



## Analysis of Road Leger Development Based on a Geographic Information System in Monitoring and Evaluation of Road Space Utilization

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### ABSTRACT

The method used to develop the GIS-based road inventory comprised an inventory of existing road inventory data and an Extract-Transform-Load (ETL) process for data digitization and integration into a GIS environment. The resulting system was then assessed for its applicability to Rumija monitoring and evaluation, while the economic feasibility of implementation was evaluated using Return on Investment (ROI) and Benefit-Cost Ratio (BCR). The study was conducted as a case study on the Mastrip Road section in Surabaya, under the authority of the East Java Provincial Public Works (Highway Agency). The developed GIS-based road inventory identified 225 JKM points, indicating a potential increase in local government revenue (PAD) of IDR 189,591,852.00 per year.

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## **INTRODUCTION**

Road infrastructure management is a fundamental aspect of sustainable land transportation. Roads serve not only as facilities for the movement of people and goods, but also as public assets with high technical, economic, and social value. In effective road management, road ledger documents (Rumija) play a critical role as a technical database containing geometric, structural, administrative, and legal information for each road section. These ledgers serve as the primary reference for planning, maintenance, supervision, and control of road space utilization (Rumija).

However, in many local governments, road ledgers are still managed manually, in the form of printed books, paper maps, or separate files such as CAD drawings and spreadsheets. This practice hinders the effectiveness of road management and prevents decisions based on up-to-date, integrated data (Ministry of Public Works and Public Housing, 2024). Manual management presents several challenges, including delayed updates, inconsistent information, and weak integration between spatial and attribute data. Such limitations impact technical and administrative decision-making, particularly for monitoring and evaluating Rumija utilization, which encompasses legal, economic, and social dimensions.

Modern road asset management emphasizes integrated, spatially data-driven systems. For example, the Indonesia Integrated Road Management System (IRMS) centralizes road, bridge, and road user safety assets using relational databases and GIS. WebGIS-based Road Asset Management Systems (RAMS) for toll roads further demonstrate the benefits of integrating spatial and non-spatial data for visualization, analysis, and decision-making. Nonetheless, most existing systems focus on inventory and safety rather than directly linking Rumija ledgers to operational monitoring and evaluation.

Economic justification for such systems is strong. GIS-based Rumija management can improve levy accuracy, reduce operational costs, minimize revenue leakage, and accelerate permit verification. Analyses using Return on Investment (ROI) and Benefit-Cost Ratio (BCR) frameworks can quantify the system's economic and social benefits, providing local governments with evidence to support investment in digital transformation of road management.

## **THEORETICAL REVIEW**

The literature highlights the importance of GIS in modernizing road management. Studies show that desktop GIS applications like QGIS and ArcGIS are effective in supporting road inventory and technical data management. GIS enables visualization, mapping, and analysis of road assets, which improves data quality and operational efficiency compared to manual methods. Research has demonstrated that GIS-integrated road equipment inventories facilitate evaluation and monitoring, while also supporting the management of road signs, markings, and safety facilities.

Despite these advancements, existing research primarily focuses on road equipment and safety rather than integrating GIS with official road ledgers for Rumija monitoring. Rumija studies often emphasize legal, institutional, and economic aspects, including licensing, regulation, and conflict management in

toll and national roads, without detailing GIS-based operational frameworks. These studies underscore the economic and legal potential of Rumija, yet also highlight risks when utilization is not properly monitored.

From a governance perspective, road ledgers require continuous maintenance, updating, and integration of spatial data to remain a reliable reference for decision-making. Regional agencies face constraints in budget, personnel, and time, often resulting in outdated records and fragmented data collection. GIS offers a practical solution, bridging modern data-driven management with limited regional resources. Desktop GIS solutions like QGIS provide a cost-effective and accessible platform for developing spatial databases, enabling better monitoring and evaluation of Rumija utilization.

The integration of GIS-based road ledgers with Rumija M&E systems can also generate measurable economic benefits. Digitization improves levy collection accuracy, reduces operational costs, and accelerates administrative processes. High ROI and BCR values demonstrate that the benefits—such as increased local revenue, improved governance transparency, and reduced conflicts—exceed development and maintenance costs, supporting the strategic case for digital road ledger implementation.

Overall, the literature indicates a gap in operational GIS-based models that link road ledgers to Rumija monitoring and evaluation. This research addresses that gap by developing a desktop GIS-based road ledger model to improve Rumija governance, strengthen the fee collection database, and support road safety and orderly spatial utilization. The study's originality lies in focusing on secondary data, compliance with current ledger guidelines, and the design of a replicable framework as the initial step toward integrated road asset management.

## **METHODOLOGY**

Government Regulation of the Republic of Indonesia Number 34 of 2006 requires every road operator to hold a road ledger in the form of a card or digital (Government of the Republic of Indonesia, 2006). One of the uses of the road ledger document mentioned in the Regulation of the Minister of Public Works Number 78/PRT/M/2005 concerning Road Ledger is for the preparation of road management plans and programs. Ministerial Regulation of Public Works No. 78/2005 also states that the road ledger must always be up to date. Road ledger updates are carried out at least once every 5 years.

Road ledger documents in principle record the condition of a road section in a single information package consisting of a data summary, road card, and bridge card, and are conventionally presented in image format on A3 paper (Department of Public Works, Directorate of Highways, 2008). Road cards contain technical and geometric information of the section, including road identity, pavement technical data, and representation of physical conditions through situation/section drawings and cross-sections and longitudinal. Meanwhile, bridge cards present technical data on the bridge structure located on the section, equipped with longitudinal and cross-sections, as well as a top view to illustrate the position and configuration of the bridge more clearly. With

this structure, the ledger functions as an important reference document for road maintenance activities ranging from asset inventory, maintenance planning, to condition evaluation and handling needs.

The procedure for preparing road ledger documents refers to the 2024 Road Ledger Guidelines of the Directorate General of Highways, Ministry of Public Works and Public Housing, which generally consists of four stages: the preparation stage, the field survey and secondary data collection stage, the data processing stage, and the determination of the ledger document stage. In the preparation stage, activities carried out include coordination with relevant agencies, determining the scope and data requirements, and mobilizing personnel, equipment, and work devices to ensure the survey is carried out effectively and according to standards. The field survey and secondary data collection stage includes three main activities: institutional surveys, field surveys, and data verification and validation. The institutional survey aims to obtain primary administrative data and supporting data from the road authority owner, including road identity data, project/handling data on the relevant section, as-built drawings, average daily traffic (LHR), road asset value data, and the latest ledger document if the section has been previously legislated. The latest ledger document generally provides very helpful initial information, such as the coordinates of the start and end points of the section, the location of the ledger markers, situational drawings, cross-sectional drawings, and photo documentation of the road conditions at the time the previous ledger was compiled.

Road Ownership Space (Rumija) is a part of the space along the road that has an important role in the implementation of road infrastructure. According to Law Number 38 of 2004 concerning Roads, Article 1 Paragraph 5, Rumija is defined as "Space along the road that is limited by a certain width, height, and/or depth controlled by the road organizer for the purposes of road benefit space and road supervision space." Meanwhile, Government Regulation Number 34 of 2006 concerning Roads, Article 1 Paragraph 7, states "Road ownership space is space along the road that is limited by a certain width and determined by the road organizer for the purposes of road management."

Desktop-based GIS is software that runs locally on a user's computer and is designed to provide comprehensive spatial analysis capabilities. According to ESRI (2018), desktop GIS tools such as ArcGIS Desktop, QGIS, and MapInfo provide a working environment that allows users to visualize, manipulate, edit, and analyze spatial data in depth.

The main characteristics of desktop-based GIS include high data processing capabilities, stability even without an internet connection, and a comprehensive range of features for advanced geoprocessing. These features include overlay analysis, buffering, interpolation, surface modeling, and network analysis. Furthermore, desktop GIS offers great flexibility in data digitization and editing, making it ideal for technical work and spatial database development that requires a high level of detail.

Data analysis in this study was conducted in three main steps, namely designing and validating the process of transforming existing ledgers into GIS

ledgers through a clear ETL flow, testing position accuracy using RMSE, and assessing the completeness of attributes against established standards, so that a procedure for developing GIS ledgers is obtained that is spatially accurate, attribute-complete, and ready to be used as a standard SOP. Second, compiling a detailed cost model for developing GIS-based road ledgers by identifying all activity components, grouping them into Initial Investment Costs and Annual Costs using official budget data, and validating them through reviews with technical parties and planners. Next, evaluating the economic feasibility of developing GIS ledgers in manual, semi-digital, and full GIS scenarios by calculating investment, operational costs, and economic benefits, then analyzing them using ROI and BCR indicators to determine the most profitable scenario and according to the institution's capabilities.

The initial steps in developing an existing ledger into a GIS ledger are:

1. Inventorying all existing ledger data sources (paper maps, CAD/Excel files, local databases).
2. ETL (Extract, Transform, Load) process, which includes digitization, georeferencing, format standardization, and loading into a GIS database.
3. Testing geometric position by calculating RMSE<sub>x</sub>, RMSE<sub>y</sub>, and RMSE<sub>h</sub> with the following steps:
  - a. Preparing coordinate data pairs for a total of  $n$  test points, each consisting of the reference coordinates of the centroid ( $x_{ref}$ ,  $y_{ref}$ ) and the coordinates of the extracted ledger ( $x_{obs}$ ,  $y_{obs}$ ).
  - b. Next, the coordinate difference at each point is calculated from its reference, namely  $\Delta x_i = x_{obs,i} - x_{ref,i}$  and  $\Delta y_i = y_{obs,i} - y_{ref,i}$ . This difference value is then squared to eliminate the negative sign and confirm the magnitude of the deviation, so that  $(\Delta x_i)^2$  and  $(\Delta y_i)^2$  are obtained.
  - c. The squares of the differences for each component are summed for all points, then averaged by dividing by the number of points  $n$ , using equation (2.1) the RMSE<sub>x</sub> value is obtained and with equation (2.2) the RMSE<sub>y</sub> value is obtained, to obtain the combined horizontal accuracy, equation (2.4) is used which produces the RMSE<sub>h</sub> value which provides a single measure of the overall horizontal position accuracy.
4. Evaluate attribute completeness by measuring the percentage of key attributes (e.g., segment number, STA, Rumija width, utilization status, asset type) filled in against the standards established in the metadata and GIS ledger guidelines.
5. The results of the RMSE analysis and attribute completeness are used to improve the ETL flow, clarify data entry rules, and develop QA/QC procedures.

This process is then tested in sample areas and validated through technical reviews with users in the agency, resulting in a GIS ledger development process that is proven to be spatially accurate and attribute-adequate, and ready to be adopted as a standard procedure.

To develop a detailed cost model for developing a GIS-based road ledger, the first step is to identify all required components, from inventory and digitization of existing ledger data, spatial database development, hardware and software procurement, human resource training, to operational data updates and system maintenance. Each component is then systematically grouped into:

Investment costs, such as:

1. Initial development costs
2. Server/computer procurement
3. Initial licenses, and
4. Initial training; and

Annual costs, such as:

1. System maintenance costs
2. Routine data updates
3. Annual licenses
4. Technical support, and
5. QA/QC activities.

Total Benefits:

1. Operational cost savings
2. Improved work efficiency
3. Increased revenue
4. Reduced losses

Cost data is obtained from budget documents (DPA/RKA), government cost standards, the value of levies received, and vendor bid references, then parameterized (e.g., per km of road, per segment, or per work unit) so that the model can be used for various scales of application. The results of the preparation of this cost model are validated through reviews with financial parties or planners and technical practitioners, so that a realistic, transparent investment and annual cost structure is obtained and can be used as a reference for budgeting for the development of GIS ledger.

To evaluate the benefits of developing GIS ledgers in manual, semi-digital, and full GIS scenarios, an ROI analysis is used, which provides a percentage of investment efficiency. The following steps are used to calculate ROI:

1. Group the types of investment costs, annual costs, and benefit values as described previously.
2. Using equation (2.5), the ROI value is determined by comparing the difference between total benefits and total costs to the total investment cost.

Narratively, ROI shows the net profit generated compared to the funds invested.

Benefit Cost Ratio (BCR) analysis is used to assess the economic feasibility of implementing a GIS Road Ledger, taking into account the time value of money. The steps taken to determine the BCR are as follows:

1. Determine the analysis period (t) based on the useful life of the GIS Road Ledger system. In this study, a period of 5 years was determined, in accordance with the maximum limit for updating the ledger.

2. Determine the discount rate ( $i$ ), which is the benchmark interest rate, inflation, or minimum rate of return set by the government. This discount rate is used to convert all future benefits and costs to their present value.
3. Calculate the Present Value of Benefits ( $PV(Bt)$ ). Using equation (2.6), the annual benefits from implementing a GIS-based Road Ledger ( $Bt$ ) are discounted to their present value using a predetermined discount rate. All annual benefits are summed to obtain the Present Value of Benefits ( $PV(Bt)$ ).
4. Calculate the Present Value of Costs ( $PV(Ct)$ ). All costs associated with the GIS Ledger project, including initial investment and annual costs (operational and maintenance), are calculated at their present value to obtain the Present Value of Costs ( $PV(Ct)$ ) using equation (2.7).
5. Calculate and interpret the BCR by comparing  $PV(Bt)$  to  $PV(Ct)$  using equation (2.8). In the context of GIS-based Road Ledger projects:

$BCR > 1$  indicates that the benefits of implementing the GIS Ledger outweigh the costs, making the project economically feasible.

$BCR = 1$  indicates a break-even point,

$BCR < 1$  indicates that the system is not yet economically feasible.

By using ROI and BCR analysis, the implementation of a GIS-based Road Ledger can be quantitatively evaluated from an economic perspective. ROI describes the return on investment, while BCR ensures that the benefits of the digital ledger system outweigh the long-term costs. This analysis provides a strong basis for decision-making regarding the development and implementation of a GIS-based Road Ledger system in road management agencies.

## RESULTS AND DISCUSSION

The collected permit data contains administrative and technical information. Operationally, Rumija permit data is used to control road space utilization, ensure all activities comply with regulations, and avoid spatial conflicts and safety risks. This data also serves as material for evaluating potential retribution revenue, cross-sector coordination, and rezoning in the event of road construction or widening. The administrative information from the permit data is as follows:

- a. Applicant's name
- b. Name of business location
- c. Applicant's letter number and application date
- d. Description of utility/non-utility type
- e. Application location
- f. Agency recommendation
- g. Retribution amount

The DPA/RKA for Road Ledger Making activities is an official budget document that contains details of the planned cost requirements, activity outputs, and program targets related to the preparation of road ledgers. In the DPA/RKA, the ledger making activity is listed as part of the road implementation program, including budget allocations for field surveys, technical data collection, document digitization, geometric information processing, and preparation of digital and printed ledger formats. This document serves as a formal reference for agencies in ensuring that all stages of the activity have financial support and are within the corridor of annual budget planning regulations. Information obtained according to DPPA/A.3/1.03.0.00.00.10.0000/001/2024 that the price of making provincial road ledger documents per kilometer is Rp 6,538,808.00.

The existing road ledger data obtained consists of a combination of PDF, CAD, and Excel files, as well as photogrammetry. Each format has varying levels of readability and information content. Therefore, these files need to be processed by adding information or removing unnecessary details before being converted into shapefiles. Layer adjustments are needed as needed, including:

- a. Village boundaries
- b. Roadside boundaries
- c. Business points
- d. Buildings
- e. Utility networks (telecommunication cables, electricity, and piping)
- f. Non-utility points (entrances and exits)

The purpose of reducing layers in CAD files is to make it easier to group lines according to function and required points such as business unit points and to make it easier to re-digitize for non-utility identification needs that are not yet listed in secondary data, so that the data processing process becomes more efficient, structured, accurate, and supports optimal integration into geographic information systems.

Component identification is carried out to map the budget requirements for the construction and operation of a project. The investment budget includes all initial investment expenditures, such as document preparation, equipment procurement, system installation, and training costs. Meanwhile, the operational cost budget covers routine operational costs, including maintenance, labor, energy, consumables, periodic repairs, and daily administrative and operational costs. Separating these two components is essential for estimating budget requirements, calculating financial feasibility, and understanding the project's long-term cost structure.

Economic benefit estimates are calculated to assess the extent to which a project provides financial and non-financial benefits. The types of benefits that can be measured in this study are:

- Increased Revenue

Based on the analysis in sub-chapter 4.2.b, there was an increase in Regional Original Revenue (PAD) after the use of the GIS ledger of IDR 147,091,652 per year.

- Operational Cost Savings

The potential JKM (Jarnet Revenue) for PAD after the use of the GIS ledger is as follows:

$$\begin{aligned} \text{JKM} &= \text{Digitized JKM} - \text{Registered JKM} \\ &= 225 - 12 \\ &= 213 \text{ points} \end{aligned}$$

If the field survey team's productivity is able to measure 10 points in one day, the total potential JKM can be measured in 21.3 days (rounded to 21 days) with three surveyors.

Before calculating the BCR, a discount rate needs to be determined. Bappenas recommends a Social Discount Rate of 6%-10% for public sector projects. In this study, the discount rate was set at 6% with a value of  $i = 1.3382$  and an analysis horizon of 5 years. Using equations (2.6) and (2.7), the  $B_t$  and  $C_t$  values are obtained.

## CONCLUSION AND RECOMMENDATION

Based on the data analysis, the following conclusions can be drawn the GIS ledger development at the study site revealed 225 digitized JKM points, compared to only 12 registered JKM points. This leaves a gap of 213 points with potential for monitoring and evaluation by Rumija, which could potentially increase the Regional Original Revenue (PAD) generated from levies to Rp 189,591,852.00 per year. In terms of spatial quality, as part of the data evaluation, the accuracy test revealed a horizontal RMSE of 26.851 m and a CE90 of 40.75 m. Therefore, the extracted coordinates from the ledger should not be used as a reference; digitized coordinates can be used instead. 2. The economic analysis of the development of GIS road ledger shows the need for initial investment costs of Rp 100,012,500.00 and annual operational costs of Rp 86,598,800.00, with a total benefit of Rp 217,521,852.00 resulting in an ROI of 16.56%. Feasibility is also confirmed by  $BCR = 1.17$  (greater than 1), which means that financially the benefits obtained are able to cover the total costs, so that the development of GIS ledger is declared feasible to be implemented.

## FURTHER STUDY

The following are suggestions for further research that have not been discussed in previous studies, but are in accordance with the problem definition:

1. Future research is recommended to expand the scope of road ledger attributes analyzed, beyond basic attributes such as section name, length, width, pavement type, and road status. With more comprehensive attributes, GIS-based road ledgers will have greater utility in supporting comprehensive road asset management.
2. The application of GIS and analysis of Rumija utilization in this study are still limited to a specific case study area, namely Jl. Mastrip Surabaya. Therefore, future research is recommended to apply it to a broader area,

which is expected to provide a more representative picture of the potential use of Rumija and the effectiveness of implementing GIS-based road ledgers on a larger scale.

3. The GIS system developed in this study is still desktop-based and does not yet include advanced maintenance features or real-time data integration. For future development, it is recommended that the system be upgraded to a WebGIS or integrated road asset management system, so that data can be more widely accessed by various stakeholders.
4. The analysis of Rumija utilization in this study focused on non-utility objects, such as entrances and exits for medium-scale businesses. Future research is recommended to include other types of Rumija utilization, such as network utilities (electricity, telecommunications, water), advertising, temporary buildings, and other commercial activities. This is expected to provide a more comprehensive picture of the potential for Rumija utilization and support the optimization of regional revenue.

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