RESEARCH SUMMARY OF A GIS-BASED ANALYSIS OF THE STATUS OF STREETLIGHTING ON THE WCG ROAD NETWORK: TOWARDS A SPATIAL ASSET REPOSITORY TO GUIDE DECISION MAKING AND ASSET MANAGEMENT

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SUMMARY

The Western Cape Government (WCG) Roads Infrastructure Directorate oversees the management and maintenance of road network assets through systems like the Road Network Information System (RNIS). However, streetlight data within the RNIS is currently incomplete, unverified, and lacks consolidation, taking the form of non-spatial linear datasets that cover only partial portions of the network. Accurate and comprehensive streetlight asset records are essential for supporting initiatives such as the Green Lighting program, which promotes LED retrofits to enhance lighting infrastructure quality while reducing energy consumption. Additionally, South Africa's rising electricity costs necessitate the efficient management of streetlighting infrastructure.

This study seeks to establish a comprehensive spatial dataset of streetlighting assets along the WCG road network and leverage Geographic Information Systems (GIS) to inform decision-making processes. The primary objectives were to create a verified spatial dataset of WCG-maintained streetlight assets, to visualize a conclusive streetlight repository, and to demonstrate the application of GIS analysis in identifying areas of concern to prioritize resource allocation.

Using consumer-grade smartphones equipped with GNSS capabilities and the Esri Field Maps application, geolocated streetlight data was seamlessly integrated into a Spatial Database Engine (SDE) geodatabase. Over a two-year fieldwork period, the project captured and analysed over 9,300 streetlights and 900 traffic light sets. Captured data was analysed through spatial techniques, including buffer analysis for light coverage and kernel density for hotspot identification. The outputs provide actionable insights into streetlight density, extent, and

alignment with complementary datasets. Ultimately, the study validates GIS as a powerful tool for enhancing asset visualization, strategic planning, and infrastructure management within the WCG.

1. INTRODUCTION

The Western Cape Government (WCG) Roads Infrastructure Directorate maintains various systems relating to the asset management and maintenance of the road network. Foremost among these is the Road Network Information System (RNIS), which contains a record of road assets, furniture, and structures captured in the form of Road Logs. Currently, streetlights are represented by incomplete and unconsolidated non-spatial datasets. The existing entries lack validity and precision, as they are based on the linear extents of road sections rather than exact point features.

The effective management of streetlights, alongside strategic planning for network improvement, necessitates a complete, ground-truthed asset record. The widespread adoption of Green Lighting initiatives has driven LED retrofits to improve quality and gain environmental benefits, making accurate spatial data critical (WCG, 2020). Furthermore, South Africa's increasing electricity scarcity requires that every aspect of energy consumption be managed as efficiently as possible.

This study aims to capture and compile a comprehensive asset record of streetlighting along the WCG road network to determine the current state of infrastructure. It further seeks to establish a proof of concept demonstrating the application of GIS analysis to guide decision-makers toward areas of concern and inform strategic lighting asset management.

2. LITERATURE REVIEW ON GIS MAPPING OF ROADWAY LIGHTING

Geographic Information Systems (GIS) have played a transformative role in spatial analysis, data management, and decision-making processes. GIS allows for the comprehensive mapping and inventory of streetlights, including their type, location, and operational status, forming the foundation for building an asset register (Masser & Ottens, 2019).

2.1 Applications and Benefits

The integration of larger data sets in a spatial context allows for detailed modelling, which can lead to better decision-making related to streetlighting infrastructure (Alhamwi et al., 2021). By analysing spatial data attributes, GIS can aid in deriving energy consumption patterns of different lighting technologies. Spatial mapping and modelling allow for light intensity planning and dimming schedules to cut energy consumption, representing a significant advantage for regions facing electricity supply constraints. Furthermore, well-lit streets are often associated with lower crime rates, and improved lighting reduces road accidents (Saraiji et al., 2009).

2.2 Challenges and Advancements

One of the primary challenges in GIS-based roadway lighting analysis is ensuring data accuracy; inaccurate data can lead to errors in asset management, such as placement errors or overlooking areas requiring coverage (Xhafa & Kosovrasti, 2015). Implementing multi-user GIS systems in complex organizational environments also presents challenges, requiring proper alignment of management processes. However, advancements in big data, artificial intelligence (Geo AI), IoT, and mobile computing are transforming GIS, providing new opportunities for automated data collection, self-learning infrastructure planning, and real-time operational monitoring.

3. METHODOLOGY AND SYSTEM DEVELOPMENT

To overcome the challenges of incomplete RNIS data, the study employed a GIS-based methodology within the Esri environment to develop a mobile streetlight asset capture system.

3.1 Mobile Device and Application Suitability

Consumer-grade smartphones equipped with GNSS capabilities were selected for field data collection. These devices met the GNSS requirements, offered compatibility across operating systems, and provided a cost-efficient alternative to dedicated mapping hardware (Nielson, 2013). The Esri Field Maps application was identified as the optimal capture tool, as it is fundamentally aligned with the WCG Roads GIS enterprise environment, enabling seamless data integration without the need for post-processing.

3.2 Esri Environments and Database Infrastructure

A specific Spatial Database Engine (SDE) geodatabase was employed within the WCG Roads GIS environment. To bypass internal domain security limitations that block external internet access, datasets were housed in the WCG organizational ArcGIS Online environment, with a secure data tunnel established for live synchronization. Point feature classes (e.g., "StreetLights_Poles") were created and published as feature services, enabling field workers to edit data directly via their mobile devices.

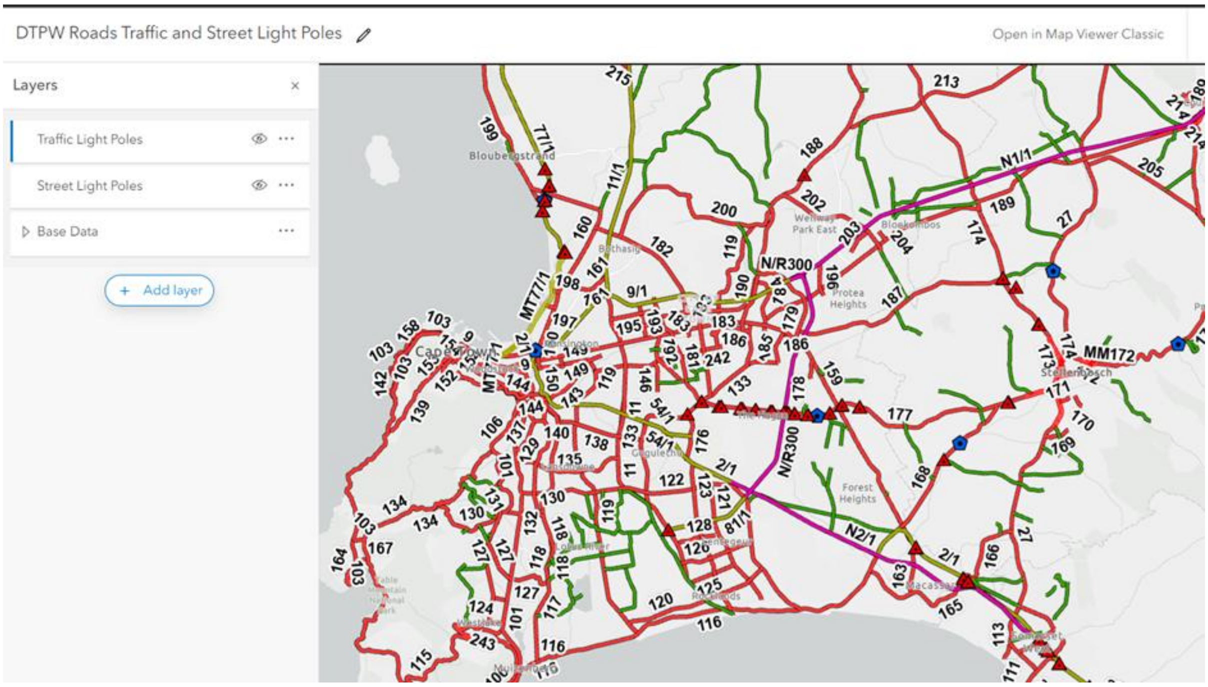

Figure 1: The DTPW Roads Traffic and Street Light Poles web map interface used by field workers.

4. FIELD WORK AND DATA CAPTURE

4.1 Defining the Capture Region

The WCG road network consists of over 7,281 km of paved road and nearly 24,936 km of unpaved road. A master feature class of existing streetlight locations, aggregated from archived RNIS data and contractor reports, was created to geographically guide fieldwork. This dataset identified 427 potential streetlight segments requiring verification across the network.

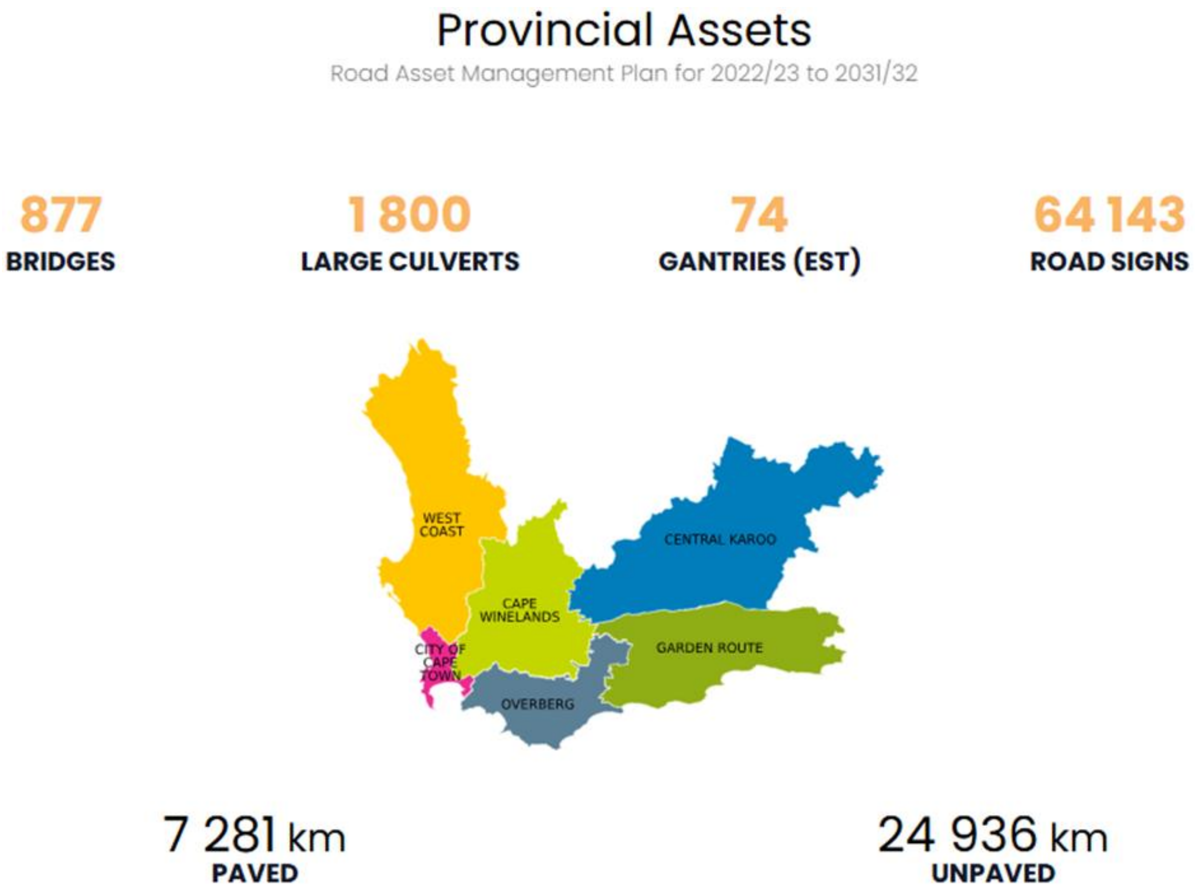

Figure 2: The vast regional extent of the Western Cape Government road network.

4.2 Capture Methodology and Quality Assurance

Data capture was integrated into the daily operations of the WCG Roads GIS unit over a two-year period. To optimize data quality under variable field conditions, the collection accuracy threshold was set to a maximum of 4 meters, and GNSS observations were increased to 5 epochs for averaging. Field workers reported challenges with GNSS signal loss during midday summer months and in mountainous terrain. Furthermore, the lack of ubiquitous cellular coverage in rural areas temporarily interrupted live synchronization, necessitating manual data additions upon return to the office.

To monitor progress, a dedicated Web Application ('Road Asset Management: Street/Traffic Light Poles') was deployed, allowing management to track live feature capture against a backdrop of aerial imagery and active project locations.

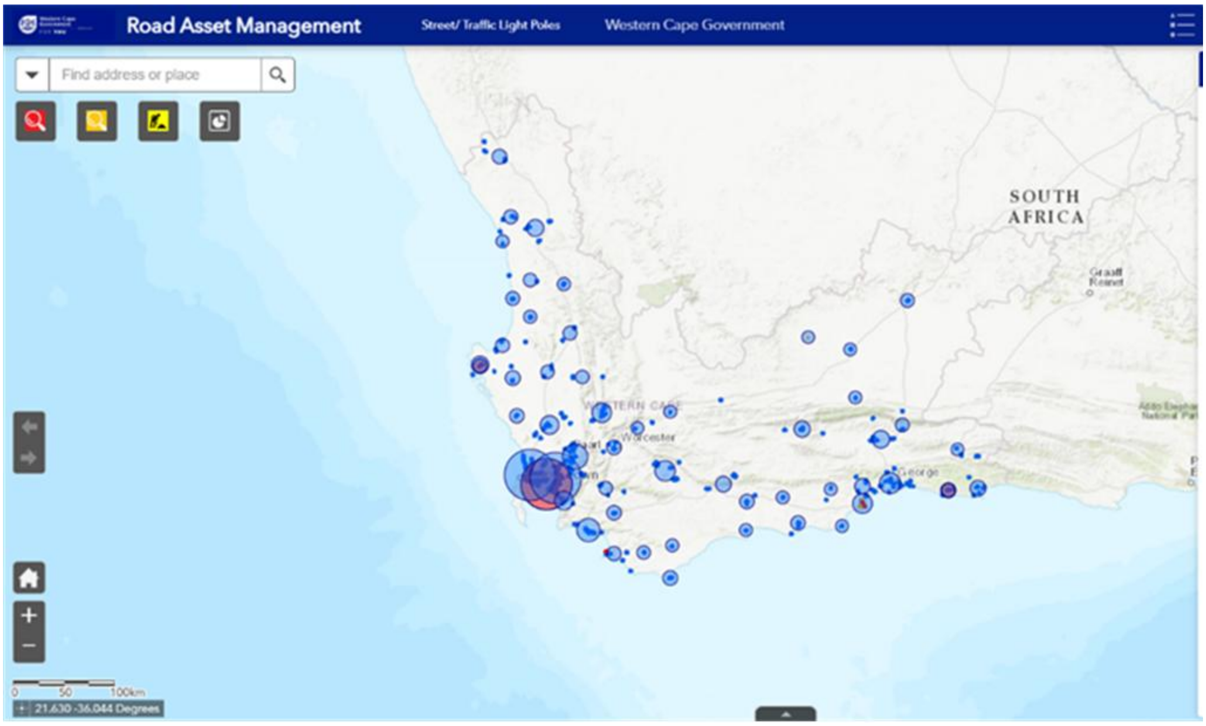

Figure 3: Web Application demonstrating live tracking of streetlight asset capture progress.

5. GIS DATA ANALYSIS

The raw captured dataset required spatial enrichment to be fully functional within the broader GIS system. Analysis was structured into three distinct components to transform the data into actionable insights.

5.1 Attribute Association

Spatial join analysis was utilized to link captured streetlight point locations with relevant attributes from the WCG road network. Using a 'Closest' match parameter, streetlights were assigned unique identifiers such as Road Number, Segment ID, and Town Names, establishing the foundational dataset for the comprehensive repository.

5.2 Streetlight Analysis

Location-based GIS tools were employed to model and assess the distribution and illumination characteristics of the assets.

- Light Coverage: Buffer analyses utilizing 22m and 28m Euclidean buffers (based on IESNA Type 3 distribution standards for 8m and 10m poles) simulated light throw to identify continuous coverage zones and highlight areas lacking illumination.

- Intersection Coverage: Spatial joins using a 28m radius around traffic intersection centroids quantified the frequency of streetlights per intersection, enabling a qualitative classification of lighting sufficiency.

- Light Intensity: Overlapping count methods were applied to the coverage buffers to quantify and visualize regions of varying brightness.

Figure 4: Buffer analysis revealing precise light coverage polygons within a major interchange.

Figure 5: Buffer analysis revealing light coverage and derived intensity polygons within a major interchange.

5.3 Road Network Analysis

Geospatial techniques were applied to evaluate streetlighting within the context of the WCG road network.

- Road Illumination Percentage: By intersecting the WCG road sections with the dissolved light coverage polygons, the total length of illuminated roadway was calculated and represented as a percentage.

Figure 6: Percentage of road illuminated identifying roads containing street lights and the percentage coverage.

- Density Analysis: Point density and kernel density estimations were performed to identify lighting "hotspots." The kernel density tool, utilizing a 250m search radius and a 10m output cell size, fitted a smoothly tapered surface to each point to visualize the magnitude of streetlight distribution per square kilometre (Silverman, 1986).

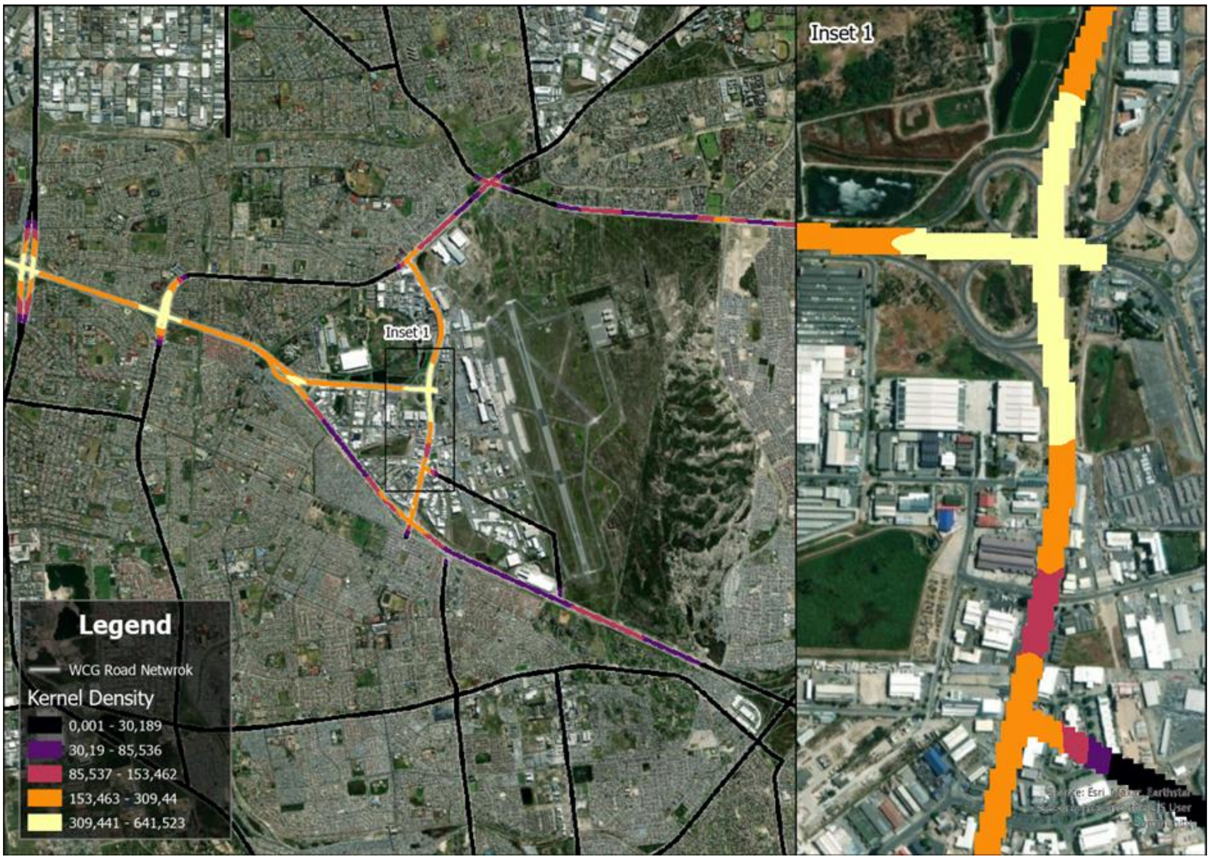

Figure 7: Kernel density mapping identifying highly concentrated streetlight infrastructure hotspots.

6. RESULTS AND DISCUSSION

This study successfully achieved its primary objective of creating a consolidated, verified streetlight asset repository, dramatically improving upon the historically fragmented RNIS data. The repository currently contains precisely located point features for over 9,300 streetlights and 900 traffic lights.

The integration of consumer mobile devices with ArcGIS Field Maps proved highly practical for large-scale data collection, effectively eliminating the need for complex post-processing. While challenges such as intermittent offline functionality and varying GNSS accuracy were encountered, they did not undermine the overall validity of the GIS workflow.

The spatial analyses served as a successful proof of concept, demonstrating GIS's capability to derive actionable insights from physical assets. Techniques like the overlapping count analysis for intensity and kernel density mapping for network distribution provide decision-makers with the quantitative data necessary to prioritize maintenance, target LED upgrades, and optimize safety infrastructure.

7. CONCLUSION AND RECOMMENDATIONS

This study validates Geographic Information Systems as a powerful, necessary tool for enhancing road asset management, strategic planning, and visualization within the WCG Roads Directorate. By facilitating data-driven decisions and establishing a robust spatial data repository, the system lays a strong foundation for future advancements.

To optimize future infrastructure initiatives, the following recommendations are made:

1. Streamline Data Capture: Allocate dedicated resources and implement team-based field operations to increase the efficiency of asset capture.

2. Ensure Offline Functionality: IT infrastructure must support robust disconnected editing capabilities to mitigate cellular network limitations in remote areas.

3. Optimize GNSS Accuracy: Maintain a practical 4-meter accuracy requirement and schedule fieldwork to avoid environmental periods of reduced satellite availability.

4. Leverage Remote Sensing: Adopt advanced data collection methods, including high-resolution satellite imagery and drones, to capture assets in logistically challenging or dangerous areas.

5. Standardize GIS Workflows: Standardize GIS as the core platform for all road asset data to foster digital twin development and predictive maintenance modelling.

6. Investigate Accident Correlation: Utilize the newly established streetlight repository alongside spatial accident data to analyse correlations between infrastructure lighting and nighttime traffic safety, effectively prioritizing future interventions.

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BIOGRAPHICAL NOTES

Jason Pierre Truter is a GIS Professional in the Western Cape Government in the Department of Infrastructure and Master of Philosophy (MPhil) candidate in Transport Studies at the Department of Civil Engineering, University of Cape Town. His work bridges the gap between traditional civil infrastructure management and advanced geospatial technologies. Working closely with the Western Cape Government (WCG) Roads Infrastructure Directorate, his research focuses on the practical application of Geographic Information Systems (GIS), mobile data capture, and spatial analysis to optimize public asset management and support data-driven decision-making in the public sector.

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