ASSESSING URBAN INTER-MODALITY IN CAPE TOWN: A MICROSIMULATION ANALYSIS OF N2 HIGHWAY TRAFFIC PATTERNS FROM 2005 TO 2023

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ABSTRACT

In the quest for sustainable urban transport solutions, the emphasis is on congestion reduction, and efficient travel times. A better understanding of the two can be achieved via comprehensive traffic modelling. Using the PTV Vissim microsimulation modelling, this research investigates changing traffic patterns occurring on the N2 highway in Cape Town since 2005.

The preliminary research indicates that there has been a significant change in actual traffic patterns, which may be attributable to several causes, such as changes in population, economy, transportation alternatives, cost of travel, quality or formal public transport services, and land development, over the years. Primary data from 2005 and 2023 served as a baseline and was used to validate and calibrate the PTV Vissim model.

The travel times which serve as the performance metric, display substantial increases, highlighting the necessity of investing in a reformed transport system. It is intended that the findings of this study provide policy directives to city officials in Cape Town, thereby contributing to the development of a transport ecosystem that is more integrated, efficient and user friendly.

1. INTRODUCTION

Cape Town's internal transport system is heavily dependent on highway corridors, with the N2 being particularly influential in shaping the socio-economic structure of the region. The N2 highway plays a crucial role in facilitating the transportation of both persons and cargo, as it connects various urban and suburban areas. Nevertheless, the city faces significant challenges, mostly in the form of traffic congestion, which severely hampers the everyday lives of commuters and diminishes the effectiveness of its transportation network.

The occurrence of traffic congestion in Cape Town, as well as other metropolitan areas, is not solely caused by a large number of vehicles, but it is also greatly affected by spatial planning and policy decisions. Downs (2004) discusses the complexity of traffic congestion in metropolitan areas, highlighting how spatial planning and policy decisions significantly impact urban transport infrastructure. These determinations have a lasting impact on the transport infrastructure and spatial regulations of the municipality, ultimately influencing the levels of traffic congestion. The effectiveness of these measures can be evaluated by examining traffic congestion, which requires a thorough study and analysis to enhance traffic management (Van Wyk, 2021). Examining traffic congestion is one way to determine how effective these measures are, however, in order to improve traffic management, a thorough investigation and analysis are necessary (Cantisani, et al., 2018).

The city's expanding population and the ensuing rise in motorised traffic exacerbate the problem of traffic congestion (Malibari et al., 2022). This reality demands for innovative and sustained interventions; one option is the use of microsimulation models to identify these interventions. Microsimulation provides a comprehensive representation of individual vehicle behaviour and interactions, allowing for a precise understanding of traffic flows and congestion patterns. According to Hasan et al. (2023), microsimulation offers a thorough depiction of each vehicle's behaviour and interactions, enabling a precise comprehension of traffic flows and congestion patterns.

This study focuses on assessing the urban inter-modality of Cape Town by conducting a microsimulation analysis on the N2 highway from 2005 to 2023. This study utilises the PTV Vissim microsimulation software to investigate the changes in traffic flow and congestion that have occurred throughout this period. A comparative analysis was conducted to examine the traffic patterns in 2023, using the 2005 data as a benchmark. The primary aim of the study is to contribute to the improvement of a more integrated, efficient, and user-friendly forecast transportation system in Cape Town guided by data-driven insights.

1.1 Study Area

The study was conducted on the N2 highway in Cape Town from the airport on ramp to just after the main road off ramp. The simulations were extended to the M3 highway just after the main road, as shown in Figure 1.

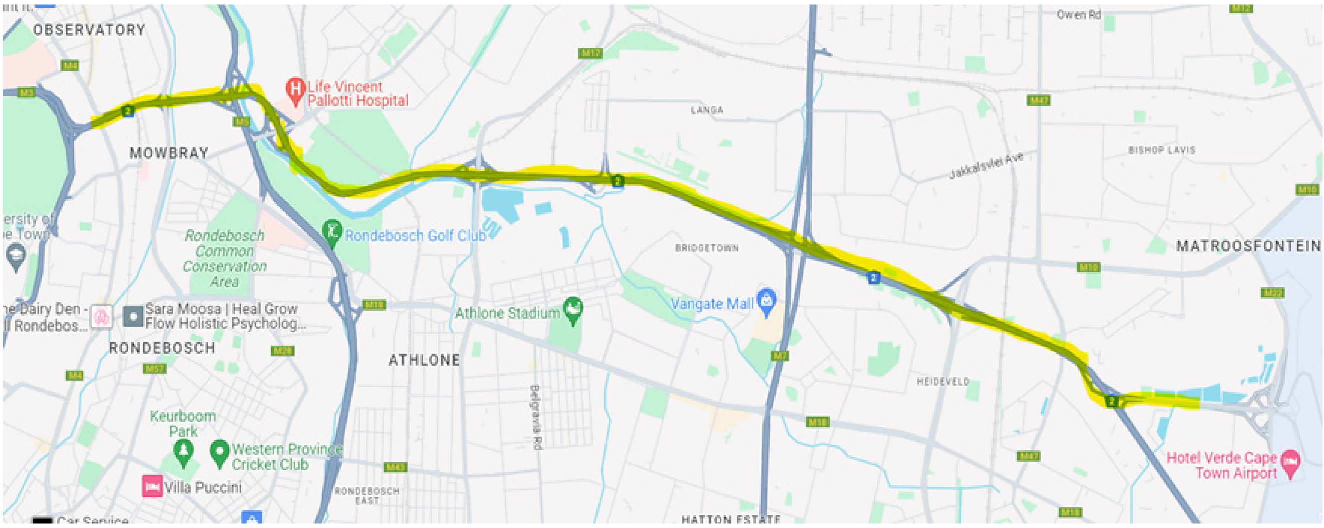

Figure 1: Study Area

1.2 Aim of the Paper

The objective of this paper is to conduct an extensive analysis of traffic patterns on the N2 highway in Cape Town, assessing changes from 2005 to 2023. Understanding the interconnected factors, including urban growth, policy shifts, technology advances and the availability of public transit shape traffic flows, congestion rates, and overall transport dynamics, forms part of the paper’s central goal. Khattak and de Palma (1997) explore how growth in technology advances shape traffic flows and congestion rates, underlining the necessity of innovative strategies for sustainable transport. By delving into these influences and their impacts over time, the investigation aims to produce relevant and actionable insights for decision makers, urban planners, transport authorities, and stakeholders. Applying these insights can lead to innovative strategies and interventions that promote more sustainable transport practices, congestion relief, and improved urban living quality. The paper's ultimate aspiration is to contribute to a more effective, integrated, end user friendly transportation system in Cape Town, leading to a resilient and thriving urban ecosystem.

1.3 Scope of the Paper

The paper examines the utilisation of the PTV Vissim software to understand traffic patterns in Cape Town. The main objective is to use traffic data from the year 2005 to calibrate the model and compared it with the projected figures for 2023. The study explores the impact of transport initiatives and changes in the land use of traffic patterns, while also examining the development of commuting habits. Button et al. (1993) emphasises the significance of examining the development of commuting habits and the impact of transport initiatives on traffic patterns. The conclusions and recommendations derived will serve as a significant aid to urban planners and policymakers in enhancing traffic management and fostering sustainable cities.

2. THE MICROSIMULATION MODEL

In their discussion of the development of microsimulation models, Vanderschuren (2006), and Wunderlich et al. (2019) emphasise the importance of these models for analysing vehicle behaviour and interactions in transportation networks. The microsimulation model used in this study aims to analyse urban inter-modality in Cape Town through a comprehensive analysis of N2 highway traffic patterns from 2005 to 2023. By simulating the movement of vehicles and their interactions within the transportation network, this model provides valuable insights into the dynamics of traffic flow and its implications for the city's transportation system. It allows for a detailed examination of factors such as travel times, speed variations, and changes in vehicle class distribution, which are essential for understanding the changes and opportunities in urban transportation.

2.1 Model Input Data

The model’s input data initially comprised traffic volumes recorded between 06h00 and 10h00 in 2005. This historical data provides a robust basis for calibrating the simulation model, ensuring that the simulated traffic behaviour closely mirrors real-world conditions. In 2023, additional data from SANRAL, which included information on class 1, 2, and 3 vehicles was incorporated into the calibrated model. To facilitate ease of modelling and account for the different input requirements of the two models (PTV Vissim and Paramics), both the 2005 and 2023 data were converted to person car equivalents. Additional input data includes road geometry and vehicle characteristics, which are crucial for creating a realistic traffic scenario in the Vissim environment. Figure 2 provides the primary data incorporated into the software.

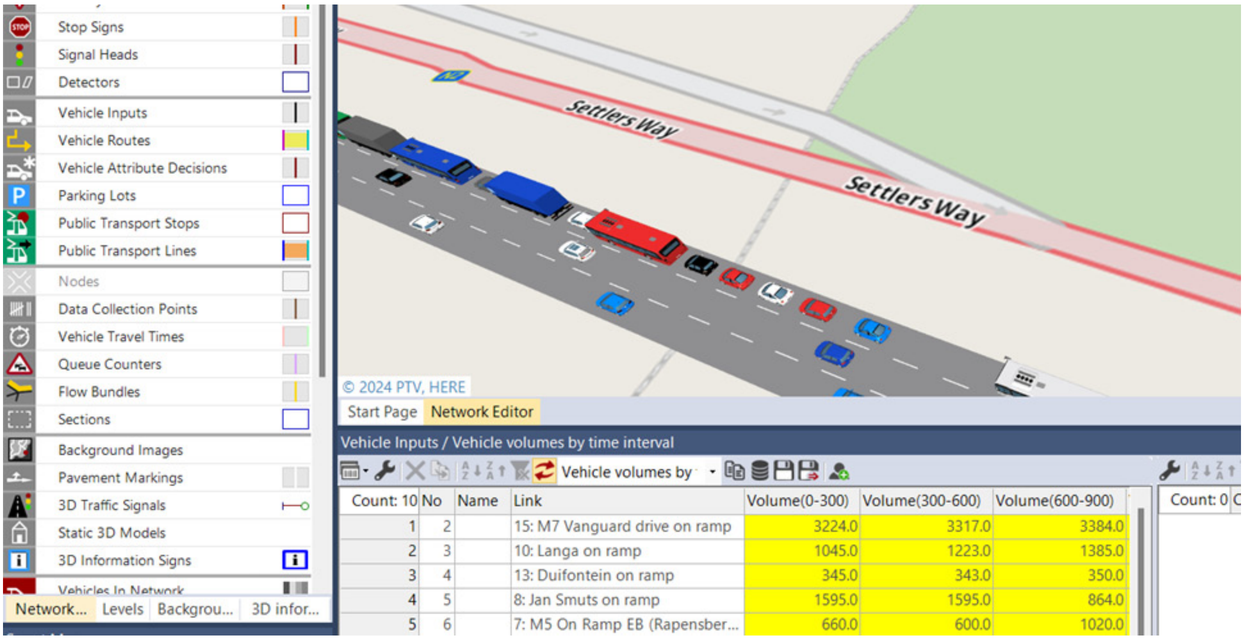

Figure 2: Model input data

2.2 Data Collection Process

On March 29, 2023, a detailed data collection was carried out on one of the busiest days of the year on the N2 highway, to ensure a robust analysis of peak traffic patterns. SANRAL's vehicle detecting stations (VDS), strategically placed at various segments of the highway, operated continuously from 06h00 to 10h00. These stations were not just passive data recorders; they represented an advanced traffic monitoring technology capable of capturing nuanced details such as varying vehicle types, their volumes, and speeds. This period was specifically chosen as it represented the morning peak hours, a critical window to understand the maximum stress on the road network and road user patterns on the N2 highway.

Data Conversion and Advanced Modelling in Vissim: The subsequent step involved the translation of this multifaceted data into standardised format-person car equivalents (PCEs). This conversion was pivotal for modelling in Vissim as it allowed for a more accurate consistent representation of traffic flow, irrespective of vehicle size and type. In the Vissim environment, the PCE-based data was meticulously fed to recreate a detailed and dynamic simulation of the traffic conditions. This simulated environment was not only a digital representation; it was a complex, interactive model that reflected real-world conditions, including the variability in driver behaviour in the interactions between different vehicle types. By focusing on the peak hours of the busiest day, the simulation aimed to provide an exhaustive analysis of the traffic dynamics, offering valuable insights for traffic management and infrastructure planning on the N2 highway.

2.3 The Calibration Process

Calibration of the microsimulation model was a critical phase, involving a meticulous comparison of travel times from the 2023 Vissim model against those from the 2005 Paramics model. This comparison was not a straightforward task, due to the temporal gap and the different natures of the software involved. It required careful analysis of peak hour traffic data, considering the traffic volumes, road network complexities, and various traffic management strategies implemented over the years.

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2.4 Measured Travel Times

The actual travel times were measured on the N2 highway in Cape Town from the airport on ramp to just after the main road offramp. The exercises were conducted both in 2005 and 2023 on one of the busiest days of the year. The data was then used for calibration in both models (Paramics in 2005 and PTV Vissim in 2023). Figure 3 shows scatter plots of the comparisons of the actual measured travel times.

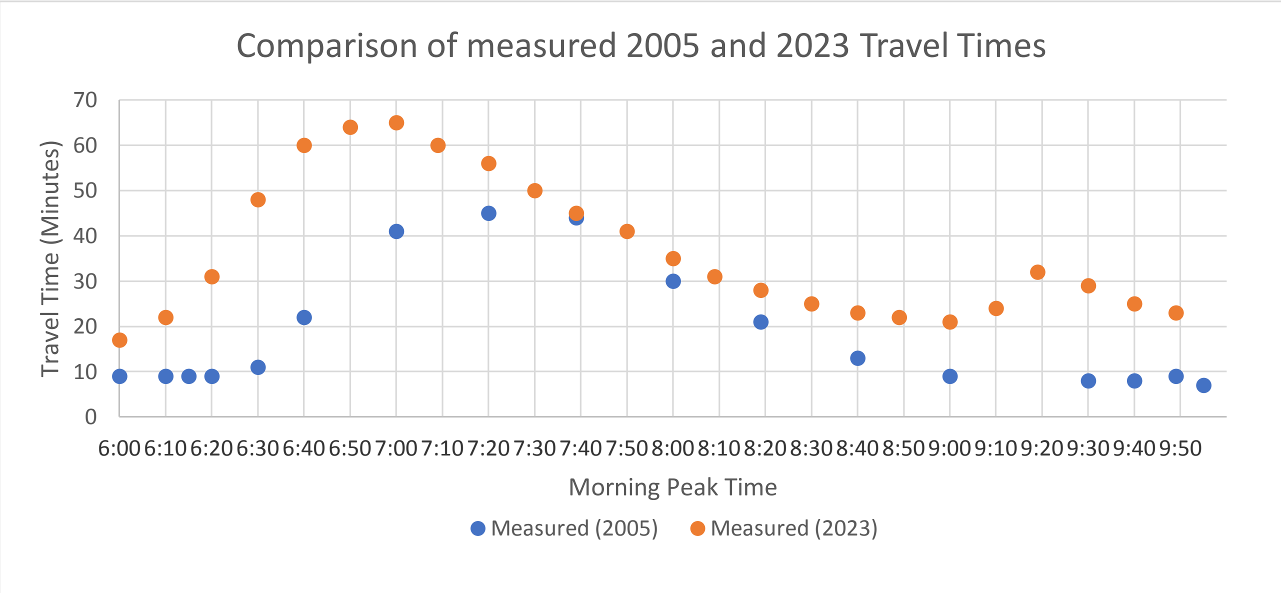

Figure 3: Measured Travel Times

Analysis: During the morning peak hour:

- Travel times increase sharply during the morning peak hour, and this is evident in both 2005 and 2023 with travel times peaking at around 7:00 and 7:50AM.

- Increased congestion in 2023: Comparing the two years, it is clear that travel times in 2023 were generally higher than in 2005 at almost every measured point in the morning hours. This suggests that traffic congestion has worsened over the past 18 years.

- Peak congestion time: The peak congestion time have shifted slightly later in the morning in 2023 compared to 2005. This could be due to changes in work patterns or school times, influencing when the majority of commuters are on the road.

- Persistent congestion: In 2023, high travel times persist until around 8:30 in the morning, which indicates a prolonged period of congestion that starts in the early peak hour and lasts through the mid-morning.

The trend, in this case, is that travel times on the N2 highway in Cape Town have increased from 2005 to 2023 during the morning hours, reflecting a growth in traffic congestion. This could be due to a variety of factors such as increased vehicle ownership, urban development leading to more commuters, or insufficient infrastructure improvements to keep pace with the increase in demand.

2.5 Calibration Results

In the detailed calibration results shown in Figure 4, a noticeable variation in travel times between the two models was evident. These discrepancies were particularly pronounced during peak traffic hours.

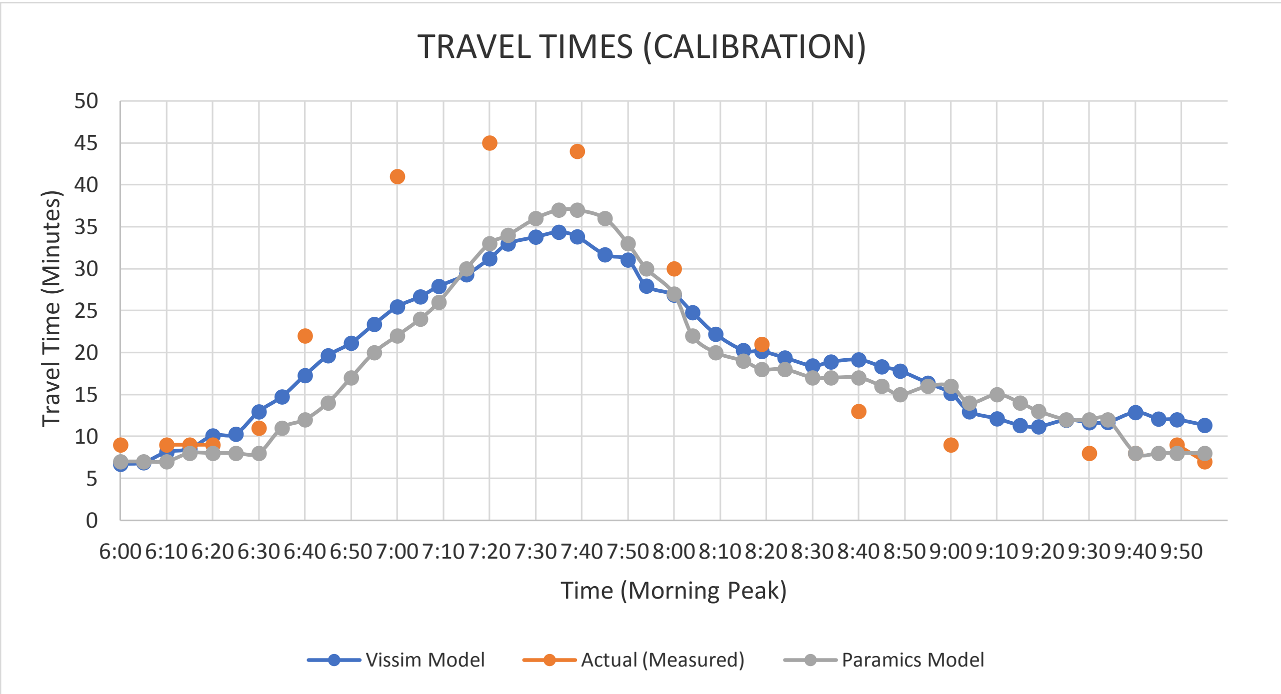

Figure 4: Simulated Travel Times

While the Vissim model often showed longer travel times, it's crucial to note that these differences were not uniform across all intervals or sections of the highway. Some areas showed closer alignment than others reflecting a complex interplay of various factors affecting traffic flow.

The difference in travel times could be attributed to a number of factors:

- Modelling Software Differences: Vissim and Paramics utilise distinct algorithms and traffic flow modelling techniques. These inherent differences naturally result in variations in the simulation outcomes, even when the same input data is used.

- Evolution of Traffic Patterns: Although the same 2005 data was used for calibrating both models, traffic patterns and behaviours have evolved over the years. This evolution might not be fully captured by the older model, leading to some disparities.

- Vehicle Classification and Conversion: The process of converting various vehicle types into person car equivalents involves assumptions and generalisations. This process, while necessary, introduces a level of approximation and can impact the accuracy of the simulation.

- Dynamic Traffic Conditions: Traffic is influenced by a multitude of dynamic factors like road works, weather conditions, and changes in driving behaviour over time. These elements add a level of unpredictability to the simulation, impacting calibration accuracy.

3. MODEL OUTPUT DATA

Through the micro simulation analysis, the authors obtained model output data offering a crucial perspective on the N2 highway's traffic patterns in Cape Town. The simulation enabled unlocking the intricate relationship between different modes of transport and their effects on travel durations and speed fluctuations. The Monash University Accident Research Centre (2008) provided evidence on how speed variations impact road safety, which is crucial for understanding the findings from the Vissim model outputs. The analysis conducted covers the period from 2005 to 2023 and provides a comprehensive overview of the changes in traffic conditions over this time. Analysing this output data reveals trends and patterns that enable informed decisions and policymaking about urban planning and transport infrastructure.

3.1 Increase In Travel Times

The analysis of the Vissim model outputs reveals a significant increase in traffic volumes on the N2 highway from 2005 to 2023. The increasing number of automobiles corresponds to the global rise in urbanisation and growing populations in cities. The acceleration in Cape Town can also be attributed to factors such as urbanisation and growth, which align with the traditional narratives from urban and traffic studies. Figure 5 shows one of the bottlenecks along the N2 highway that contributes to increased travel times.

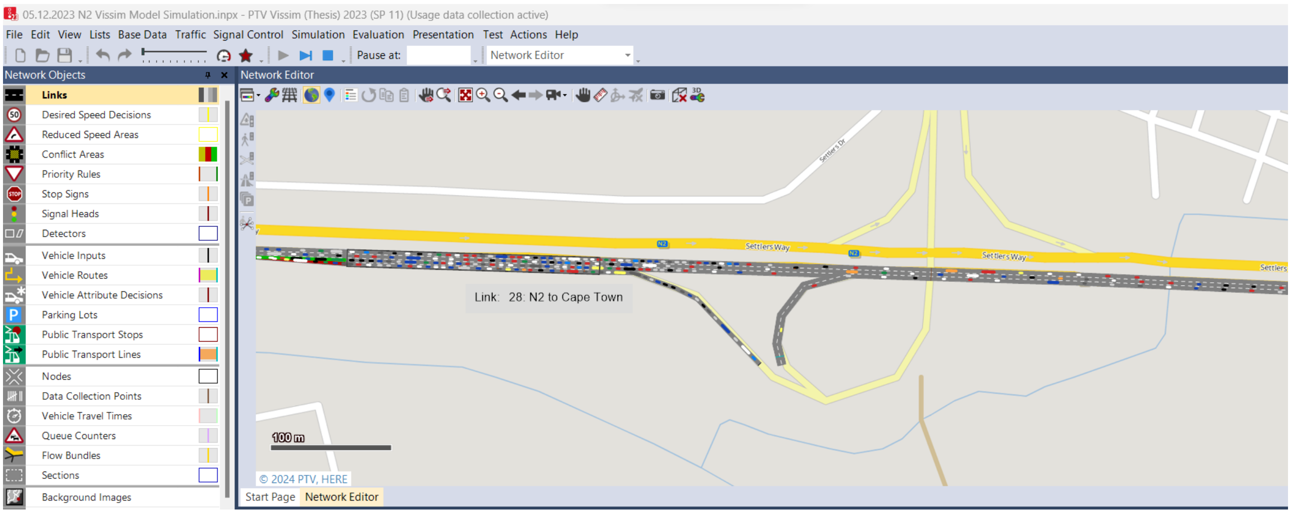

Figure 5: Congested Bottlenecks

3.2 Extensive Changes in Travel Times

By 2023, there has been a significant increase in peak-hour travel time compared to 2005. The increase in trip durations can be attributed to the effects of changes in road infrastructure and the growing number of vehicles throughout time. Increased traffic volumes, changes in the road grid, implementation of traffic control schemes, construction projects, and modifications in street configurations are the factors that contribute to longer trip durations.

3.3 Notable Speed Variations

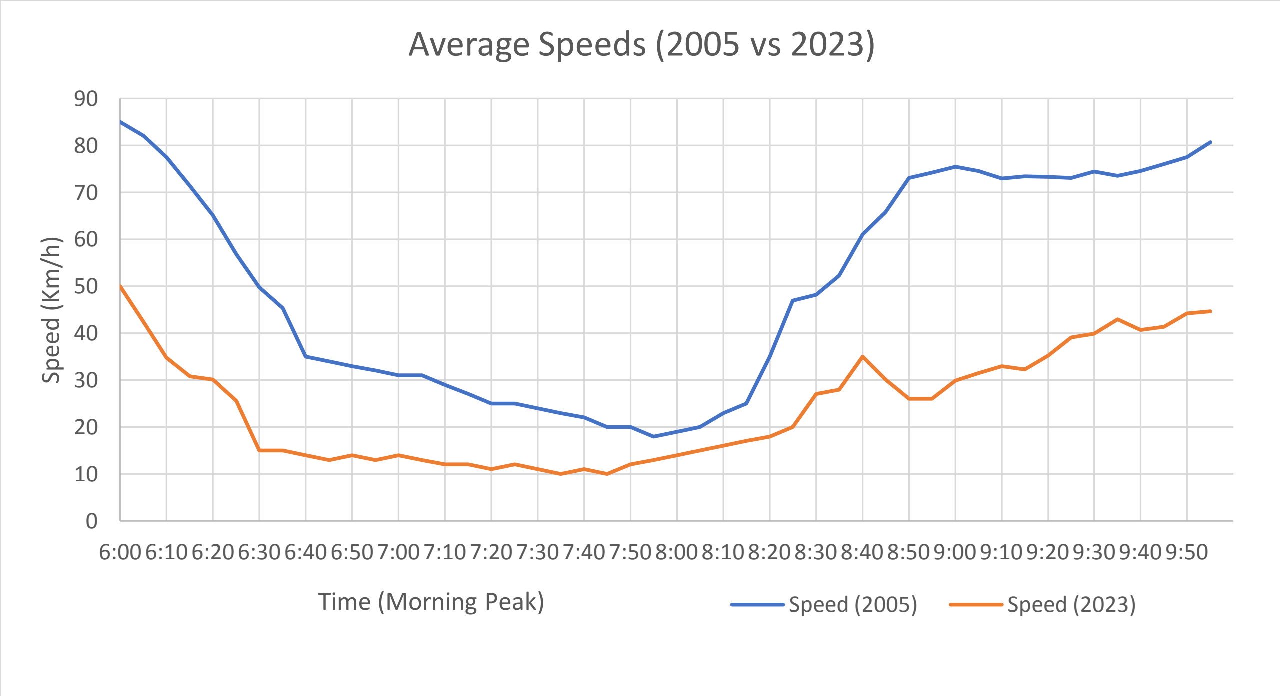

Figure 6: Drop in speeds during peak hours

A drop in average speeds during peak hours was seen in 2023 data simulation. This phenomenon corresponds to worldwide findings of declining speeds in urban roads, attributed to variables, such as increased congestion, enforcement of reduced speed restrictions for safety purposes, and the evolving characteristics of urban street environment. Research reveals that regulating vehicle speeds through design and intersection control is vital for promoting road safety (Global Designing Cities Initiative, 2020).

Analysis:

- Morning Speed drop: This significant drop in average speeds as the morning progresses in both years, starting high at 6:00 AM and reaching the lowest speeds at around 8:00AM for 2005 and slightly earlier for 2023. This pattern aligns with typical peak hour traffic where speeds decrease as congestion increases.

- Lower speeds in 2023: Throughout the morning period, average speeds in 2023 are consistently lower than in 2005. This suggests that there is more congestion on the highway in 2023, likely due to an increase in the number of vehicles on the road.

- Speed recovery: After the initial drop in speeds during the early morning, there is a recovery phase where speed gradually increase. This is particularly pronounced in 2005, where average speeds increase sharply after 8:00AM. In 2023, this speed recovery is more gradual and does not reach the same levels as in 2005, indicating longer-lasting congestion.

- End of the peak hour: Towards the end of the measured time period, average speeds in 2005 return to near the starting values, suggesting that the congestion has largely cleared. In 2023, Speeds also improve but remain well below the starting values, further suggesting increased and sustained congestion.

In summary, the average speeds on the N2 highway have decreased from 2005 to 2023, indicating that congestion has become worse over the years. The morning peak hour causes a significant decrease in speed due to traffic congestion, and the duration of the peak hour appears to have increased by 2023, affecting traffic speeds for a more extended period of the morning.

4. FINDINGS AND DISCUSSION

Microsimulation analysis of the N2 highway's traffic patterns between 2005 and 2023 revealed transformations in the urban interplay of varied travel modes in Cape Town. This transformation is rooted in increased traffic volumes, augmentation of travel times, adjustments in vehicle category distribution, and variations in speed. The Global Designing Cities Initiative's Global Street Design Guide offers insights into how urban interplay and varied travel modes are transformed by increased traffic volumes, supporting the findings of the study on the N2 highway. The study provides crucial insights into the consequences of these changes and serves as the foundation for ongoing discussion and research on the strategies to address these challenges and enhance travel within the city.

4.1 Implications of Increased Traffic Volumes

This substantial increase in traffic volumes on the N2 highway from 2005 to 2023, as demonstrated by the Vissim model outputs, emphasises the immediate requirement for efficient traffic management techniques. This rise is a clear indication of the worldwide urban growth patterns that have been seen. With the expansion of the metropolitan areas, it becomes imperative to use efficient traffic management strategies to avoid congestion and ensure smooth traffic flow. Strategies, such as implementing dynamic traffic control systems and enhancing public transportation can be effective responses to increased traffic volumes (Downs, 2004).

4.2 Addressing Extended Travel Times

The observed increase in travel times during peak hours necessitates interventions to improve traffic efficiency. Vanderschuren (2006) in her PhD thesis, discusses how ramp metering controls the rate at which vehicles enter the highway through on-ramp signals thereby managing traffic flows, hence reducing congestion. Since accidents also contribute to increased traffic congestion, incident management like rapid response to accidents or breakdowns can help clear lanes faster thereby reducing congestion.

Additionally, encouraging flexible work hours or remote working options can help distribute traffic more evenly throughout the day, thus reducing peak hour congestion (Khattak & de Palma, 1997).

4.3 Managing Shifts in Vehicle Class Distribution

The shift towards public transport, hence a higher proportion of larger vehicles, requires adjustments in road design and traffic regulations. Larger vehicles have different operational characteristics and can impact overall traffic flow. Implementing weight restrictions or designated lanes for heavy vehicles during peak hours could mitigate their impact on traffic congestion (Button et al., 1993). Heavy vehicles cause more wear and tear on road surfaces compared to lighter vehicles and by restricting their usage during peak hours means that the roads are preserved, leading to fewer repairs and road closures which can contribute to traffic congestion. Again, heavy vehicles often move slower than smaller vehicles and restricting their usage during peak times means that the overall traffic flow can be smoother and faster for other vehicles.

4.4 Responding to Speed Variations

The declining trend in average vehicular speeds, particularly during traffic peak hours, necessitates specific speed regulation strategies. The inclusion of traffic calming measures, for example, speed humps or lane narrowing, in select areas can control vehicle speed and promote safety. Additionally, raising awareness amongst drivers about their applications of speed on traffic fluidity and safety can also be beneficial (Monash University Accident Research Centre, 2008).

5. CONCLUSION AND RECOMMENDATIONS

A comprehensive analysis using microsimulation of the traffic patterns of Cape Town's N2 highway from 2005 to 2023 has yielded critical information about urban intermodality in the city. Utilising dynamic modelling tools, extensive data collection, and sophisticated modelling in Vissim, the simulation model effectively mirrored the escalation in travel times, substantial shift in commuting times, and noticeable speed fluctuations throughout the highway.

Main Findings: The study discovered that, despite some calibration errors, the data still offers insightful information and a strong basis for future model improvement. The observed differences in traffic patterns emphasise the necessity of updating models on a regular basis and incorporating real-time data to improve accuracy.

Implications: These data suggest that changing commuting patterns and rising traffic volumes are placing an increasing burden on the city's transport system. This emphasises how important it is to plan strategically and make focused interventions in order to improve the efficiency of Cape Town's transport system.

Future Steps: Adding more recent traffic data, modifying modelling parameters to account for modern driving habits, and investigating sophisticated calibration methods to reduce discrepancies are some examples of future steps that may be taken. This would make it more likely that the model will continue to offer precise and pertinent insights into the flow of traffic on the N2 highway.

Policy Recommendations: In light of the study's findings, it is advised that local authorities concentrate on enhancing intermodality and reducing the negative impacts of traffic patterns on urban mobility. This could entail putting laws into place that support sustainable transportation methods, enhance road infrastructure, and encourage the use of public transportation. Strategic urban transport planning is essential for enhancing Cape Town's transport system, as Wunderlich et al. (2019) highlighted.

6. ACKNOWLEDGEMENTS

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