integrates these dimensions into one empirical model using Structural Equation Modeling–Partial Least Squares (SEM-PLS). The study therefore provides a more comprehensive perspective on the implementation of Halfslab Precast by connecting managerial, human resource, technical, and external aspects with project performance. This approach is expected to contribute both theoretically and practically to the development of construction management strategies for improving project efficiency and completion performance.

Based on the background and research gap described above, this study aims to analyze the influence of top management, human resources, engineering, and external factors on project performance and to examine the relationship between project completion time and cost efficiency in the implementation of the Halfslab Precast method on the Serang–Panimbang Toll Road.

Based on the foregoing background, the research problems can be formulated as follows:

1. How do top management, human resources, engineering, and external factors affect project completion time using the Halfslab Precast method on the Serang–Panimbang Toll Road?
2. How does project completion time affect project cost efficiency using the Halfslab Precast method on the Serang–Panimbang Toll Road?

Thus, this study is expected to provide empirical evidence regarding the factors that influence project performance in the implementation of the Halfslab Precast method and to provide practical recommendations for project managers in optimizing construction time and cost efficiency.

RESEARCH METHOD

This study employs a quantitative method with a descriptive approach. According to (Sugiyono, 2016), quantitative research is a research method grounded in the philosophy of positivism that tests hypotheses through the analysis of numerical data. The variables in this study were measured using indicators developed and adapted from relevant construction project management literature to the context of Halfslab implementation. Top Management was measured through management support, strategic decision-making, resource and budget allocation, and coordination; Human Resources through workforce competence, skills, experience, productivity, and coordination; Engineering through design, construction methods, technical specifications, working drawings, and implementation practices; External Factors through weather, site conditions, project access, material mobilization, price changes, and external policies; Project Cost Efficiency through the optimization of project costs and the use of labor, materials, and equipment without compromising quality; and Project Completion Time through the achievement and control of the project completion schedule. The indicators were measured using a five-point Likert scale and were contextualized based on relevant literature, including Amran (2019), Ahmed et al. (2016), and Belferik et al. (2023). The respondents consisted of 58 professionals, including estimators, project managers, site managers, quality control personnel, and supervisors, who were directly involved in the project, with total sampling applied. SEM-PLS using SmartPLS 3.2.9 was employed because the study examines multiple latent constructs measured by several indicators and their structural relationships simultaneously, allowing the measurement and structural models to be evaluated within an integrated analytical framework.

RESULTS AND DISCUSSION

Outer Model

Validity Test

Based on the PLS method, the validity of reflective indicators can be tested in two stages. The first stage convergent validity testing is a validity test based on the factor loadings of each construct, and the next stage is discriminant validity testing, which is a validity test based on comparison.

Table 1. Results of the Convergent Validity Analysis

	Project Cost Efficiency	External	Top Management	Human Resources	Engineering	Completion Time
BP_1	0.809					
BP_2	0.807					
BP_3	0.932					
BP_4	0.920					
BP_5	0.796					
BP_6	0.846					
BP_7	0.914					
BP_8	0.898					
BP_9	0.957					
BP_10	0.909					
EKS_1		0.889				
EKS_2		0.881				
EKS_3		0.853				
EKS_4		0.863				
EKS_5		0.880				
EKS_6		0.831				
EKS_7		0.872				
EKS_8		0.840				
EKS_9		0.844				
EKS_10		0.920				
MP_1			0.923			
MP_2			0.865			

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MP_3	0.898			
MP_4	0.870			
MP_5	0.852			
MP_6	0.873			
MP_7	0.880			
MP_8	0.808			
MP_9	0.824			
MP_10	0.769			
SDM_1		0.948		
SDM_2		0.828		
SDM_3		0.919		
SDM_4		0.861		
SDM_5		0.900		
SDM_6		0.859		
SDM_7		0.909		
SDM_8		0.898		
SDM_9		0.804		
SDM_10		0.874		
TK_1			0.911	
TK_2			0.834	
TK_3			0.857	
TK_4			0.858	
TK_5			0.901	
TK_6			0.850	
TK_7			0.825	
TK_8			0.845	
TK_9			0.861	
TK_10			0.799	
WPP_1				0.808
WPP_2				0.807
WPP_3				0.932
WPP_4				0.920
WPP_5				0.796
WPP_6				0.846
WPP_7				0.914
WPP_8				0.898
WPP_9				0.957
WPP_10				0.909

Based on the results of the convergent validity test, which included outer loading values, all indicators under the variables of Manajeen Puncak, Human Resources, Engineering, Land, External Factors, Project Cost Efficiency, and Project Completion Time were deemed valid. This is indicated by the outer loading values for each indicator, which are above 0.70, thereby meeting the validity criteria according to (Ghozali & Latan, 2015) and (Santosa, 2018). Although some literature, such as Chin (1998) and Rivard & Huff (1988), permits the use of indicators with loadings between 0.60 and 0.70 or even greater than 0.50 under certain conditions all indicators in this study have exceeded the minimum threshold of 0.70, thereby further strengthening the construct's convergent validity.

The second stage of validity testing is discriminant validity testing. This test is based on the cross-loading values of the measurements with the construct and the Average Variance Extracted (AVE) value. Cross-loading factors are used to determine whether latent variables have adequate discriminant power by comparing the correlations between indicators and other latent variables (Yamin, 2009). If the correlation between a construct and its measurement items is greater than the correlation with other constructs, this indicates that the latent construct better predicts the measures in its own block than those in other blocks, and the construct is said to have high discriminant validity. The following are the results of the discriminant validity based on the cross-loading values between the indicators and their respective constructs:

Table 2. Results of the Discriminant Validity Analysis Test

	Project Cost Efficiency	External	Top Management	Human Resources	Engineering	Completion Time
BP_1	0.809	0.772	0.809	0.856	0.844	0.808
BP_2	0.807	0.689	0.795	0.796	0.794	0.807
BP_3	0.932	0.870	0.929	0.891	0.917	0.932
BP_4	0.920	0.871	0.910	0.885	0.917	0.920
BP_5	0.796	0.721	0.789	0.805	0.762	0.796
BP_6	0.846	0.827	0.827	0.856	0.813	0.846
BP_7	0.914	0.886	0.876	0.899	0.864	0.914
BP_8	0.898	0.863	0.891	0.884	0.867	0.898
BP_9	0.957	0.914	0.937	0.941	0.939	0.957
BP_10	0.909	0.860	0.894	0.872	0.909	0.909
EKS_1	0.851	0.889	0.865	0.841	0.845	0.851
EKS_2	0.788	0.881	0.790	0.774	0.790	0.788
EKS_3	0.772	0.853	0.740	0.783	0.768	0.771
EKS_4	0.802	0.863	0.785	0.785	0.769	0.802
EKS_5	0.818	0.880	0.796	0.783	0.810	0.818
EKS_6	0.819	0.831	0.794	0.821	0.772	0.819
EKS_7	0.823	0.872	0.802	0.807	0.776	0.824
EKS_8	0.828	0.840	0.837	0.838	0.832	0.828
EKS_9	0.790	0.844	0.765	0.790	0.793	0.790
EKS_10	0.877	0.920	0.854	0.868	0.860	0.877
MP_1	0.922	0.845	0.923	0.912	0.928	0.922
MP_2	0.828	0.791	0.865	0.800	0.822	0.828
MP_3	0.875	0.812	0.898	0.867	0.849	0.875
MP_4	0.874	0.860	0.870	0.875	0.856	0.874
MP_5	0.857	0.833	0.852	0.869	0.844	0.857
MP_6	0.843	0.797	0.873	0.822	0.834	0.843

MP_7	0.873	0.800	0.880	0.859	0.883	0.873
MP_8	0.798	0.721	0.808	0.796	0.748	0.798
MP_9	0.822	0.746	0.824	0.803	0.796	0.822
MP_10	0.733	0.728	0.769	0.778	0.753	0.732
SDM_1	0.940	0.860	0.940	0.948	0.931	0.939
SDM_2	0.787	0.781	0.804	0.828	0.768	0.787
SDM_3	0.902	0.867	0.900	0.919	0.892	0.902
SDM_4	0.856	0.814	0.841	0.861	0.822	0.856
SDM_5	0.886	0.844	0.867	0.900	0.856	0.886
SDM_6	0.840	0.701	0.838	0.859	0.839	0.840
SDM_7	0.905	0.888	0.896	0.909	0.906	0.905
SDM_8	0.898	0.878	0.894	0.898	0.877	0.898
SDM_9	0.795	0.780	0.770	0.804	0.792	0.795
SDM_10	0.874	0.799	0.862	0.874	0.857	0.874
TK_1	0.900	0.824	0.907	0.885	0.911	0.900
TK_2	0.808	0.815	0.809	0.781	0.834	0.808
TK_3	0.850	0.730	0.861	0.859	0.857	0.849
TK_4	0.861	0.862	0.817	0.842	0.858	0.860
TK_5	0.891	0.848	0.865	0.890	0.901	0.891
TK_6	0.837	0.771	0.838	0.832	0.850	0.837
TK_7	0.806	0.725	0.790	0.782	0.825	0.806
TK_8	0.821	0.792	0.823	0.830	0.845	0.820
TK_9	0.821	0.772	0.799	0.788	0.861	0.821
TK_10	0.786	0.761	0.787	0.800	0.799	0.786
WPP_1	0.809	0.772	0.809	0.856	0.844	0.808
WPP_2	0.807	0.689	0.795	0.796	0.794	0.807
WPP_3	0.932	0.870	0.929	0.891	0.917	0.932
WPP_4	0.920	0.871	0.910	0.885	0.917	0.920
WPP_5	0.796	0.721	0.789	0.805	0.762	0.796
WPP_6	0.846	0.827	0.827	0.856	0.813	0.846
WPP_7	0.914	0.886	0.876	0.899	0.864	0.914
WPP_8	0.898	0.863	0.891	0.884	0.867	0.898
WPP_9	0.957	0.914	0.937	0.941	0.939	0.957
WPP_10	0.909	0.860	0.894	0.872	0.909	0.909

The table above shows the cross-loading values of each indicator on the variables used in this study, and all indicators met the criteria because they had loading values above 0.70 on their original constructs, and were therefore considered good or reflective according to the criteria set by Ghozali & Latan (2015). This confirms that each indicator better represents the variable it measures compared to other variables, meaning that all constructs have met the criteria for discriminant validity and are suitable for further analysis.

Reliability Test

A reliability test is an assessment designed to determine the extent to which a measurement instrument can be relied upon or trusted. A measurement instrument is considered reliable when it consistently measures a construct and produces stable and consistent results across repeated measurements (Hair et al., 2022). Based on the PLS method, the reliability of the indicators in this study was determined from the composite reliability and Cronbach's alpha values for each block of indicators. As a rule of thumb, the alpha or composite reliability value should be greater than 0.7, although a value of 0.6 is still acceptable.

Tabel 3. Hasil Uji Cronbach Alpha dan Composite Reliability

	Cronbach's Alpha	rho_A	Composite Reliability	Average Variance Extracted (AVE)
Project Cost Efficiency	0.967	0.969	0.972	0.775
External	0.963	0.964	0.968	0.753
Top Management	0.960	0.961	0.965	0.735
Human Resources	0.968	0.969	0.972	0.776
Engineering	0.959	0.960	0.964	0.730
Completion Time	0.967	0.969	0.972	0.775

The table above shows the results of the Cronbach's alpha and composite reliability tests, in which all values for the variables meet the minimum test requirements and are reliable, making them suitable for use in hypothesis testing.

Inner Model

Test of the Coefficient of Determination/R-Square (R^2)

Table 4. R-Square Test Results

	R Square	R Square Adjusted
Project Cost Efficiency	0.988	0.987
Completion Time	0.976	0.975

The R-squared value for the Project Cost Efficiency variable is 0.988, indicating that 98.8% of the Project Cost Efficiency variable can be explained by the variables Top Management, Human Resources, Engineering, and External Factors. The R-squared value for the Project Completion Time variable is 0,976, indicating that 97,6% of the Project Completion Time variable can be explained by the Project Cost Efficiency variable.

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F-Test

Tabel 5. Uji F Square Result

	Project Cost Efficiency	External	Top Management	Human Resources	Engineering	Completion Time
Project Cost Efficiency						344049.002
External	0.094					
Top Management	0.208					
Human Resources	0.358					
Engineering	0.279					
Completion Time						

Based on the results of the f-square analysis in the table above, it is evident that the Top Management variable has an f^2 value of 0.208, indicating a moderate effect on Project Cost Efficiency. The Human Resources variable has an f^2 value of 0.358, indicating a significant effect on Project Cost Efficiency. Furthermore, the Engineering variable has an f^2 value of 0.279, indicating a large effect on Project Cost Efficiency, while the External variable has an f^2 value of 0.094, indicating a small effect on Project Cost Efficiency. The Project Cost Efficiency variable has an f^2 value of 344,049.002 with respect to Completion Time, indicating a very significant influence.

T-Test

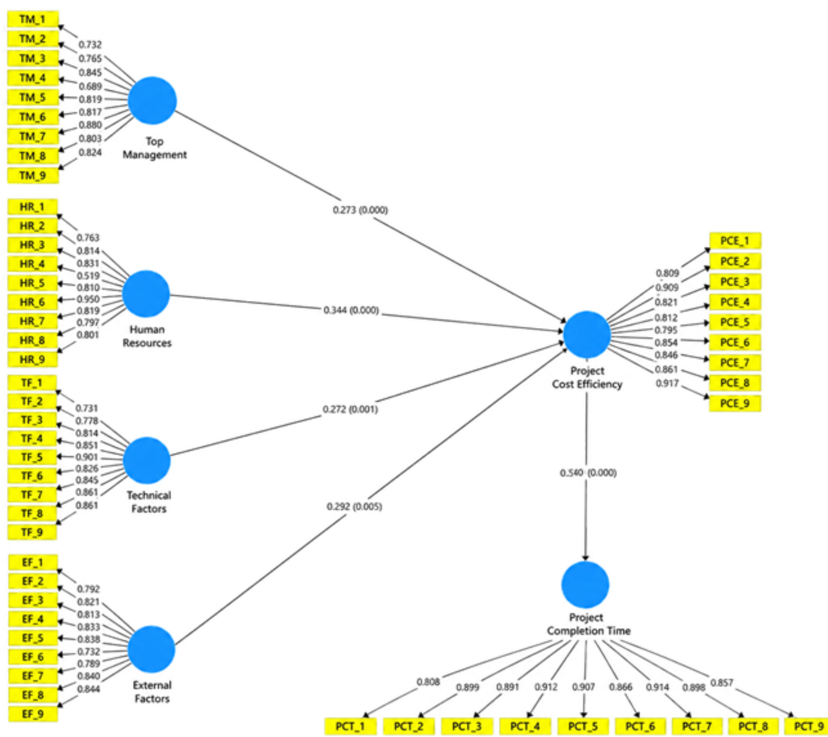

Figure 1. Inner Model

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Table 6. Statistical Test Results

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
Top Management → Project Cost Efficiency	0.273	0.271	0.048	5.722	0.000
Human Resources → Project Cost Efficiency	0.344	0.371	0.088	4.166	0.000
Engineering → Project Cost Efficiency	0.272	0.272	0.079	3.423	0.001
External → Project Cost Efficiency	0.292	0.093	0.034	2.850	0.005
Project Cost Efficiency → Completion Time	0.540	0.538	0.095	5.684	0.000

The results show that top management has a positive and significant effect on project cost efficiency. This finding indicates that the implementation of the Halfslab method is not solely determined by the technical advantages of the construction method, but also by the extent to which project management provides strategic support for its implementation. In other words, a technically efficient construction method will not automatically produce cost efficiency if management is unable to provide timely decisions, adequate resources, and effective coordination.

In the Serang–Panimbang Toll Road Project, top management plays an important role because the implementation of the Halfslab method involves changes in construction procedures, resource allocation, coordination between project divisions, and adjustments to work planning. Management support allows these changes to be implemented consistently rather than being treated as isolated technical adjustments. Effective decision-making can also reduce waiting time, prevent unnecessary resource use, and minimize rework caused by unclear instructions or delayed approvals. Therefore, the contribution of top management to cost efficiency can be understood primarily through its ability to create an organizational environment that supports the efficient implementation of the Halfslab method.

This finding is consistent with Ahmed et al. (2016), who found that multidimensional top management support contributes positively to project success. The finding is also in accordance with Ngwai et al. (2019), who demonstrated that appropriate project management practices can strengthen construction cost control. Similarly, Pratiwi et al. (2026) and Kerzner (2025) emphasize that construction and project management involve planning, organizing, directing, controlling resources, and making decisions to achieve project objectives in terms of cost, time, and quality. Thus, the present study strengthens previous findings by demonstrating that top management support remains important when a construction project adopts a design and construction-method innovation such as Halfslab.

Human Resources Affect Project Cost Efficiency Using the Halfslab Method on the Serang-Panimbang Toll Road

Human resources have a positive and significant effect on project cost efficiency and represent the strongest influence among the independent variables examined in this study. This result indicates that workforce competence is a particularly important determinant of whether the technical and economic potential of the Halfslab method can be achieved in practice.

The dominant role of human resources can be explained by the characteristics of Halfslab construction itself. Although the use of precast elements can simplify several activities at the construction site, the method still requires workers and project personnel who understand installation procedures, reinforcement arrangements, erection sequences, quality requirements, and coordination between precast production and on-site activities. Workers with adequate experience and technical competence are more capable of executing these activities correctly at the first attempt. Consequently, the possibility of installation errors, material waste, idle time, and rework can be reduced. Cost efficiency is therefore not simply a consequence of using a more efficient construction method; it also depends on the ability of the workforce to operate that method correctly.

This finding supports Primantari et al. (2025), who emphasize the importance of human resource quality in improving time and cost efficiency in construction projects. It is also consistent with Belferik et al. (2023), who explain that successful project implementation requires the integration and effective utilization of available resources, including human resources. The present study provides a more specific application of this argument by showing that workforce competence becomes particularly important when a project introduces a construction innovation that changes the conventional work process.

The finding also has an important managerial implication. Investment in workforce competency should be considered part of the cost-efficiency strategy rather than merely an additional project cost. Technical training, experience sharing, clear work procedures, and effective coordination can reduce errors and improve productivity. In the context of the Serang–Panimbang Toll Road Project, strengthening the competence of personnel involved in precast production and Halfslab installation can therefore help ensure that the expected economic benefits of the method are achieved consistently.

Engineering Factors Affect Project Cost Efficiency Using the Halfslab Method on the Serang–Panimbang Toll Road

Engineering factors also have a positive and significant effect on project cost efficiency. This result demonstrates that cost efficiency in the Halfslab implementation is closely associated with the quality of technical planning and execution. The use of Halfslab does not automatically guarantee lower costs; the expected efficiency depends on whether the design, drawings, material specifications, joint details, erection procedures, and site implementation are technically appropriate.

The relationship is particularly relevant because the transition from Fullslab to Halfslab changes several aspects of construction execution. The project must accommodate precast elements, erection activities, reinforcement installation, joint details, and in-situ concrete work. When these elements are properly planned and coordinated, construction activities can become more controlled and predictable. Conversely, technical inaccuracies may generate additional work, material waste, installation problems, or rework, which can reduce the economic benefits of the innovation.

This finding is consistent with Belferik et al. (2023), who emphasize that project performance depends on the efficient integration of technical resources and implementation processes. It is also in line with Ramadhan & Kurniasari (2024), whose research shows that Value Engineering can be used to identify opportunities for construction cost savings. Sugiono & Winarno (2023) further demonstrate that the success of construction innovation is influenced by the technical capabilities and experience of project implementers. The present study extends these findings by showing that technical capability is also relevant to the cost efficiency of Halfslab implementation on a toll-road project.

Therefore, engineering should be understood as an important mechanism linking construction innovation to economic efficiency. Accurate technical planning, appropriate drawings, quality control, and proper erection procedures help ensure that the intended reduction in resources and construction activities is actually achieved. The practical implication is that any future implementation of Halfslab should be preceded by adequate technical preparation and coordination between design, precast production, and field execution teams.

External Factors Affect Project Cost Efficiency Using the Halfslab Method on the Serang–Panimbang Toll Road

The results indicate that external factors have a positive and significant effect on project cost efficiency, although their influence is weaker than that of top management, human resources, and engineering. This finding suggests that external conditions do not determine cost efficiency as strongly as internal project capabilities, but they remain important because construction activities are directly exposed to conditions that cannot be fully controlled by the project team.

External factors in construction may include weather conditions, site accessibility, material mobilization, fluctuations in resource prices, and changes in external policies or conditions. These factors can interrupt work activities, reduce labor productivity, delay material delivery, or increase operational expenditure. Consequently, effective management of external conditions can help prevent disruptions that would otherwise reduce the efficiency gained from the Halfslab method.

This finding is consistent with Rogalska et al. (2008), who emphasize the importance of external conditions in construction scheduling and time-cost optimization. Senouci et al. (2018) also identify weather conditions as a project risk that can contribute to delays, while Dong et al. (2025) demonstrate that weather variables such as temperature, humidity, rainfall, and wind can influence construction performance. In addition, Wijaya (2021) and Suryawinata (2024) show that external conditions can influence construction costs and cost control.

The relatively weaker influence of external factors should not be interpreted as meaning that they can be ignored. Rather, the finding suggests that external factors are more effectively managed through anticipation and mitigation than through direct control. In the Serang–Panimbang project, maintaining material access, adjusting work activities to weather conditions, and planning mobilization can reduce downtime and unnecessary operational costs. Thus, external-factor management complements the internal capabilities of management, human resources, and engineering in maintaining the efficiency of Halfslab implementation.

Project Cost Efficiency Affects Project Completion Time Using the Halfslab Method on the Serang–Panimbang Toll Road

The results further demonstrate that project cost efficiency has a positive and significant relationship with project completion time. This finding indicates that cost efficiency and time performance should not be viewed as two completely separate project objectives. In the implementation of the Halfslab method, more efficient utilization of labor, materials, equipment, and temporary works can simultaneously contribute to faster construction execution.

The mechanism underlying this relationship can be observed in the changes from Fullslab to Halfslab construction. The use of precast elements allows part of the structural production process to be performed outside the main work area. At the same time, the reduction in conventional formwork and shoring requirements simplifies several on-site activities. These changes can shorten work cycles and reduce the amount of labor and equipment required for certain activities. Consequently, the same factors that generate cost efficiency can also contribute to faster project execution.

This finding is consistent with Sari et al. (2025), who argue that effective cost control and resource management are important components of operational efficiency and successful project delivery. Tanuwihardjo & Anondho (2024) similarly show that optimization of time and cost is closely connected in construction project implementation, while Tarukan (2024)emphasizes that efficient cost management aims to optimize resource utilization. The finding is also consistent with Saga & Karim (2025), who demonstrate the importance of managing the time-cost relationship in improving construction project effectiveness. Lestiyono (2025) further shows that construction time and resource utilization are closely related to project cost efficiency.

The project-level calculation provides additional evidence for this relationship. Although the direct saving obtained from each repeated work unit is relatively small, the time reduction generated by the Halfslab method produces a much greater cumulative economic effect through the reduction of overhead costs. This demonstrates that the economic value of a construction innovation should not be evaluated solely from direct material savings. Time savings can create indirect financial benefits because a shorter construction period reduces the duration for which project overhead, equipment, labor, and other supporting resources must be maintained.

The reduction in construction duration from 461 days under the Fullslab cast-in-place approach to 250 days under the Halfslab approach illustrates this mechanism. The shorter duration is associated with the ability to produce precast components in parallel with site activities and the reduction of conventional formwork and shoring requirements. Therefore, the Halfslab method creates a form of integrated efficiency in which technical simplification, resource optimization, and schedule acceleration reinforce one another.

Discussion of Cost and Time Efficiency

The cost and time efficiency analysis was conducted by comparing the estimated cost and duration of the Fullslab cast-in-place method with those of the Precast Halfslab method for the same work scope. Cost efficiency was calculated based on the difference between the Fullslab and Halfslab costs, while the efficiency percentage was obtained by dividing the cost difference by the Fullslab cost and multiplying by 100%. Similarly, time savings were calculated from the difference between the Fullslab and Halfslab construction durations, with the percentage reduction obtained by dividing the time difference by the Fullslab duration and multiplying by 100%.

For the direct construction cost, the comparison for 2 spans/MRPS resulted in a saving of Rp 4,642,505.20, equivalent to 0.034% of the corresponding Fullslab cost. This percentage is calculated as:

$$\text{Cost efficiency (\%)} = (\text{Fullslab cost} - \text{Halfslab cost}) / \text{Fullslab cost} \times 100\%$$

Thus, although the direct saving per 2 spans/MRPS is relatively small, the saving becomes economically meaningful when the same work unit is repeated throughout the project. Based on 45

MR-PS units with a length of 52.5 m, the estimated cumulative direct cost saving is Rp 208,912,734.00. This indicates that the economic benefit of the Halfslab method is influenced not only by the percentage saving per work unit but also by the number of repeated work units.

The time efficiency shows a substantially larger improvement. The Fullslab cast-in-place method requires 461 days, whereas the Precast Halfslab method requires 250 days. Therefore, the reduction in construction duration is:

$$\text{Time saving} = 461 \text{ days} - 250 \text{ days} = 211 \text{ days}$$

The percentage reduction in construction time is:

$$\text{Time efficiency (\%)} = (461 - 250) / 461 \times 100\% = 45.77\%$$

Therefore, the Halfslab method reduces the estimated construction duration by 211 days, or approximately 45.77%, compared with the Fullslab method. The reduction is attributed to the possibility of producing Halfslab precast elements before the work area at the main site is fully ready, together with reduced requirements for shoring and conventional on-site formwork. These conditions simplify the construction cycle and allow several activities to proceed more efficiently.

The cost saving associated with the reduction in construction duration was also considered through overhead efficiency. The overhead saving resulting from the 211-day time reduction was calculated at Rp 269,882,166.00 per 2 spans/MRPS. When this amount is combined with the direct cost saving of Rp 4,642,505.20, the total saving becomes:

Total saving = Direct cost saving + Overhead saving
= Rp 4,642,505.20 + Rp 269,882,166.00
= Rp 274,524,671.20

Based on the value reported in the project calculation, this corresponds to approximately 2.02% of the relevant Fullslab cost. For the 45 spans @ 52.5 m scope, the detailed calculation before rounding gives a total potential saving of Rp 12,353,610,190.85.

These calculations demonstrate that the economic benefit of the Halfslab method consists of two components: (1) direct construction cost savings resulting from differences in construction methods and quantities, and (2) indirect savings arising from the reduction in project duration, particularly project overhead costs. Therefore, cost efficiency in this study should not be interpreted solely as a reduction in direct construction expenditure, but also as an improvement in resource utilization and project execution time. The results support the hypothesis that greater project cost efficiency is associated with improved project completion time.

CONCLUSION

This study concludes that the implementation of the Halfslab method on the Serang–Panimbang Toll Road Project is significantly influenced by top management, human resources, engineering, and external factors in improving project cost efficiency, with all four factors showing positive and significant effects. Among these variables, human resources have the strongest influence, indicating that workforce competence, experience, technical skills, and coordination are important in supporting the efficient implementation of the Halfslab method. Furthermore, project cost efficiency has a positive and significant effect on project completion time, indicating that improved cost efficiency is associated with more effective project execution and better achievement of the planned completion time. The cost and time analysis also shows that the application of the Halfslab method can provide greater efficiency compared with the conventional Fullslab method, reducing the construction duration from 461 days to 250 days, or by 211 days (45.77%), while the combined direct cost and overhead savings amount to Rp. 274,524,671.00 per 2 spans/MRPS, equivalent to 2.02%. Overall, these findings demonstrate that the effectiveness of the Halfslab method depends on managerial support, competent human resources, appropriate engineering practices, and effective management of external factors, so that the method can be considered a value engineering approach that integrates cost efficiency, acceleration of project completion, and more effective utilization of project resources. Therefore, project managers should strengthen management support, improve workforce competence through relevant technical training, ensure appropriate engineering planning and implementation, and anticipate external factors that may affect project execution to support the achievement of cost efficiency and timely project completion.

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