MEDIA KOMUNIKASI TEKNIK SIPIL
Jurnal Ilmu dan Terapan Bidang Teknik Sipil
BMPTTSSI
Website : mkts.sipil.undip.ac.id
e-ISSN : 2549 - 6778
doi: 10.14710/mkts.v29i2.56309

Practical Optimization of Access Road Construction Methods in Soft Soil Areas

Angga Trisna Yudhistira[1*], Teuku Faisal Fathani[1], Arief Setiawan Budi Nugroho[1], Naseem Agung Prianugroho[1], Himawan Wibisono[2]
[1]Department of Civil and Environmental Engineering, Faculty of Engineering,
Universitas Gadjah Mada
[2]PT. Pembangunan Perumahan (Persero) Tbk, Jakarta
*)angga.trisna.y@mail.ugm.ac.id

Received: 11 Juli 2023 Revised: 27 Januri 2024. Accepted: 1 Maret 2024

Abstract

In one of the smelter projects at West Kalimantan, access road construction was planned to use soil embankment above the geo-membrane layer. But this method is not highly effective considering rainfall intensity was very high in the project location. Therefore, optimization needs to be done to obtain the most effective method in terms of cost and timely accomplishment of the access road. The optimization method was done by making a comparison matrix of the output results of the running simulation schedule on software. From the several methods proposed, the duration of completion, completion costs, and resource requirements were compared and scored to get the most optimized method. Other than that, carbon emissions resulting from each method were also compared. The optimization result concluded that boulder stone layer addition with optimum quantity in the embankment is the most optimal method considering the remaining time and encountering intensive rainfall. This optimized method can result in an accelerated construction duration of 140 days, cost efficiency of 11.46%, and a reduction in carbon emissions of 44% compared to the initial method. This optimization method is expected can be applied to access road embankment projects of soft soil areas in other locations, especially in the Kalimantan region.

Keywords: *Road on soft soil, construction management, optimization, time-saving, cost reduction*

Abstrak

Pada salah satu proyek pembangunan smelter di Kalimantan Barat, direncanakan pembangunan jalan akses menggunakan timbunan tanah di atas lapisan geo-membran. Namun cara ini tidak terlalu efektif mengingat intensitas curah hujan yang sangat tinggi di lokasi proyek. Oleh karena itu, optimasi perlu dilakukan untuk mendapatkan metode yang paling efektif dari segi biaya dan penyelesaian jalan akses tepat waktu. Metode optimasi dilakukan dengan membuat matriks perbandingan hasil keluaran simulasi penjadwalan pada perangkat lunak. Dari beberapa metode yang diusulkan, durasi penyelesaian, biaya penyelesaian, dan kebutuhan sumber daya dibandingkan dan diberi skor untuk mendapatkan metode yang paling optimal. Selain itu, emisi karbon yang dihasilkan dari masing-masing metode juga dibandingkan. Dari hasil optimasi disimpulkan bahwa penambahan lapisan batu boulder dengan jumlah optimum merupakan metode yang paling optimal, mengingat waktu yang tersisa dan menghadapi curah hujan yang intensif. Metode optimal ini dapat menghasilkan percepatan durasi konstruksi selama 140 hari, efisiensi biaya sebesar 11,46%, dan pengurangan emisi karbon sebesar 44% dibandingkan dengan metode awal. Metode optimasi ini diharapkan dapat diterapkan untuk pembangunan jalan akses pada tanah lunak di lokasi lain khususnya di Kalimantan.

Kata kunci: *Jalan di atas tanah lunak, Manajemen konstruksi, Optimasi, Penghematan waktu, Penghematan biaya.*

Introduction

The challenge of construction on soft soil areas has become one of the major challenges in Indonesia. Managing construction in soft soil areas requires appropriate execution methods. The inaccuracy of project execution methods is one of the most influential factors resulting in project delays

(Rauzana & Dharma, 2022). As well as in Mempawah, West Borneo which area is mostly dominated by peat soil and soft soil (Geological Agency of the Ministry of Energy and Mineral Resources, 2019). This condition has impacted many road subgrade constructions to become unstable. In a Smelter Construction Project in West Borneo, 4.2 km road access has been designed to be constructed above the soft soil shown in Figure 1. One layer of geosynthetic layer has been recommended by the geotechnical expert to separate the existing soil and new filled soil.

Despite the design, the construction method is also critical to finishing the work on time (Andiyan *et al*., 2021). The numerous road damages that occur in West Kalimantan are mainly caused by poor construction material, relative movement of pavement layers due to unstable subgrade, poor drainage system, and improper construction methods (Hamid *et al*., 2018). This road design shown in Figure 2 has been designated to deliver construction materials such as precast concrete spun pile, reinforcement bar, and heavy equipment from the port to the site project. The timeliness of this construction work became a concern of the stakeholders. If the construction is delayed, all the successor works for smelter construction activities will also be delayed (Susanti, 2020). As the project was running, the road construction has met several obstacles. The main obstacle was regarding the land acquisition and the high intensity of rain. Due to the high intensity of rain, the soil filling and compaction cannot be carried out properly. There were too many losses because the soil in the quarry has become wet. If road construction was forced to continue, it will result in the road subgrade becoming unstable (Mamat *et al*., 2019). Hence, an optimization method needs to be done to overcome these problems.

Initial concepts and procedures were not always optimal. This is due to a number of factors, such as time constraints, data constraints, and a lack of information regarding site conditions. Therefore, there are always opportunities to optimize. In the district of Bengkalis, an office building was constructed utilizing design optimization as an example. Several reinforced concrete columns were replaced with steel columns with wide flanges in order to optimize the structure,hence 5.075% cost savings has achieved (Mirani *et al*., 2022). In another instance, the design and construction methods of the Perum Perumnas building were optimized by substituting conventional concrete structures with prefabricated structures. The result was a 7% cost reduction compared to the original design and method (Sari & Dinata, 2022).

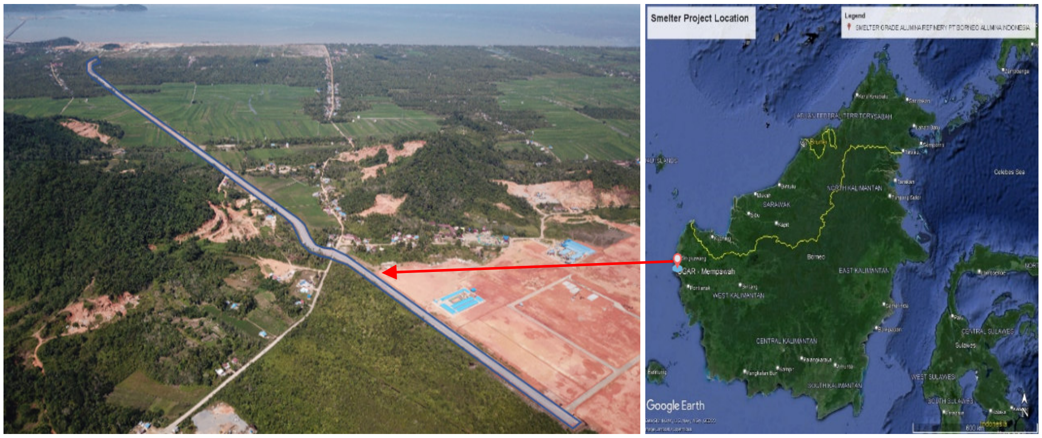


Figure 1. Project location and aerial view road access of smelter project in West Borneo

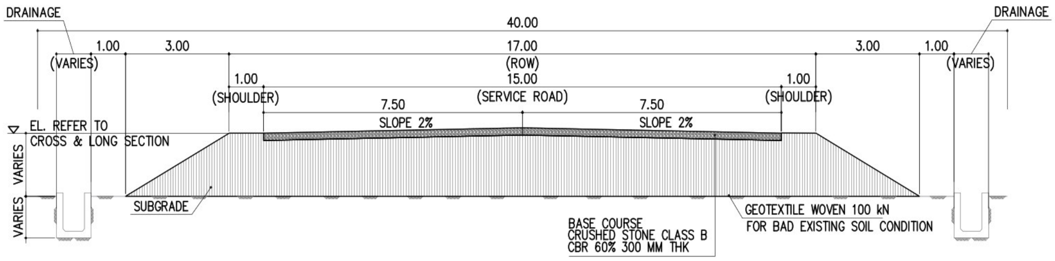


Figure 2. Typical design road construction access for smelter project in West Borneo

Optimization was also implemented in the road construction, as evidenced by the STA 198–STA 216 Lueng Gayo – Arongan Lambalek road construction project in West Aceh Regency, Aceh Province. By optimizing a number of criteria, it was possible to determine that the modified chicken claw method would result in a 10% reduction in expenses (Amir & Zakia, 2018). In Malang regency road construction, STA 2+350 to 6+300 critical path method (CPM) has adjusted with crashing procedure in order to cover up for social and weather-related delays. Consequently, the projected time for completion of the project, originally 273 days, was reduced to 184 days, representing an 89-day acceleration (Dewi & Kamandang, 2023).

Using the Fast-Track method, medium-sized houses were also built in Malang, East Java, using the same methodology. So as to achieve a 34% time savings and a 2.45% cost savings (Tjaturono, 2009). In addition to CPM, Program Evaluation and Review Technique (PERT) can be used to determine the optimal duration. The PERT method was utilized to optimize the implementation schedule of hospital project in Bogor in order to achieve a 12-day acceleration (Harjanto *et al*., 2019). The CPM and PERT methodologies can also be applied to highway and access road construction projects. Similar to how the South Japek II road was constructed. The CPM method was utilized to obtain a 31-day acceleration from the normal schedule (Irsyad *et al*., 2022).

This research investigates the effects of design and methods optimization on time, cost, and carbon emissions that have not been observed in previous research. The road construction has scheduled to finish on 5 months. But due to a land acquisition problem, the construction has been delayed for up to 4 months.

The optimization has been conducted to get the most effective and efficient construction method to deliver good road subgrade quality timely. The main idea is to increase the workability although heavy rain was occurred by replacing the material from random soil with boulder stone. The boulder stone can be found in a quarry near the project site, so the transportation cost will not increase. Therefore, the following 2 options were proposed as a result of method optimization in terms of cost, quality, and time shown in Figure 3 and Figure 4.

In addition to backfilling, boulder stones serve as construction access. A cost feasibility analysis was only applied to half of the proposed boulder stone. Option 1 involves completely substituting boulder stone for half of the soil embankment. This modification effectively mmitigates the substantial impact of heavy rainfall on the embankment. Option 2 involves halving the thickness of the boulder stones; the stone embankment is deemed adequate so long as it. enables the access of heavy equipment and dump trucks.

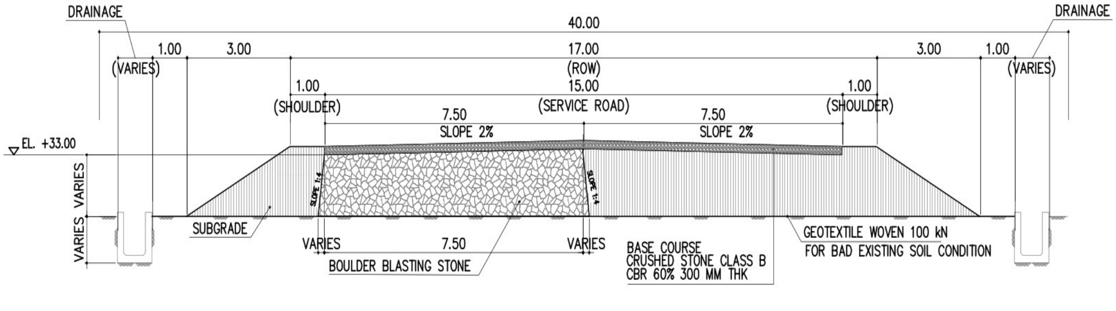


Figure 3. Modification road subgrade method with material replace – full embankment (1st option)

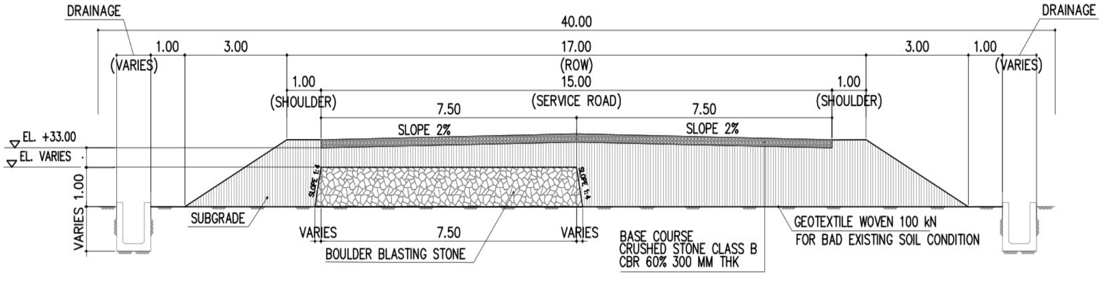


Figure 4. Modification road subgrade method with material replace – half embankment (2nd option)

Research methodology

Soil Parameter

Soil investigations have been carried out to obtain soil parameter data for road pavement design as presented in Figure 5. A total of 3 geotechnical drilling, 6 cone penetration tests, and 20 dynamic cone penetrometer tests have been carried out along the planned access road construction path. The undisturbed soil sample was then tested in the laboratory to obtain detailed soil parameters such as soil classification, shear angle, shear strength, triaxial, laboratory CBR, and consolidation.

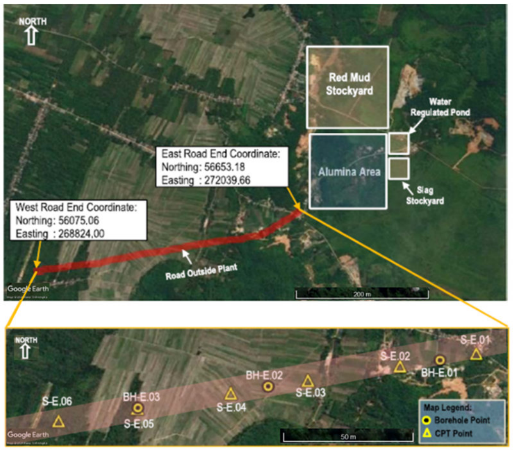


Figure 5. Satellite photograph of borehole and CPT point along the planning road access

From Figure 6., based on the results of the soil investigation, it is known that the top layer of soil is soft soil to a depth of 7-13 meters. Then the layer below is medium stiff soil at a depth of 11-35 meters. Soft soil has a low bearing capacity and a high rate of settlement. Due to soft and expansive soils, there have historically been numerous accidents on highways, railroads, slopes, water conservation, and civil buildings, resulting in significant financial losses (Wu *et al.*, 2021). In order to construct a building or road on top of it, structural strengthening techniques were required to prevent settlement and collapse of the structure above it (Acar & Mollamahmutoğlu, 2023).

Thus, to build an access road, it was necessary to replace the original material with imported soil from the local quarry. The results of laboratory testing of soil samples from the quarry have met the requirements of backfill soil. In addition to changing the soil material, additional geosynthetic layers were also needed as a barrier between the original soil (soft soil) and the new fill soil. The application of geosynthetic layers can improve the performance of pavements built on soft soils. The addition of this layer can result in a redistribution of the load to a wider area thereby reducing stress concentrations. This behavior results in less permanent deformations in the subgrade. In addition, the resilient modulus of subgrade can be increased by almost double (Farsakh *et al.*, 2016).

In the settlement analysis, the measured settlement during the opening period includes the embankment load-induced settlement and the settlement caused by traffic loading. To calculate the settlement of traffic loading accurately, it is necessary to determine the settlement amount caused by the embankment (Wu *et al.*, 2022). Therefore the settlement due to road embankment has been calculated as shown in Figure 7. This settlement analysis is based on soil parameters in Table 1 which were obtained from soil investigation.

From the results of the analysis it was found that the safety factor in embankments without a geosynthetic layer was 1.70, whereas with the addition of a geosynthetic layer it was 1.84 in static condition. Meanwhile the settlement caused by consolidation was 18.04 cm, and it remained unaffected by the addition of the geosynthetic layer. The safety factor has already met the minimum requirement for permanent construction that is 1.50 and the maximum settlement due to consolidation was 25 cm (Indonesian Standardization Agency, 2017).

Table 1. Soil parameters for embankment stability and settlement analysis

Depth (m)	Layer Name	Consistency	*Weight Volume (kN/m^3)*	*Undrained Shear Strength s_u (kPa)*	*Internal Friction Angle (°)*	*Poisson's Ratio, ν*	*Effective Modulus E' (kPa)*	C_C	C_S	e_o	*OCR*	k_v (m/s)
-	Fill Material	Medium Stiff	16.5	67	-	0.30	9380	-	-	-	-	5×10^{-8}
0 - 7.5	Fat Clay	Very Soft to Soft	15.0	16	-	0.35	2240	0.47	0.047	1.3	2.0	1×10^{-8}
7.5 - 9	Silt	Medium Stiff	16.0	40	-	0.30	5600	-	-	-	-	1×10^{-8}
9 - 11	Sandy Silt	Stiff	17.0	100	-	0.30	14000	-	-	-	-	1×10^{-8}
11 - 25	Sandy Silt	Very Stiff	18.0	174	-	0.30	24360	-	-	-	-	1×10^{-8}
25 - 30	Granite	Hard	18.0	335	-	0.30	46900	-	-	-	-	1×10^{-8}

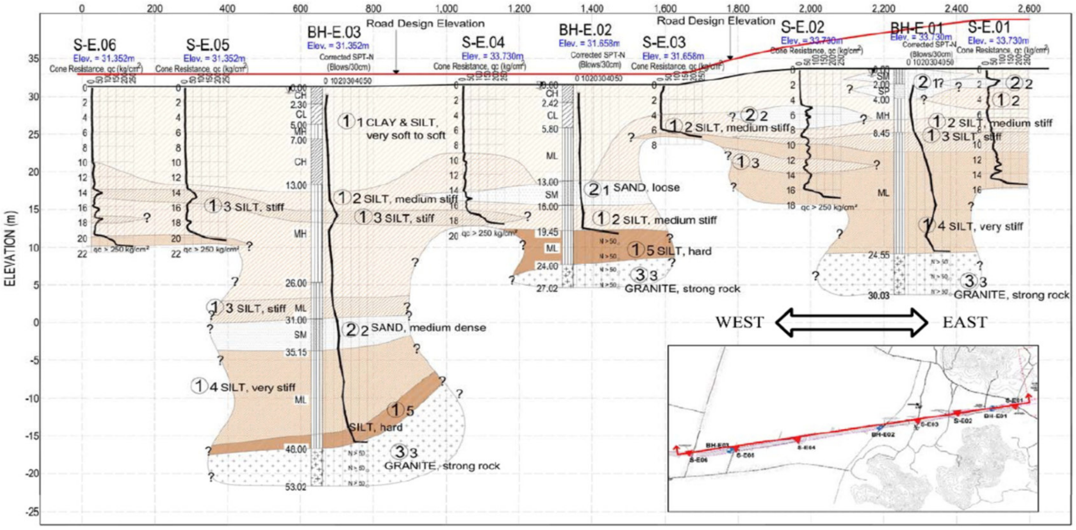


Figure 6. Subsurface cross section along the planning road access based on soil investigation result

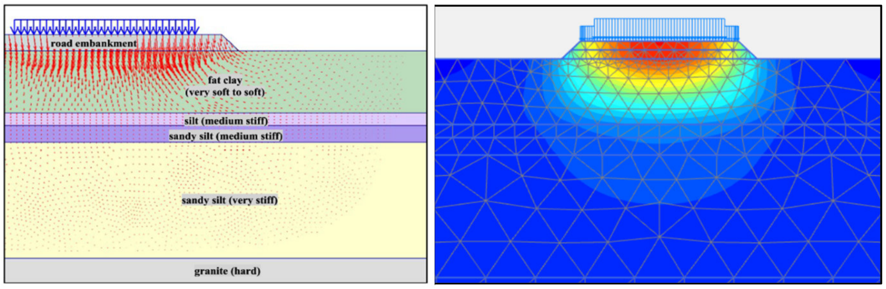


Figure 7. Road embankment model and displacement simulation analysis result

Rainfall historical data

Delay in the execution phase of road construction is one of the major challenges, especially in project locations with soft soil characteristics (Ghaleh *et al*., 2021). A lot of factors were affecting delay in the field, based on research using Delay Risk Assessment Models (DRAMs) shows that weather conditions and late land acquisition were the most probable and severe delay factors (Antoniou, 2021).

On the East coast of Malaysia, risk assessment was done using the Analytic Hierarchy Process (AHP) method, in which the analysis result shows that project risk becomes the major reason factor for the delay that happens because of land acquisition issues, environmental, the uncertainty of the weather, operational risk, and late approval of construction drawing (Razi *et al*., 2021).

Based on data from the Indonesian Meteorological, Climatological, and Geophysical Agency (BMKG) shown in Table 2, the average rainfall from 2013 to 2017 in Sungai Kunyit Area from August – December is quite high, above 150 mm/month. It even reached 330 mm in November. The highest number of rainy days is in November, which was 15.6 rainy days in a month. This condition resulted in the road construction process scheduled for August – December could not be carried out properly. Soil embankment cannot be carried out when it rains, so a lot of idle time occurs, progress were delayed and the target were not achieved.

Resources availability

Besides land acquisition and weather conditions, material shortage and poor productivity become major factors that cause project delays (Reddy & Rao, 2022). The availability of the Dump Truck (DT) in the Project area was quite abundant. The majority of DTs were owned by residents to serve supply demand from the quarry to the project area. Therefore the availability of DT will not be an obstacle in the effort to accelerate construction. However, the large demand from other projects causes the supply of materials to the project to become one of the main concerns. Therefore, mapping of material provider resources and binding contracts was carried out in the early stages to anticipate low productivity in material delivery. The availability of material can be seen in Figure 8.

Table 2. Rainfall historical data in kunyit river area (BMKG, 2018)

Years	Month (mm)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2013	260	324	36	233	213	52	415	192	128	131	245	442
2014	59	0	152	112	169	44	34	293	258	122	203	343
2015	400	115	107	84	147	145	110	48	159	213	556	226
2016	365	132	60	48	449	178	226	95	128	259	434	281
2017	245	149	72	98	77	148	245	235	206	122	212	111
Total	**1329**	**720**	**427**	**575**	**1055**	**567**	**1030**	**863**	**879**	**847**	**1650**	**1403**
Average	**265.8**	**144**	**85.4**	**115**	**211**	**113.4**	**206**	**172.6**	**175.8**	**169.4**	**330**	**280.6**

Years	Month (total rainy days)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2013	8	10	3	9	7	4	10	7	6	8	14	19
2014	6	0	8	7	8	7	3	15	11	7	14	15
2015	19	10	7	8	9	6	8	5	3	12	18	13
2016	12	10	9	9	17	10	9	3	9	18	17	14
2017	16	9	9	7	10	5	11	9	16	15	15	12
Total	**61**	**39**	**36**	**40**	**51**	**32**	**41**	**39**	**45**	**60**	**78**	**73**
Average	**12.2**	**7.8**	**7.2**	**8**	**10.2**	**6.4**	**8.2**	**7.8**	**9**	**12**	**15.6**	**14.6**

No	Quarry Owner	Distance (km)	Material
1	Quarry 1	2.5	Stone
2	Quarry 2	1.8	Stone
3	Quarry 3	2.0	Stone
4	Quarry 4	4.0	Stone
5	Quarry 5	4.6	Random Soil
6	Quarry 6	3.9	Stone
7	Quarry 7	3.3	Random Soil
8	Quarry 8	1.1	Random Soil
9	Quarry 9	3.4	Random Soil
10	Quarry 10	2.2	Random Soil

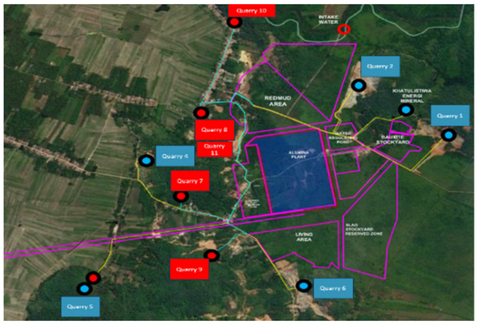


Figure 8. Available quarry around project site

	Task Name	Duration	Start	Finish
31	**Land Acquisition**	**60 days**	**Tue 23/06/20**	**Tue 01/09/20**
32	Area X	60 days	Tue 23/06/20	Tue 01/09/20
33	Area Y	60 days	Tue 23/06/20	Tue 01/09/20
34	Area Z	60 days	Tue 23/06/20	Tue 01/09/20
35	**STA 1 + 600 - STA 2 + 000**	**95 days**	**Tue 01/09/20**	**Wed 16/12/20**
36	a. Excavation	21 days	Tue 01/09/20	Thu 24/09/20
37	b. Layering Geotextile	14 days	Thu 24/09/20	Fri 09/10/20
38	c. Full Stone Access Layering	30 days	Fri 09/10/20	Thu 12/11/20
39	d. Backfilling	30 days	Thu 12/11/20	Wed 16/12/20
40	**STA 2 + 000 - STA 2 + 400**	**104 days**	**Thu 24/09/20**	**Tue 19/01/21**
41	a. Excavation	21 days	Thu 24/09/20	Sat 17/10/20
42	b. Layering Geotextile	14 days	Sat 17/10/20	Mon 02/11/20
43	c. Full Stone Access Layering	30 days	Thu 12/11/20	Wed 16/12/20
44	d. Backfilling	30 days	Wed 16/12/20	Tue 19/01/21
45	**STA 2 + 400 - STA 2 + 800**	**113 days**	**Sat 17/10/20**	**Sun 21/02/21**
46	a. Excavation	21 days	Sat 17/10/20	Tue 10/11/20
47	b. Layering Geotextile	14 days	Tue 10/11/20	Thu 26/11/20
48	c. Full Stone Access Layering	30 days	Wed 16/12/20	Tue 19/01/21
49	d. Backfilling	30 days	Tue 19/01/21	Sun 21/02/21

Figure 9. Schedule simulation using the microsoft project software with the critical path method (Option 1)

Schedule simulation and productivity analysis

Schedule planning and control are important tasks in construction project management. Furthermore, effective project management techniques are the principal to ensuring successful project performance. The application of the critical path method can improve the schedules that were used previously. Moreover, the computational times used in solving general instances of practical projects are encouraging (Zareei, 2018). The schedule simulation method in this study was carried out using the Microsoft Project software with the Critical Path Method shown in Figure 9. Productivity analysis was carried out by collecting previous historical data, taking into account several efficiency factors such as access, equipment conditions, and weather conditions. Based on this historical data the average productivity for the initial method was 6.97 m’/day, compared to 10.61 m’/day using the 1st option modified method and 11.15 m’/day for the 2nd option modified method. The study was carried out specifically on areas that have not been completed due to land problems with a length of 2,600 m.

Construction cost analysis method

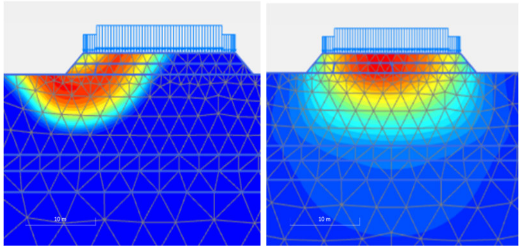
A comprehensive efficient work breakdown structure (WBS) can prove essential within project management planning processes by dividing projects into stages, deliverables, and work packages. Consequently, it can positively influence other project management processes, such as activity definition, project schedule, risk analysis and response, control tools, or project organization (Irdemoosa *et al.*, 2015).

Cost overrun and delays in the completion of road construction projects are the risks that have an impact on the economic aspect. To avoid cost increases and delays, it is necessary to take steps to reduce risk in road construction projects. Some of these steps include review and analysis of scientific works on the research topic; development of an optimization model for the distribution of investment volumes by measures to reduce the impact of risks within the road construction project; implementation of the developed model on a practical example (Sturova *et al.*, 2022). The method of calculating construction costs is done by dividing the WBS up to the level of activity using the decomposition technique. Based on the breakdown activities, all resources such as manpower, materials, and equipment can be calculated. The cost analysis result of each option will be compared to get the most efficient and optimized method. Therefore, this option can technically be implemented.

Results

Technical requirement

From the analysis result shown in Figure 10, additional boulder stone have slight impact to the soil stability. The safety factor for option 2 has reduced to 1.61 for static condition compared to 1.84 using full soil embankment. This because the boulder stone density has bigger than soil density. However the safety factor still met the standard and the consolidation settlement is 19.47 cm still below the minimum requirement 25 cm. Therefore, this option can be technically implemented.



(a) **(b)**

Figure 10. (a) Soil stability and (b) settlement analysis for Option 2

Schedule comparison simulation result

From the schedule simulation analysis, it is found that the duration of project completion with several methods is presented in Table 3. The calendar used in the schedule simulation is a 7-day work calendar with the number of working hours per day: 8 hours. Based on the simulation results above, the method that produces the fastest execution time is option 2 with a total duration of 233 days. This method provides an acceleration of 140 days from the initial method.

Table 3. Result of schedule simulation analysis for three different methods

No	Option	Duration (days)	Start date	End date
1	Initial Method	373	01-Sep-20	08-Sep-21
2	Option 1	245	01-Sep-20	03-May-21
3	Option 2 (selected)	233	01-Sep-20	21-Apr-21

Cost and resources comparison simulation results

Resource optimization is a critical issue and research domain in many fields and applications. For instance, the management and optimization of resources directly affect the cost, schedule, quality, etc., and therefore the project outcome. There are various methods to manage and optimize project resources in projects. Project network planning is an effective management practice to control construction plans and ensure the timely accomplishment of construction goals. Under certain conditions, it can optimize project resources, ensure appropriate allocation of resources in the construction of the project, thus increasing the profit from the construction of the project, and play an essential role in managing and optimizing the construction of the project (Lin *et al.*, 2022). From the results of the schedule simulation, the resource requirements for each construction method can be analyzed. The list of resource requirements for each option can be seen in Table 4. From the total resource requirements and duration, the cost of each method can be calculated, as presented in Table 5. From the cost comparison shown in Table 6, using the option 2 method, it is obtained cost efficiency of IDR 3,224,871,800 (11.46%) compared to the initial method. From the simulation results, it can be seen by optimizing the construction method the total duration of construction can be reduced. As a result, fewer resources were needed and costs can be reduced. However, there were additional material costs due to the change in the method. But overall, the selected method has the most efficient cost and resources.

Comparison matrix of method optimization result

An optimization method is an attempt to get the most optimal solution for a problem from several available options. In a construction project, optimization is very necessary, especially to get the design and implementation method with the most efficient cost and the shortest construction duration. Optimization can be done by comparing several alternative solutions with several indicators such as cost, quality, and time (Zavari *et al.*, 2022). In this study, the optimization method is done by making a comparison matrix of the output results of the running simulation schedule on Microsoft Project. From the several methods proposed, the duration of completion, completion costs, and resource requirements were compared and scored to get the most optimized method.

From the results of the analysis of schedule, cost, and resource requirements, a comparative matrix table is made to determine which method option is the most optimum. The results of the optimization comparison matrix can be seen in Table 6. The comparison Matrix shown in Table 6 is comparing 3 indicators, which are schedule, cost, and resource usage. The value used is 1 to 5, with the highest value being 5 while the value 1 being the lowest. On the schedule column, the faster the duration of the construction completion, the higher the value given.

In the cost column, the more efficient the construction costs, the higher the value given. Meanwhile, in the resource section, the fewer resources needed, the higher the value. From the comparison matrix above, it was proved that using the option 2 method is the most optimized in terms of cost, time, and resource needs.

Table 4. Comparison of resource requirements

No	Option	Duration (days)	Equipment resources	Manpower resources	Material resources
1	Initial Method	373	Excavator: 4 units Dozer D65E: 2 units Vibratory Roller: 2 units Fuel tank 8000: 1 unit Motor Grader: 1 unit Dump Truck: 20 units	51 persons	Soil Embankment: 97,289 m^3
2	Option 1	245	Excavator: 4 units Dozer D65E: 2 units Vibratory Roller: 2 units Fuel tank 8000: 1 unit Motor Grader: 1 unit Dump Truck: 16 units	44 persons	Soil Embankment: 54,124 m^3 Boulder Stone: 43,165 m^3
3	Option 2 (selected)	233	Excavator: 4 units Dozer D65E: 2 units Vibratory Roller: 2 units Fuel tank 8000: 1 unit Motor Grader: 1 unit Dump Truck: 16 units	44 persons	Soil Embankment: 75,165 m^3 Boulder Stone: 22,124 m^3

Table 5. Simulation Analysis of Implementation Costs Comparison

No	Option	Equipment Cost (IDR)	Manpower Cost (IDR)	Material Cost (IDR)	Total Cost (IDR)
1	Initial Method	16,336,049,740	2,868,370,000	8,931,130,200	28,135,549,940
2	Option 1	10,307,782,100	1,651,300,000	17,918,083,200	29,877,165,300
3	Option 2 (selected)	9,802,911,140	1,570,420,000	13,537,347,000	24,910,678,140

Resources usage and carbon emission

The recent topic of carbon emission reduction is carried out, all over the world including Indonesia is focusing to apply a sustainable environment according to Sustainable Development Goals (SDGs) which one is established Net Zero Emission. The road construction sector is contributing to emissions. A lot of factors affect the output of carbon emissions in a project planning and execution stage. Besides 14% of greenhouse gas emissions generated from the process of transporting materials in the construction process (Sandanayake *et al*., 2017). In the planning stage, there is a practical method to mitigate the environmental impact using Mass Flow Emissions (MFE) model that calculates carbon dioxide emission using mass haul optimization software. The model is applied to a road construction project where two alternate supply chain is being evaluated and compared so the option can be obtained and implemented (Krantz *et al*., 2017).

In the execution stage, using scenario analysis with a methodological framework shows that the choice of equipment and application of sustainable material significantly affect emission and project cost (Luo *et al*., 2021). In line with Luo *et al*. (2021) research, infrastructure construction equipment produces a big environmental impact. Equipment impact on air, sound, and vibration pollution near Uganda, Kampala city shows mostly emission fulfill the standard for reducing emission effect on the environment, except particulate matter. But the concentration of some CO, NO_2, and particle concentrate does not meet the safety limit of air quality around workers. All of the equipment is having noise level above recommendation 70db, except the wheel loader. On vibration criteria only excavators that produce vibration higher than the safety limit by 4% (Robinah *et al*., 2022).

In this study, the calculation of carbon emissions has been done based on Intergovernmental Panel on Climate Change (IPCC) guidelines. Every piece of heavy equipment is being analyzed in terms of CO_2 output. From the total equipment resources and duration of use, the carbon emission of each method can be calculated, as presented in Table 7. From the calculation results, using the option 2 method, it obtained an emission efficiency of 1,060,600.12 $kgCO_2$ or cut 44% of carbon emission compared to the initial method. Thus, the benefits of method optimization not only provide an acceleration of construction schedule and cost efficiency but also make a positive contribution to the environment.

Conclusions

In this study, optimization of the road construction method was carried out on soft soil locations with high rainfall intensity conditions. From the optimization analysis result, it was obtained the most efficient and optimal method from the cost, time and resources need factors. Besides that, emission impact on the environment can be minimized. Optimization was done by changing the construction method of soil embankment to boulder stone embankment with a certain volume that eliminates the delay work risk because of high rainfall intensity. Change of soil embankment to boulder stone embankment with the right volume will produce more efficient cost and optimal construction time. However, the addition of boulders results in an extra 9.42% consolidation settlement, which remains within the specified technical parameters.

Table 6. Comparison Matrix of Method Optimization

No	Option	Schedule		Cost		Resources		Total score	Rank
		Duration (days)	Score	IDR (billion)	Score	Qty (units)	Score		
1	Initial method	373	1	28	3	30	2	6	3
2	Option 1	245	3	29	2	26	3	8	2
3	**Option 2 (selected)**	**233**	**4**	**24**	**4**	**26**	**3**	**11**	**1**

Table 7. Comparison of carbon emission calculation result

Equipment	Carbon emission ($kgCO_2$)		
	Initial Method	Option 1	Option 2 (selected)
Excavator	466,085.88	306,142.20	291,147.48
Dozer D65E	501,938.64	329,691.60	313,543.44
Vibratory Roller	170,093.15	111,723.38	106,251.22
Motor Grader	101,777.02	66,850.86	63,576.53
Dump Truck	1,175,464.01	617,670.10	587,416.87
Generator set	19,121.47	12,559.68	11,944.51
Total	2,434,480.17	1,444,637.82	1,373,880.05

Based on a case study conducted on the construction of an access road in the West Kalimantan smelter project, the optimization of this road construction method can result in an accelerated construction duration of 140 days, cost efficiency of 11.46%, and a reduction in carbon emissions of 44% compared to the initial method. This optimization method is expected can be applied to access road embankment projects of soft soil areas in other locations, especially in the Kalimantan region.

Acknowledgement

The author appreciates PT. Pembangunan Perumahan Persero through a project entitled the construction of an alumina smelter factory access road in Mempawah, West Kalimantan and its willingness to publish the lessons learned from the project.

References

Acar, Y., & Mollamahmutoğlu, M. (2023). The Effect of Components' Characteristics on Rigid Inclusion System on Soft Soil. *Iranian Journal of Science and Technology - Transactions of Civil Engineering*, *47*(2), 1125–1137. https://doi.org/10.1007/s40996-022-01026-1

Agency, I. S. (2017). *Indonesian National Standard geotechnical design requirements SNI 8460:2017. 8460*, 1–323.

Amir, A., & Zakia, Z. (2018). Optimasi Biaya Pelaksanaan Konstruksi Jalan Dengan Aplikasi Rekayasa Nilai (Value Engineering). *Jurnal Teknik Sipil Dan Teknologi Konstruksi*, *1*(1), 72–83. https://doi.org/10.35308/jts-utu.v1i1.723

Andiyan, Putra, R. M., Rembulan, G. D., & Tannady, H. (2021). Construction Project Evaluation Using CPM-Crashing, CPM-PERT and CCPM for Minimize Project Delays. *Journal of Physics: Conference Series*, *1933*(1). https://doi.org/10.1088/1742-6596/1933/1/012096

Antoniou, F. (2021). Delay risk assessment models for road projects. *Systems*, *9*(3). https://doi.org/10.3390/systems9030070

Dewi, P. F., & Kamandang, Z. R. (2023). Optimizing Project Performance by Applying the Crashing Method to Road Construction Project. *Advance Sustainable Science Engineering and Technology*, *5*(2), 0230203. https://doi.org/10.26877/asset.v5i2.15944

Farsakh, A. M., Hanandeh, S., Mohammad, L., & Chen, Q. (2016). Performance of geosynthetic reinforced/stabilized paved roads built over soft soil under cyclic plate loads. *Geotextiles and Geomembranes*, *44*(6), 845–853. https://doi.org/10.1016/j.geotexmem.2016.06.009

Geological Agency of the Ministry of Energy and Mineral Resources. (2019). *Distribution of Indonesian Soft Soil*.

Ghaleh, R. M. B., Pourrostam, T., Mansour Sharifloo, N., Majrouhi Sardroud, J., & Safa, E. (2021). Delays in the road construction projects from risk management perspective. *Infrastructures*, *6*(9). https://doi.org/10.3390/infrastructures6090135

Hamid, A., Midyanti, D. M., & Marga, M. B. (2018). Kegagalan/kerusakan jalan dengan lapisan perkerasan lentur di kalimantan barat. *Seminar Nasional Penerapan Ilmu Pengetahuan Dan Teknologi (PIPT) Tahun 2018*, 1–11.

Harjanto, R., Azis, S., & Hidayat, S. (2019). The accelerating of duration and change of cost on construction project implementation. *International Journal of Civil Engineering and Technology*, *10*(1), 825–832.

Irdemoosa, E. S., Dindarloo, S. R., & Sharifzadeh, M. (2015). Work breakdown structure (WBS) development for underground construction. *Automation in Construction*, *58*, 85–94. https://doi.org/10.1016/j.autcon.2015.07.016

Irsyad, A., Puspita, I. A., & Tripiawan, W. (2022). Schedule Acceleration Planning in Construction Project (Case Study: Japek II Selatan Tollroad). *International Journal of Innovation in Enterprise System*, *6*(01), 24–37. https://doi.org/10.25124/ijies.v6i01.145

Krantz, J., Lu, W., Johansson, T., & Olofsson, T. (2017). Analysis of alternative road construction staging approaches to reduce carbon dioxide emissions. *Journal of Cleaner Production*, *143*, 980–988. https://doi.org/10.1016/j.jclepro.2016.12.023

Lin, J. C., Lv, Q., Yu, D., & Srivastava, G. (2022). Optimized scheduling of resource-constraints in projects for smart construction. *Information Processing and Management*, *59*(5), 103005. https://doi.org/10.1016/j.ipm.2022.103005

Luo, W., Sandanayake, M., Zhang, G., & Tan, Y. (2021). Construction cost and carbon emission assessment of a highway construction—a case towards sustainable transportation. *Sustainability*

(Switzerland), *13*(14). https://doi.org/10.3390/su13147854

Mamat, C. R., Kasa, A., & Razali, M. S. F. (2019). a Review of Road Embankment Stability on Soft Ground: Problems and Future Perspective. *IIUM Engineering Journal*, *20*(2), 32–56. https://doi.org/10.31436/iiumej.v21i1.996

Mirani, Z., Natalia, M., Syahputra, J., Sipil, J. T., & Padang, P. N. (2022). Penerapan Value Engineering Pekerjaan Balok, Kolom Dan Pelat Lantai (Studi Kasus: Gedung Perpustakaan Daerah Kabupaten Bengkalis). *Media Komunikasi Teknik Sipil*, *28*(1), 32–39.

Rauzana, A., & Dharma, W. (2022). Causes of delays in construction projects in the Province of Aceh, Indonesia. *PLoS ONE*, *17*(1 January), 1–12. https://doi.org/10.1371/journal.pone.0263337

Razi, P. Z., Ali, M. I., & Ramli, N. I. (2021). Exploring risk associated to public road infrastructure construction projects. *IOP Conference Series: Earth and Environmental Science*, *682*(1). https://doi.org/10.1088/1755-1315/682/1/012030

Reddy, M. V., & Rao, H. (2022). Analysing the critical delay factors and delay in material supply for construction projects in India. *Materials Today: Proceedings*, *60*, 1890–1897. https://doi.org/10.1016/j.matpr.2021.12.529

Robinah, N., Safiki, A., Thomas, O., & Annette, B. (2022). Impact Of Road Infrastructure Equipment On The Environment And Surroundings. *Global Journal of Environmental Science and Management*, *8*(2), 251–264. https://doi.org/10.22034/GJESM.2022.02.08

Sandanayake, M., Zhang, G., Setunge, S., Luo, W., & Li, C. Q. (2017). Estimation and comparison of environmental emissions and impacts at foundation and structure construction stages of a building – A case study. *Journal of Cleaner Production*, *151*, 319–329. https://doi.org/10.1016/j.jclepro.2017.03.041

Sari, Y. A., & Dinata, Y. (2022). Innovation of Prefabrication Construction Methods for Cost and Time Efficiency in The High Rise Building Project of Perum Perumnas. *Media Komunikasi Teknik Sipil*, *28*(1), 79–89. https://doi.org/10.14710/mkts.v28i1.38640

Sturova, M., Novik, A., Radaev, A., & Shangutov, A. (2022). ScienceDirect ScienceDirect Optimization model for the distribution of investment volumes by Optimization model for the distribution of investment volumes by measures to reduce the impact of risks in road construction measures to reduce the impact of risk. *Transportation Research Procedia*, *63*, 2866–2874. https://doi.org/10.1016/j.trpro.2022.06.333

Susanti, R. (2020). Cost overrun and time delay of construction project in Indonesia. *Journal of Physics: Conference Series*, *1444*(1). https://doi.org/10.1088/1742-6596/1444/1/012050

Tjaturono. (2009). Pengembangan Metode Fast-Track untuk Mereduksi Waktu dan Biaya Pelaksanaan Proyek Studi Kasus Rumah Menengah di Malang, Jawa Timur. *Media Komunikasi Teknik Sipil*, *17*(1), 39–54.

Wu, T., Jin, H., Guo, L., Sun, H., Tong, J., Jiang, Y., & Wei, P. (2022). Predicting method on settlement of soft subgrade soil caused by traffic loading involving principal stress rotation and loading frequency. *Soil Dynamics and Earthquake Engineering*, *152*(September 2021), 107023. https://doi.org/10.1016/j.soildyn.2021.107023

Wu, Y., Shi, K., Han, Y., Han, T., Yu, J., & Li, D. (2021). Experimental Study on Strength Characteristics of Expansive Soil Improved by Steel Slag Powder and Cement Under Dry–Wet Cycles. *Iranian Journal of Science and Technology - Transactions of Civil Engineering*, *45*(2), 941–952. https://doi.org/10.1007/s40996-020-00473-y

Zareei, S. (2018). Project scheduling for constructing biogas plant using critical path method. *Renewable and Sustainable Energy Reviews*, *81*(August 2017), 756–759. https://doi.org/10.1016/j.rser.2017.08.025

Zavari, M., Shahhosseini, V., Ardeshir, A., & Sebt, M. H. (2022). Multi-objective optimization of dynamic construction site layout using BIM and GIS. *Journal of Building Engineering*, *52*(April), 104518. https://doi.org/10.1016/j.jobe.2022.104518