PROPOSED METHODOLOGY OF OPTIMIZING THE SECONDARY PUBLIC TRANSPORT NETWORK OF A CITY IN DEMAND

Mashudu Rathogwa and **Afika Singano**

CSIR

Mrathogwa@csir.co.za; ASingano@csir.co.za

ABSTRACT

In 2019/20, it was of major importance to identify an alternative network within the Integrated Public Transport Network (IPTN) that can meet the increasing population demands. Being composed of high-capacity corridors, the current IPTN still requires a secondary network to meet day to day transporting needs (City of Joburg, 2019). Since the city's land isn't utilized very densely, the main network only serves a small part of it. High-capacity modes may service the primary network. The secondary network is necessary to support the primary network. The capacity of the secondary network is far lower than the city's real demand for public transportation. The majority of public transportation journeys cannot be accommodated by the primary network. This is because they are built on roads that don't work as well and aren't good for high-capacity technologies like Bus Rapid Transit (BRT). The secondary network provides services in places where it would be too expensive to set up and run the primary network. The smaller buses and minibus taxis that make up the secondary network have fewer seats. For example, while the primary network requires 365 000 seats during peak hours (assuming a seat utilization rate of 60%), the secondary network requires approximately 2 million seats during peak hours (City of Joburg, 2019). This paper explores using the traveling salesman method to identify and analyze the secondary network that meet the current demands.

1.INTRODUCTION

The minibus taxi business is a big part of the economy and helps people get around in both rural and urban areas. The industry employs a large number of individuals and circulates vast sums of money. Despite the fact that the organization of the taxi industry varies from country to country and even within countries, there are commonalities across the globe. A lot of people work in the minibus taxi business, such as minibus taxi drivers and marshals. The wages paid by minibus taxi owners to the two aforementioned parties have piqued the interest of scholars from diverse fields, including economics, medicine, labor, and psychology. But most of this research only looks at a small part of the problem and doesn't relate to each other.

According to the 2019/2020 Johannesburg Household Survey, about 60% of households spend more than 10% of their finances on public transport in the City of Joburg (CoJ). Morning peak-period travel refers to a trip that starts between 06:00 am and 09:00 am (National Household Travel Survey South African, 2020). Work trips accounted for 43% of total morning peak-period trips, and education-related trips made up about 12% of the total during the morning peak. Minibus taxis were the most common mode of transportation, followed by cars driven by the passenger and walking the entire distance was the least common mode of transportation.

Household members rated various aspects of the minibus taxi service based on their level of satisfaction. Even though more people are satisfied with minibus taxi services than are dissatisfied, customers are typically dissatisfied with the prices, the conduct of the drivers, and the safety of the vehicles (National Household Travel Survey South African, 2020). People choose to not utilize taxis because they prefer to drive their own vehicles which is further motivated by the expensive taxi fare. In the majority of instances, taxis are not roadworthy, which is one of the least frequently cited reasons for not using them.

Longer travel times and reliance on lower capacity modes of transportation in a city with a rapidly expanding population indicate that the quality of service at the CoJ and Gauteng Province is deteriorating. Criminal activity is also becoming a threat to public transportation riders. Walking to access public transportation is particularly unsafe for respondents. People who take public transportation need to feel safer. Law enforcement services therefore need to work collectively in mitigating the concerns from public transport users (National Household Travel Survey South African, 2020).

The main aim of this research is to optimize the current routes used by taxi operators into routes that are more beneficial to the taxi users, operators, the environment and the economy. This will be achieved by obtaining and cleaning the datasets of interest (taxi routes, taxi ranks, economic nodes, population), followed by using the Traveling Salesman Problem algorithm to determine the optimized route and lastly, to validate the algorithm used.

2. LITERATURE REVIEW

2.1. Traveling Salesman Problem Algorithm

The Traveling Salesman Problem (TSP) is a well-known mathematical optimization problem that is widely used in a variety of fields, such as transportation, logistics, and supply chain management (Robinson, 1949).

The disadvantages and the advantages according to Robinson (1949) of the TSP are outlined below.

Advantages of TSP:

1. TSP provides an efficient way to find the optimal route for a vehicle to visit a set of customers, or delivery locations.
2. TSP can be used to minimize the total distance traveled, thus reducing fuel consumption and other transportation costs.
3. TSP can be used to minimize the total travel time, thus increasing the efficiency of delivery or transportation operations.
4. TSP can be used to consider multiple objectives such as minimizing distance, minimizing time, or maximizing profits.

Disadvantages of TSP:

1. TSP can be computationally intensive for large numbers of customers or delivery locations, which can make it impractical for real-world applications.
2. In real-world applications, TSP's assumption that the distance or time between each pair of customers or delivery locations is fixed may not be accurate.

3. TSP may not be able to account for additional crucial factors such as traffic congestion, weather conditions, or vehicle capacity.

The second disadvantage is mitigated in this research as points of interests are considered as zones rather than a single point of minimal area to account for the fixed location assumption. TSP is a potent algorithm that can be used to determine the optimal routes for transportation and delivery problems. However, it is essential to be aware of its limitations and to employ other strategies when necessary (Robinson, 1949).

2.2. Characteristics of public transportation

In 2020, a National Household Travel Survey was conducted among South African homes. The objectives of the survey included, but were not limited to: determining the transport needs of households and travelers; determining the cost of transport and determining whether households can afford to pay for the mobility that is essential to their survival; assessing attitudes toward transport services and facilities; measuring the availability and use of motor vehicles; and gaining an understanding of the travel preferences of different market segments (National Household Travel Survey). This survey is the most comprehensive of its kind ever conducted in South Africa and will be used to describe aspects of public transportation in the country.

As stated previously, the affordability of public transportation is one of the most significant challenges facing developing economies. Approximately less than 20% of South African households surveyed have a monthly income greater than R6000. The majority of households (more than 80%) had a monthly income of less than R6,000. According to the National Household Travel Survey, bus and taxi services are substantially more accessible than rail services in terms of walking distance to modes of transportation.

This is predictable due to the flexible route and network characteristics of bus and taxi services. It is intriguing to notice that even at the lowest levels of household income, automobile ownership is achievable. This climbs gradually and is quite high for households with monthly incomes over R6,000. This is a worrisome trend in the nation, as the middle class is expanding rapidly due to the nation's strong economic performance. Formerly reliant on public transportation, an increasing number of people are opting to drive for their mobility needs. The poll indicates that 26.1% of families had access to a motor vehicle, with an average of 0.40 vehicles per home. In the first world, the increasing popularity of private automobiles does not bode well for public transportation systems. Over half of the families surveyed indicated that the most significant problem with public transportation was that it was either unavailable or too far away. One-third of households cited safety from accidents and bad driver behavior as the most important transport issue (particularly in relation to taxi services), while 20% cited the cost of transportation as a serious issue (National Household Travel Survey, 2020). 71% of users were unsatisfied with crowding on trains, 64% were dissatisfied with security during the walk to stations, and 63% were dissatisfied with security on trains. 74% of bus riders were unsatisfied with bus stop amenities, 54% with overcrowding, and 51% with insufficient off-peak frequencies. Users of minibus taxis were most dissatisfied with safety from accidents (67%), lack of facilities at taxi ranks (64%), and lack of vehicle roadworthiness (60%).

2.3. Background of the Minibus taxi industry

The minibus taxi business (primarily running 16-seater minibuses) carries around 65 percent of the nation's commuters. In 1982/83, the industry began small-scale operations. The list below shows the operating statistics for Minibus taxis in South Africa (Walters, 2008).

- Number of people using taxi services each day: 14 million +
- Number of officially registered minibus taxis on South African roads: 120 000 +
- Average number of taxis per owner: 2
- Average number of hours taxi drivers spend daily on the road: 8.8.
- Number of days each taxi driver works per week: 6.33.
- Average monthly kilometers driven by a taxi: 8,000.
- Average number of passengers transported monthly per vehicle: 3,161.
- Average time spent daily in a taxi by a passenger: 65 minutes.
- Average number of trips per passenger per day: 2.3.

During a national transport strategy review in 1986, government law encouraged the arrival of this mode of transportation, which quickly grew to become the main means of transportation in the country (Walters, 2008). The list above displays taxi industry statistics. Due to the lack of a strong regulatory framework, the industry has been operating in a de facto unregulated environment (Boudreaux, 2006). This has led to an oversupply, problems with capital replacement, and a lack of economic viability over the long term. In the early years of the taxi industry's inception, it also resulted in intense inter-association and operator competition, as well as dramatic taxi wars. This was the outcome of rising competition for passengers on routes among taxis (Boudreaux, 2006). Rivalry persists and frequently results in bloodshed, fatalities, and injuries. Inadequate service standards, low-quality (for their intended purpose) and generally dangerous vehicles, a general lack of adequate maintenance, and economic viability problems plague the business.

As the industry expanded, a large number of local route organizations were formed, which eventually led to the formation of larger local, regional, and interregional associations (Boudreaux, 2006). This hindered government engagement with the industry. This prompted the government to establish a single formal consultation body through which to consult with the industry. Provincial elections and provincial structures were organized. As a result of these arrangements, in 2001 the South African National Taxi Council (SANTACO) was established in Durban. However, not all operators participated, resulting in the exclusion of a number of large regional associations from the SANTACO procedure (Boudreaux, 2006). Notwithstanding this, the government has continued to include SANTACO in all of its taxi industry discussions.

Industry sustainability has always been a problem. The majority of taxis are quite old and have traveled considerable distances (Walters, 2008). The majority of vehicles are typically regarded as unfit for the road due to their poor condition. This circumstance is the result of a lack of financial viability, which prevents the industry from adequately recapitalizing or maintaining its vehicles (Walters, 2008).

2.4 Route and rank control

Competition between operators and associations for the right to operate on routes and into ranks is a significant source of industry problems. Routes and ranks are currently administered by operator associations (Walters, 2008). The federal government intends to seize control of routes and ranks currently "owned" by route operator associations. These associations regulate

access to certain routes and ranks by imposing entrance fees and limiting the number of operators on each route. As it affects the livelihoods of numerous industry association members across the country (Walters, 2008).

3. METHODOLOGY

This section aims to highlight the various methods used to successfully achieve the objectives of this research.

3.1. Study Area Description

This research was performed in Region F of the City of Joburg, Gauteng province, South Africa, with coordinates 26.2301° S, 28.0523° E. This province covers an area of 322 km^2 on the southeastern portion of CoJ. This region contains the CBD which is the densest regions within the CoJ. Figure 1 shows the location of the study area from a South African perspective.

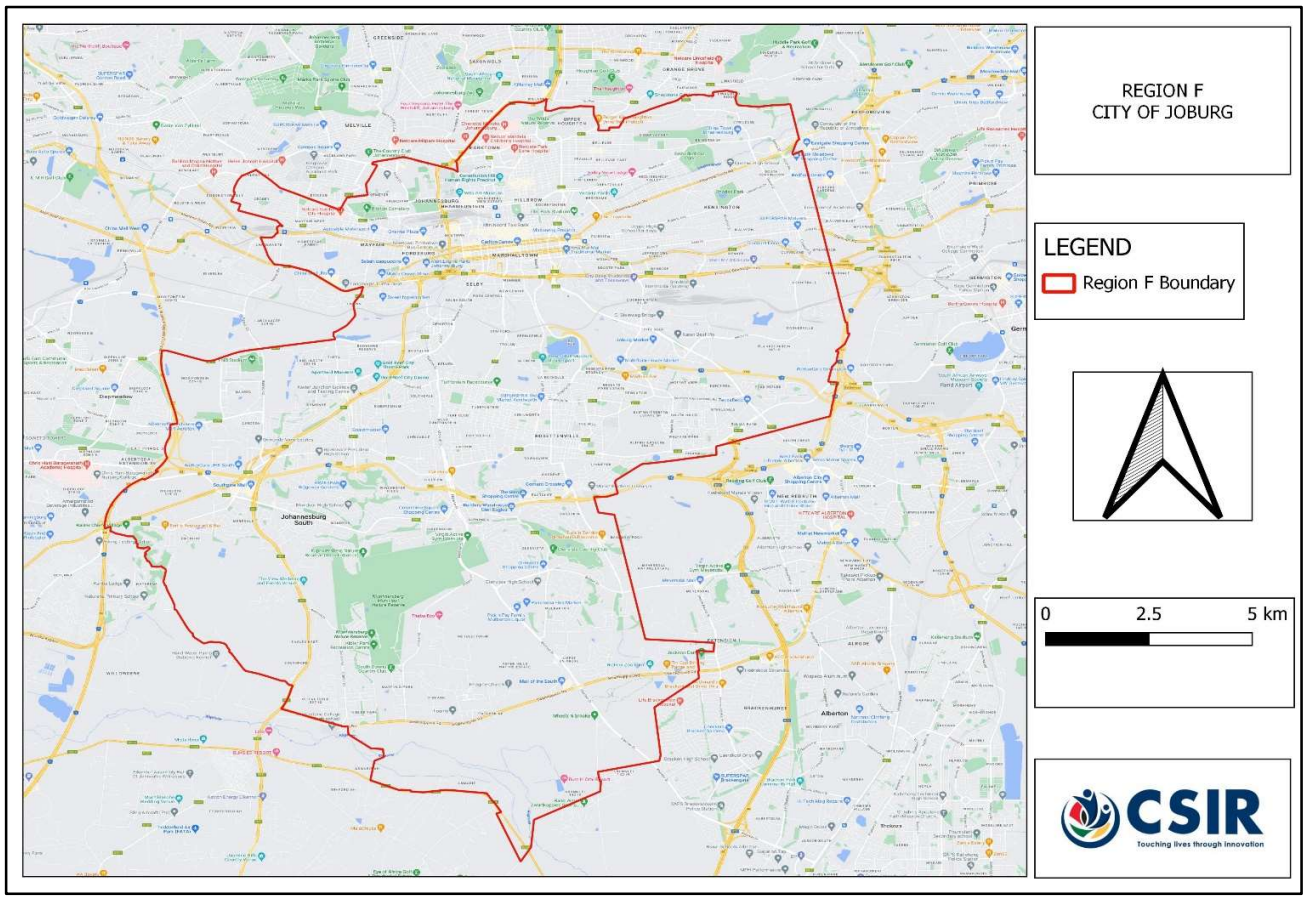

Figure 1: Map showing the boundary of region F.

3.2. Data and materials

The primary datasets for this study include taxi routes surveyed in the City of Joburg Region F, as well as points of economic interest/desired locations within the region. The desired locations are either taxi ranks (a physical structure) or economic nodes within region F. These datasets

are obtainable from the CoJ municipality. The datasets were further cleaned for analysis on a GIS. Figure 2 shows the datasets used in this research.

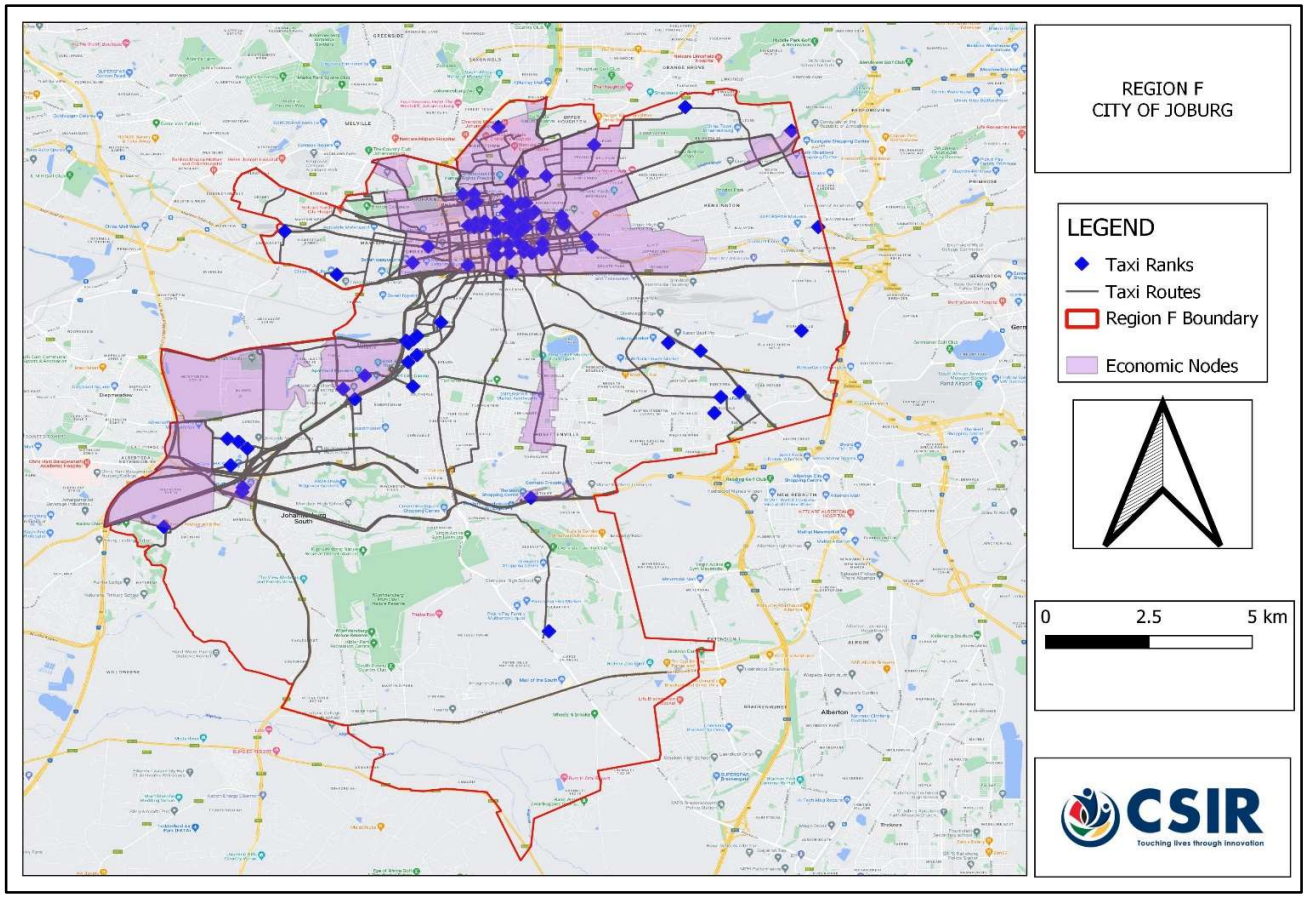

Figure 2: Map showing datasets used in this research.

The minibus taxi routes and regions of interest were used as inputs into the GIS platform using ArcGIS Pro so that they could be visually assessed. A network dataset was then created using the minibus taxi routes as the "network" and taxi ranks and economic nodes as the "stops." The Traveling Salesman Problem (TSP) algorithm was then applied to the network dataset using the Network Analysis tool in ArcGIS Pro. This made it possible to find the best order and routes for stopping at different locations. During processing, the TSP algorithm makes an origin-destination cost matrix for all the stops that need to be put in order. It then uses a local search-based algorithm to find the best order of stops based on "cost." In this regard, "cost" refers to the route/network distance and time taken to travel from one point to the next.

This algorithm was chosen because it can find efficient routing solutions, which helps optimize and reduce costs (in terms of distance and time). This should help you figure out the best way to get to and from taxi stands.

The TSP algorithm is perfect for applications that need to find the best route because it can be used in complex and changing situations and adapt to new distances, times, etc. This algorithm

also works better when global optimization techniques like neural networks and simulated annealing are added to it. The TSP algorithm, on the other hand, is not ideal for a large number of "stops." This is because TSPs are hard to solve computationally and take exponential time to converge, which makes the outputs uncertain.

After the route optimization process was done, a network layer was generated that showed the best route with the least amount of cost to and from each stop (taxi rank). To make sure these results were correct, two taxi ranks were chosen to represent the start and end of a minibus taxi route. The TSP algorithm was then used on this new network dataset, which had similar properties to the first network dataset. This was done to see if the algorithm would pick routes that were similar to the ones in the first network dataset, which had all the stops.

4. RESULTS AND DISCUSSION

This section is meant to show the most important results of this research and talk about the most interesting things that were found.

The results obtained from TSP indicated the ideal optimized taxi route. This route is ideal because it provides the most efficient and effective route to transport people from their origin to their destination. The optimization process takes into account various factors such as distance, people (demand), as well as the type of transport being used. These factors, together with modeling techniques, aim to minimize travel time, reduce fuel consumption, lower operating costs, and, above all, maximize the overall efficiency of the transport system. Figure 3 below shows the identified optimized taxi routes obtained from TSP route analysis.

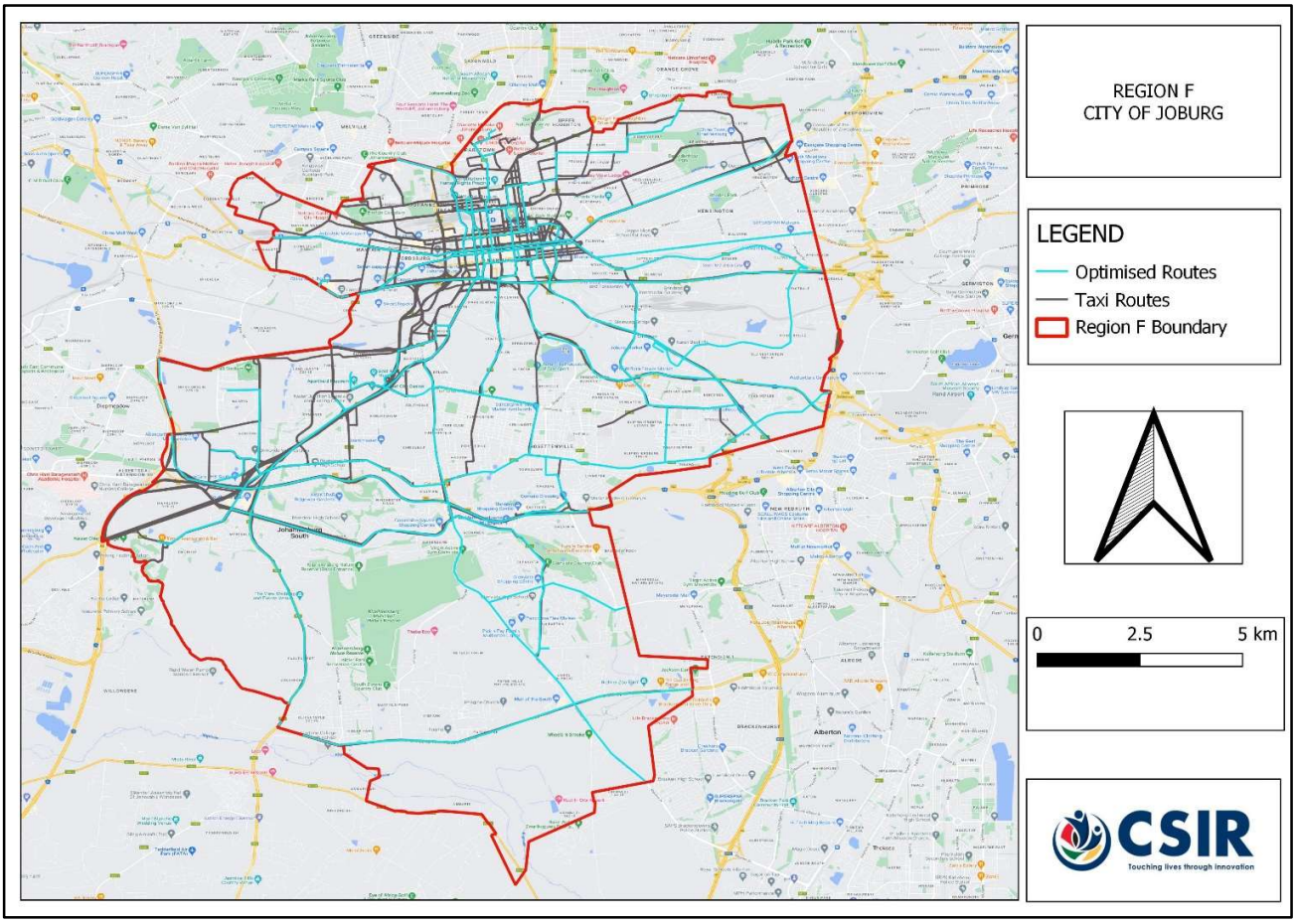

Figure 3: Optimized route vs current taxi routes.

The optimized route was overlaid with the taxi route datasets, and differences were observed using a GIS. The main factors that were observed from the resultant optimized route are listed below:

- Improved Efficiency: The optimized route reduces the distance and time required to transport people from one point to another. This reduction in travel time and distance translates to improved efficiency, which helps to reduce the cost of transportation and increase profits which benefit both taxi operators and government.
- Increased Safety: The optimized route considers road conditions, traffic patterns, and other safety factors in question. By taking these factors into account, transport engineers can identify the safest and most reliable route, reducing the risk of accidents and improving safety.
- Enhanced Customer Satisfaction: The optimized route enables the delivery of goods or services as well as people within the agreed timelines, improving customer satisfaction. Satisfied customers are more likely to return and recommend the service to others, which translates to more business.
- Reduced Environmental Impact: The optimized route reduces the amount of fuel consumed, which leads to reduced greenhouse gas emissions and a smaller carbon footprint. This is a crucial factor in today's world, where climate change and environmental sustainability are major concerns.

- Cost Savings: The optimized route helps to reduce operating costs by minimizing fuel consumption, reducing wear and tear on vehicles, and improving driver efficiency. These cost savings are beneficial to both the taxi operator/owner and the customers who benefit from lower transportation costs.

The TSP method used was validated by selecting one origin and one destination in order to determine on a local scale, without excess information, whether an optimized taxi route would be selected. Figure 4 below shows the optimized route identified which meets the desired requirements as mentioned above.

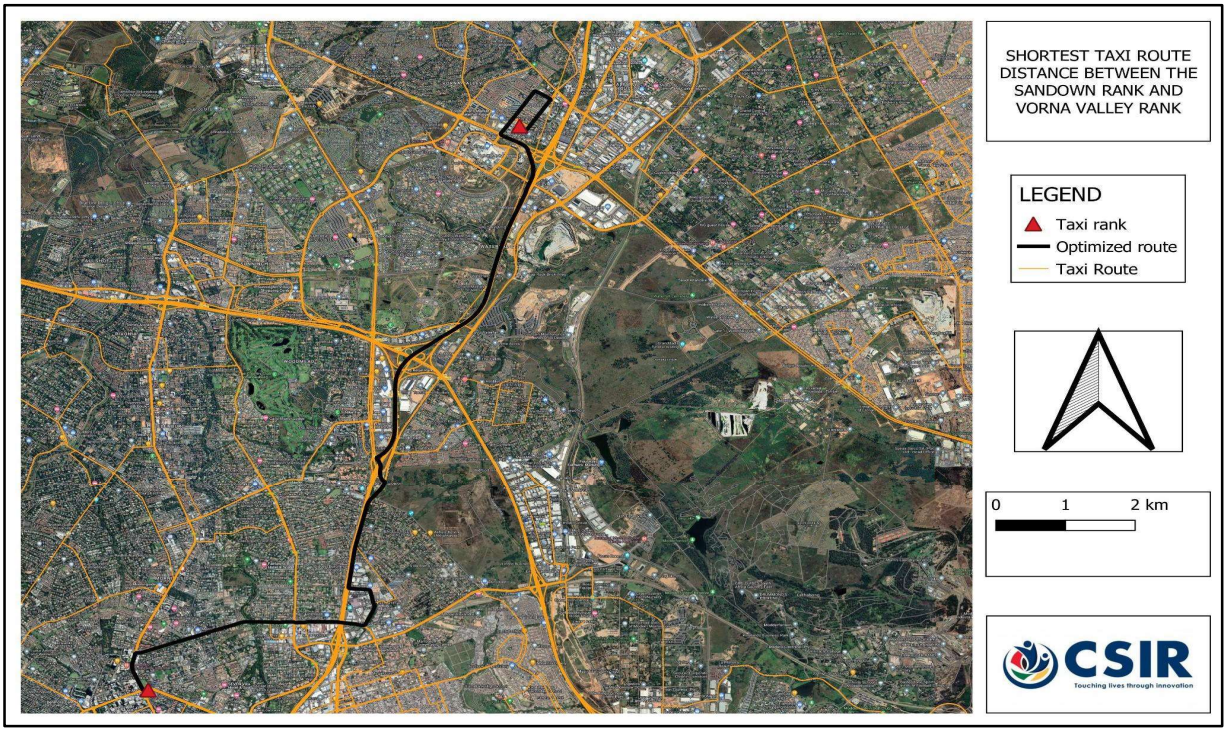

Figure 4: Optimized route between an origin and destination point.

5. CONCLUSION

In conclusion, getting an optimized route is important for making sure that transportation is safe, efficient, and cost-effective, while also reducing the damage that transportation activities render to the environment. The methods proposed in this study are intended to significantly alter the operations of the industry. Formalization of the industry, including minimum operating hours, maximum work hours, and tax compliance mandates, will be necessary. The route-specific nature of operating rights will also result in greater industry order, which will benefit both users and operators. If these measures are effective, the nation can anticipate a variety of public transportation options that operate in accordance with integrated transport plans.

6. REFERENCES

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