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Assessment of Cross-Section Interval Variations for Earthwork Volume Estimation on Straight and Curved Road Alignments

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Abstract

Cross-sectional interval variations on cut and fill volume estimation for straight and curved road alignments. Unlike previous studies that focused on a single road geometry, this study compares straight and curved road sections under identical survey conditions. Data were collected using an Electronic Total Station with cross-sectional intervals of 10 m, 25 m, and 50 m, representing dense, moderate, and sparse survey sampling scenarios commonly applied in road construction projects. Earthwork volumes were calculated using the Average End Area method based on SWDTM, Microsoft Excel, and AutoCAD Civil 3D. A paired sample t-test was applied to evaluate the significance of volume differences among interval scenarios. The results show that larger cross-sectional intervals produced greater discrepancies in cut and fill volume calculations. On straight road sections, estimated fill volumes ranged from 237.050 m³ to 254.250 m³, while on curved road sections they ranged from 333.100 m³ to 360.250 m³. Statistical analysis indicated that all calculated t-values were lower than the critical t-value at the 95% confidence level, suggesting that interval variations did not produce statistically significant differences in calculated volumes. However, wider intervals generated larger practical discrepancies and relative errors. These findings indicate that a 25 m cross-sectional interval provides a practical balance between survey efficiency and earthwork volume estimation reliability for road construction projects.

Keywords: Cross-section interval, earthwork volume, road geometry, cut and fill, volume accuracy, Average End Area.

1. Introduction

Improving regional accessibility is one of the key factors supporting economic growth and infrastructure development. Road construction, as a component of land transportation infrastructure, plays a strategic role in enhancing regional connectivity, facilitating the distribution of goods and services, and supporting community mobility (Fisu et al., 2020). In road construction projects, earthwork volume calculation, particularly cut and fill volume estimation, is an essential stage because it directly affects material requirements, work efficiency, and construction costs (Azzumardi et al., 2022).

Earthwork volume calculations can be performed using several methods, including the average end area method, prismoidal method, contour method, and borrow pit method (Basuki, 2011; Firmansyah et al., 2023; Wolf and Ghilani, 2012). However, in road construction projects, the average end area method remains the most commonly applied method due to its simplicity and its ability to provide reasonably accurate results (Adi, 2017; Ghilani and Wolf, 2017). This method calculates the average area of two consecutive cross-sections and multiplies it by the distance between them (Purwati, 2020). The accuracy of the calculated volume is highly influenced by the interval distance between cross-sectional profiles used during field measurements.

Accurate earthwork volume estimation is an important factor in road construction projects because it directly affects project budgeting, material allocation, equipment utilization, and construction scheduling (AASHTO, 2018; Wati, 2023). Inaccurate volume calculations may lead to material shortages or excesses, resulting in cost overruns and reduced construction efficiency (Purwati, 2020). Therefore, the selection of appropriate cross-sectional intervals is essential to ensure reliable volume estimation results, particularly in large-scale infrastructure projects. Even relatively small errors in earthwork volume estimation can result in substantial deviations in project costs when applied to large-scale road construction projects. Overestimation may lead to excessive material allocation and increased transportation costs, whereas underestimation may cause material shortages, construction delays, and budget overruns. Therefore, improving the reliability of earthwork volume estimation is essential for effective project planning and resource management.

In practice, cross-sectional measurement intervals in the field still vary and have not yet been standardized. Using excessively large intervals may reduce the representation of actual ground surface conditions, thereby affecting the accuracy of volume calculations. Conversely, shorter intervals provide a more detailed representation of the surface but require more time and higher survey costs (Azzumardi et al., 2022; Balqis et al., 2023; Putra, 2022). This issue becomes more complex in road sections with different geometries, such as straight and curved roads, because the characteristics of elevation changes and cross-sectional shapes differ between these road types. Straight road sections generally have more uniform cross-sections, whereas curved road sections tend to exhibit more complex geometric variations that may affect volume estimation results (Azzumardi et al., 2022).

Several previous studies have examined the effect of cross-sectional intervals on earthwork volume calculations. Azzumardi et al. (2022) reported that variations in station interval distances influence the accuracy of cut and fill volume calculations, where shorter intervals generally produce higher accuracy. In addition, Firmansyah et al. (2022) conducted a comparative analysis of volume calculation methods using a paired sample t-test and concluded that the Average End Area method is suitable for cut and fill volume estimation. Although previous studies have demonstrated the importance of cross-sectional spacing in earthwork calculations, most investigations were conducted on a single road geometry or focused primarily on methodological comparisons. Consequently, the influence of interval variation on volume estimation accuracy under different road geometric conditions remains insufficiently explored. Road geometry may affect terrain representation because curved road sections often exhibit more complex elevation changes and cross-sectional variations than straight road sections. Therefore, evaluating the sensitivity of earthwork volume estimation to interval spacing under different geometric conditions is necessary to provide practical recommendations for topographic surveys and earthwork calculations. Unlike previous studies, this research evaluates the influence of cross-sectional interval variations on both straight and curved road sections to assess their impact on the accuracy of cut and fill volume estimation. To the best of the authors' knowledge, no previous study has systematically compared the influence of cross-sectional interval variations on earthwork volume estimation between straight and curved road alignments under identical survey conditions. This limitation creates uncertainty regarding the selection of appropriate interval spacing for different road geometries.

Based on these conditions, this study aims to analyze the effect of cross-sectional interval variations on the accuracy of volume calculations in straight and curved road sections. The study utilized Electronic Total Station (ETS) measurements with interval variations of 10 m, 25 m, and 50 m. The calculated volumes were analyzed using the average end area method and statistically evaluated using a paired sample t-test to determine the significance of differences in volume calculation results for each measurement interval. Accuracy refers to the magnitude of volume differences and relative errors obtained from each interval scenario compared with the 10 m reference dataset, which represents the highest sampling density and the most detailed terrain representation. The findings are expected to provide practical guidance for determining optimal cross-sectional spacing in topographic surveys and earthwork computations for road construction projects.

2. Material and Method

2.1 Study Area

This study was conducted on the Kota Baru Road section located in Jati Agung District, South Lampung Regency, Lampung Province, Indonesia. The study area consisted of two road segments with different geometric characteristics, namely straight and curved road sections.

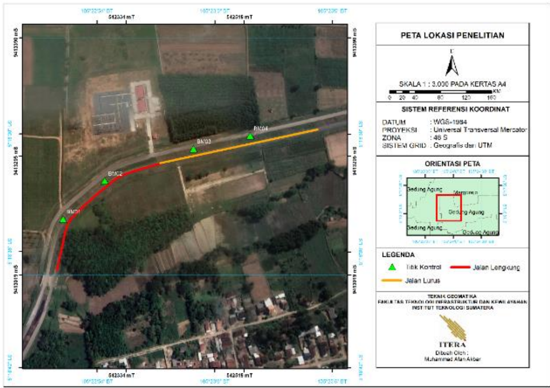

Figure 1. Location of the study area and road segments.

The curved road segment had an approximate length of 250 m, extending from coordinates 5°18'36.437" S and 105°22'51.905" E to 5°18'31.4" S and 105°22'57.734" E. Meanwhile, the straight road segment had an approximate length of 250 m, extending from coordinates 5°18'31.4" S and 105°22'57.734" E to 5°18'29.541" S and 105°23'5.606" E. The road section is a two-lane asphalt road planned for road widening and concrete pavement works.

2.2 Equipment and Software

The equipment used in this study consisted of both hardware and software components. The hardware included a Sino T300 GNSS receiver, ES-105 Total Station, Topcon Digital Waterpass, reflector prism, tripod, ranging pole, barcode staff, measuring tape, and laptop. The software used in this study included GNSS data processing software, AutoCAD Civil 3D, SWDTM (Softwel Digital Terrain Modeling), Microsoft Excel, and Microsoft Word.

2.3 Data Acquisition

Data acquisition was carried out using the polar method with the assistance of an Electronic Total Station (ETS), which is commonly applied in topographic and construction surveys (Basuki, 2011; Rahayu, 2015). Prior to detail measurements, a horizontal control network was established using the static GNSS method (Hofmann-Wellenhof et al., 2008; Leick et al., 2015), while a vertical control network was established through leveling measurements. Cross-sectional profile measurements were conducted on both straight and curved road sections using interval variations of 10 m, 25 m, and 50 m. Measurements were taken on the left and right sides of the road relative to the centerline to obtain a representation of the ground surface shape for each cross-section. Cross-sectional profiles were generated at intervals of 10 m, 25 m, and 50 m. For each 250 m road segment, the generated profiles consisted of 26, 11, and 6 cross-sections, respectively.

2.4 Data Processing

The field measurement data were processed using AutoCAD Civil 3D to generate a surface model and automatically produce cross-sectional profiles. In addition, cross-sectional processing was also performed using SWDTM to obtain the cross-sectional area for each station (STA). A representative cross-sectional profile generated from the survey data is shown in Figure 2.

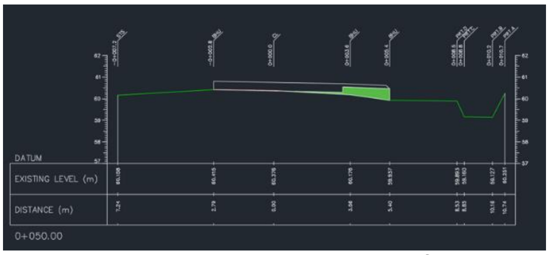

Figure 2. Representative cross-sectional profile generated using SWDTM.

The earthwork volume was calculated using the Average End Area method, which estimates the volume between two consecutive cross-sections by multiplying the average cross-sectional area by the distance between them. The equation is expressed as:

$$V = \frac{A_1 + A_2}{2} L \tag{1}$$

where V is the earthwork volume (m³), A_1 is the area of the first cross-section (m²), A_2 is the area of the second cross-section (m²), and L is the distance between consecutive cross-sections (m). This method is widely applied in road construction projects due to its simplicity and ability to provide reliable volume estimates when cross-sectional data are available.

Volume calculations were performed for each measurement interval variation, namely 10 m, 25 m, and 50 m, on both straight and curved road sections. The 10 m interval dataset was selected as the reference because it represents the highest sampling density among all interval scenarios and provides the most detailed representation of existing terrain conditions. To evaluate the influence of cross-sectional interval variations on volume estimation accuracy, the relative error of each interval was calculated using:

$$Error\ \% = \frac{V_{interval} - V_{reference}}{V_{reference}}\ x\ 100 \tag{2}$$

where Error (%) represents the relative error, Vinterval is the calculated volume obtained from the 25 m or 50 m interval, and Vreference is the volume calculated using the 10 m interval. The calculated errors were used to assess the effect of interval spacing on earthwork volume estimation accuracy.

2.5 Statistical Analysis

Statistical analysis was performed using a paired sample t-test (Montgomery and Runger, 2014) with a confidence level of 95% ($\alpha = 0.05$) to determine the significance of differences in cut and fill volume calculations among the cross-sectional interval variations. The statistical test was applied to paired volume data obtained from the 10 m, 25 m, and 50 m interval measurements on straight and curved road sections. The number of observation samples and the degree of freedom (df) were determined based on the total paired cross-sectional data used in each comparison. Hypothesis testing was conducted by comparing the calculated t-value with the critical t-table value. If the calculated t-value was lower than the t-table value, the null hypothesis (H_0) was accepted, indicating that the interval variations did not produce statistically significant differences in the calculated volumes.

3. Results and Discussion

3.1 Earthwork Volume Estimation

Earthwork volume calculations were performed using cross-sectional intervals of 10 m, 25 m, and 50 m on both straight and curved road sections. The calculations were conducted using the Average End Area method based on cross-sectional areas generated from field survey data. The 10 m interval was considered the reference dataset because it provided the highest sampling density and the most detailed representation of existing terrain conditions.

Table 1. Earthwork Volume Estimation Results for Straight and Curved Road Sections

Volume	10 meter Interval (m³)	25 meter Interval (m³)	50 meter Interval (m³)
Straight Road			
Cut	11,800	14,875	17,500
Fill	237,050	238,375	254,250
Net Volume	225,250	223,500	236,750
Curved Road			
Cut	1,800	1,375	1,000
Fill	333,100	342,250	360,250
Net Volume	331,300	340,875	359,250

For the straight road section, fill volume increased from 237.050 m³ at the 10 m interval to 254.250 m³ at the 50 m interval. Similarly, the curved road section showed an increase in fill volume from 333.100 m³ to 360.250 m³ as the interval widened. These results indicate that larger interval spacing tends to overestimate fill volumes compared to denser cross-sectional sampling.

The results indicate that variations in cross-sectional interval spacing affect the estimated cut and fill volumes. In general, larger intervals tend to simplify terrain representation between adjacent cross-sections, resulting in differences in calculated volumes. Conversely, smaller intervals provide a denser representation of surface variations and therefore produce more detailed volume estimates.

For both road geometries, the calculated earthwork volumes obtained from the 25 m and 50 m intervals showed deviations from the reference dataset. The magnitude of these deviations increased as the spacing between cross-sections became wider. This trend demonstrates that cross-sectional density plays an important role in representing terrain characteristics for earthwork volume estimation.

3.2 Effect of Interval Variation on Volume Accuracy

The influence of cross-sectional interval variation was evaluated by comparing the volume differences obtained from each interval scenario against the 10 m reference dataset. The results show that the discrepancy in both cut and fill volumes increased as the interval spacing became larger.

Table 2. Differences in Cut and Fill Volume Estimation Relative to the 10 m Reference Interval

Volume	Volume Calculation Difference at 10 m Interval (m³)	Volume Calculation Difference at 25 m Interval (m³)	Volume Calculation Difference at 50 m Interval (m³)
Straight Road			
Cut	0.470	2.605	5.230
Fill	1.465	2.790	18.665
Curved Road			
Cut	0.010	0.435	0.810
Fill	2.665	11.815	29.815

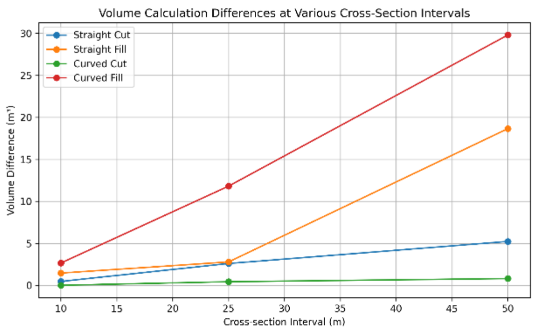

Figure 3. Volume calculation differences at various cross-sectional intervals for straight and curved road sections.

On the straight road section, the difference in cut volume increased from 0.470 m³ at the 10 m interval to 2.605 m³ at the 25 m interval and reached 5.230 m³ at the 50 m interval. A similar pattern was observed for fill volume, where the discrepancy increased from 1.465 m³ to 2.790 m³ and 18.665 m³, respectively. These findings indicate that wider cross-sectional spacing reduces the ability of the survey data to capture local terrain variations, leading to larger differences in calculated earthwork volumes.

The relative error analysis further confirms this trend. Larger intervals produced higher error values because the terrain surface between adjacent cross-sections was represented by fewer observations. Consequently, the resulting volume estimates became increasingly sensitive to local topographic variations that were not captured during data acquisition.

These findings are consistent with previous studies by Azzumardi et al. (2022) and Balqis et al. (2023), who reported that denser cross-sectional spacing generally improves earthwork volume estimation accuracy. The improved accuracy can be attributed to the increased ability of closely spaced cross-sections to capture local terrain variations, thereby providing a more representative model of existing ground conditions. Consequently, denser cross-sectional surveys tend to produce more reliable earthwork volume estimates. These findings indicate that increasing cross-sectional spacing may reduce survey efficiency gains obtained from fewer observations if the resulting volume estimation errors exceed project accuracy requirements. Therefore, selecting an appropriate interval should balance survey effort and the required level of earthwork estimation accuracy.

3.3 Road Geometry Comparison

Table 3. Comparison of Earthwork Volume Characteristics Between Straight and Curved Road Sections

Parameter	Straight Road	Curved Road
Mean Cut Volume (m³)	14.250	1.392
Mean Fill Volume (m³)	243.225	345.200
Standard Deviation of Cut Volume (m³)	2.853	0.400
Standard Deviation of Fill Volume (m³)	9.571	13.813
Dominant Earthwork Type	Cut	Fill

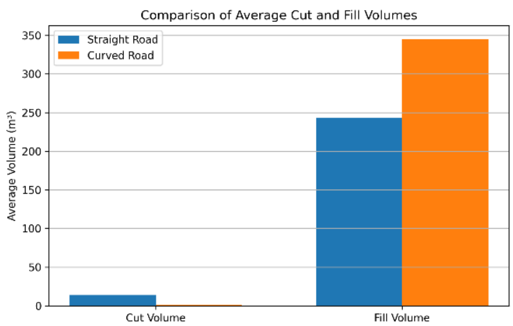

Figure 4. Comparison of mean cut and fill volumes between straight and curved road sections.

As shown in Figure 4, straight and curved road sections revealed differences in the sensitivity of earthwork volume estimation to interval variation. Although both road geometries showed increasing discrepancies as the interval became wider, the magnitude and distribution of these discrepancies differed.

The straight road section tended to exhibit larger cut volume differences, whereas the curved road section showed relatively larger fill volume discrepancies. This phenomenon may be attributed to differences in geometric characteristics and terrain representation along the alignment. Straight road sections generally have more uniform geometric conditions, while curved sections often involve more complex elevation changes and cross-sectional variations.

As a result, wider interval spacing may overlook subtle terrain changes along curved alignments, thereby affecting the accuracy of fill volume estimation. These findings suggest that road geometry should be considered when determining an appropriate cross-sectional interval for topographic surveys and earthwork calculations.

From a practical perspective, the results indicate that interval selection should not only consider survey efficiency but also the geometric characteristics of the road alignment. Curved road sections may require denser cross-sectional spacing to adequately represent terrain variability and reduce volume estimation errors.

3.4 Statistical Validation

To evaluate whether the observed volume differences were statistically significant, a Paired Sample T-Test was performed for each interval scenario. The statistical analysis showed that all calculated t-values were lower than the critical t-value of 4.303 at the 95% confidence level.

Table 4. Paired Sample T-Test of Cut and Fill Volumes on Straight Road Sections

Data	t-table	t-calculated	Result
Cut Volume			
STA Interval 10 m	4.303	0.285	H_0 Accepted
STA Interval 25 m	4.303	1.581	H_0 Accepted
STA Interval 50 m	4.303	3.175	H_0 Accepted
Fill Volume			
STA Interval 10 m	4.303	0.265	H_0 Accepted
STA Interval 25 m	4.303	0.505	H_0 Accepted
STA Interval 50 m	4.303	3.378	H_0 Accepted

Table 5. Paired Sample T-Test of Cut and Fill Volumes on Curved Road Sections

Data	t-table	t-calculated	Result
Cut Volume			
STA Interval 10 m	4.303	0.043	H_0 Accepted
STA Interval 25 m	4.303	1.882	H_0 Accepted
STA Interval 50 m	4.303	3.505	H_0 Accepted
Fill Volume			
STA Interval 10 m	4.303	0.334	H_0 Accepted
STA Interval 25 m	4.303	1.481	H_0 Accepted
STA Interval 50 m	4.303	3.739	H_0 Accepted

The highest calculated t-value was 3.739 for fill volume on the curved road section at the 50 m interval. Although this value approached the critical threshold, it remained below the critical t-table value of 4.303, indicating that the null hypothesis could not be rejected at the 95% confidence level.

These results suggest that variations in cross-sectional interval spacing did not produce statistically significant differences in the calculated earthwork volumes within the study area. Therefore, the null hypothesis was accepted for all tested interval scenarios.

Although the statistical test indicated no significant differences, the practical analysis demonstrated that wider intervals produced larger discrepancies and higher relative errors. This finding highlights the distinction between statistical significance and practical accuracy. From an engineering perspective, smaller intervals remain preferable when high-accuracy volume estimation is required, particularly for projects involving complex terrain conditions or strict quantity control requirements. This finding indicates that statistical insignificance does not necessarily imply equivalent practical accuracy, especially when earthwork quantities are used for project cost estimation, budgeting, and construction planning.

Therefore, although all tested interval scenarios were statistically acceptable, the 25 m interval can be considered the most practical option because it provides a reasonable balance between survey efficiency and volume estimation accuracy. Therefore, the selection of cross-sectional spacing should consider project objectives, required accuracy levels, and available survey resources.

4. Conclusion

This study evaluated the influence of cross-sectional interval variations on cut and fill volume estimation in straight and curved road sections using the Average End Area method. The results demonstrated that increasing the interval spacing generally increased the discrepancies in calculated earthwork volumes. The results demonstrated that increasing the interval spacing generally increased the discrepancies in calculated earthwork volumes, indicating that denser cross-sectional surveys provide a more detailed representation of terrain conditions and potentially improve the reliability of earthwork volume estimates. Road geometry was also found to affect volume estimation, where straight road sections tended to exhibit larger cut volume requirements, while curved road sections produced greater fill volume discrepancies due to their more complex geometric and elevation characteristics. Although the paired sample t-test indicated that volume differences among the tested interval scenarios were not statistically significant at the 95% confidence level, practical analysis showed that wider intervals generated higher relative errors. Although no statistically significant differences were detected at the 95% confidence level, the practical engineering analysis demonstrated that wider intervals generated larger discrepancies that may become important when earthwork quantities are used for budgeting, quantity control, and construction planning. Therefore, the selection of cross-sectional spacing should consider both accuracy requirements and survey efficiency. This study was limited to a single road construction project, three cross-sectional interval scenarios, and the Average End Area method. Therefore, the findings should be interpreted within the context of the investigated site conditions and methodology. Future studies should evaluate additional interval scenarios, compare alternative earthwork volume estimation methods such as the Prismoidal and TIN approaches, and investigate more complex terrain conditions and larger road networks. Among the evaluated scenarios, the 25 m interval is recommended as a practical compromise between survey efficiency and earthwork estimation reliability for road construction projects.

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