EVALUATING OPERATIONAL AND CONGESTION IMPROVEMENTS ASSOCIATED WITH THE DUALLING OF SINGLE CARRIAGEWAY ARTERIALS

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ABSTRACT

Changes in land use zoning and major developments can generate significant traffic along major arterials, resulting in congestion and worsening operational conditions if no intervention is undertaken. Road authorities mitigate this through the upgrade of roads such as dualling single carriageway arterials. The purpose of this study is to evaluate the impact of dualling a single carriageway arterial. Congestion relief and changes in operational conditions are evaluated using Floating Car Data (FCD). The upgrade of the R310 from a two-way, two-lane road to a dual carriageway road with two lanes per direction between the N2 interchange and Annandale Road in Stellenbosch is used as a case study to evaluate travel time changes and average speed along the route. The use of FCD provides a greater understanding of the differential in travel times and average speeds of the two scenarios (before and after road upgrading). The analysis demonstrates improved travel times in peak periods. The impact of the implementation of an access management strategy and signalisation illustrates a significant impact on average speed at localised positions. This study has proven that the change in traffic characteristics when dualling a single carriageway can be better understood using FCD and can assist road authorities in decision making.

1. INTRODUCTION

Changes in land use as achieved through rezoning and the introduction of major developments on properties in the transition zone between rural and urban areas serve to extend urban areas to cater for development and urban population growth. These changes in land use patterns also serve as major generators of traffic that add to an already strained existing road network. Development, together with increased traffic demand, are the main factors that contribute towards increasing congestion along peri-urban routes, triggering road authorities to upgrade major arterials and implement access management strategies.

It is important to evaluate the effect of road upgrades on traffic operations, considering the large investments made by road authorities to implement road improvements. Observations of the operational conditions before and after a road upgrade project can provide a better understanding of the effectiveness of the investment and whether it has made a positive impact on the economy by reducing travel time and congestion.

The purpose of this research is to evaluate the improvements that can be achieved in operational conditions and congestion alleviation through the dualling of heavily trafficked single carriageway highways. Road dualling projects typically include geometric road upgrades as well as improvement of access management strategies on arterials, both of which can result in improved traffic operation, traffic control and safety. The upgrade of Baden Powell Drive from a single carriageway to a dual carriageway, implemented by the Western Cape Government: Department of Transport and Public Works, is used as a case study in this paper to investigate the research question.

2. BENEFITS OF DUALLING SINGLE CARRIAGEWAY ARTERIALS

A dual carriageway road has physically separated trafficked lanes in opposite directions. Carriageway separation could be through a raised median, central barrier, or grassed median. An arterial is not considered a dual carriageway unless two full lanes are provided in each direction with physical separation of the two directions of movement (AASHTO, 2001). The main advantages of dualling arterials are increased safety and improvement of operational conditions.

The physical separation of two opposing directions of traffic reduces the occurrence of head-on collisions dramatically. The benefits are further increased when a four lane dual carriageway is implemented, affecting a reduction in the number of sideswipe collisions (Maze *et al.*, 2010). Council and Stewart (1999) conducted a study of the safety effects of the conversion of rural two-way highways into four-lane dual carriageways. Two-way highways and dual carriageways in the states of California, Michigan, North Carolina, and Washington are considered in this as case study. The study revealed that a reduction in the accident rate per km of between 40% and 60% could be expected when upgrading a two-way rural highway to a dual carriageway.

There is an expected improvement to operational conditions when dualling a single carriageway arterial such as increased capacity resulting in reduced congestion and an improved Level of Service. An increased average speed and an improvement in the travel time can also be expected.

3. APPLICATION OF FLOATING CAR DATA TO EVALUATE TRAFFIC STATE

Floating Car Data (FCD) is traffic data collected from Global Positioning System (GPS) enabled devices in vehicles, which are referred to as probes (Gühnemann *et al.*, 2004). The data collected in this manner provides a Lagrangian description as the trajectory of vehicles over space and time (Herrera and Bayen, 2010). Therefore, FCD can provide information on vehicle travel speeds, vehicle travel times, route choice, and origin and destinations of trips (Dabbas, Fourati and Friedrich, 2020).

The penetration rate of the FCD, which is the percentage of vehicles that are capturing FCD along a study route, is the most commonly used measure of the quality of the vehicle probe dataset (Blumthaler, Bursa & Mailer, 2020). Vandenberghe *et al.*, (2012) have shown in their research that a minimum penetration rate of 1% provides adequately accurate FCD for highways, while for arterials, the penetration rate varies as a factor of congestion between 1% and 5%.

FCD analysis can be classified into two categories namely ‘behavioural’ and ‘physical’. Behavioural studies provide information on route choice and origin-destination. The physical studies deal with the performance of a road segment including traffic speed estimation, travel time estimations, and determination of traffic conditions (Sun, Leurent and Xie, 2020). These are discussed below.

3.1 Traffic Speed Estimation

Fixed location speed sensors have been used for years for traffic speed estimation, however, they can only provide data at predetermined locations. FCD records traffic data along a route over time, providing great potential for speed analysis (Rempe *et al.*, 2017).

Wang *et al.*, (2014) studied 45 arterials in Shanghai using FCD to identify the effect of geometric road variables on the operational speed, enabled by FCD to conduct a dynamic assessment of speed along the routes. They determined that road design elements such as segment length, number of lanes, degree of horizontal curvature, right turn lanes, and presence of medians all significantly affect the operational speed along an arterial. Bruwer, Andersen and Merrick (2021) conducted temporal and spatial speed analysis of a roadworks section along National Route 1, in Cape Town, South Africa. They observed that already constrained inbound speeds before the construction period were further reduced for a longer period of the day during construction. Once the additional capacity was available after the roadworks were complete, the analysis showed an improved increase in vehicle speeds. Their study also analysed speed profiles from FCD during the morning and afternoon peak periods as well as mid-morning speed profiles, which allowed for the identification of bottlenecks before and during construction and were able to demonstrate the elimination of those bottlenecks after the road improvements were complete (Bruwer, et al., 2021).

Chen *et al.* (2020) used a Speed Performance Index, a factor of the average travel speed of a road segment, using FCD reported speeds and the speed limit of the road segment. This index was used to identify traffic congestion patterns on urban freeways.

3.2 Travel Time Estimation

Traditional methods for collecting travel time information require automatic vehicle identification (AVI) sensors. These devices are sparsely located along a road network and do not provide an accurate representation of travel time. Comparatively, FCD can report travel time data for any part of a network for any time of the day (Jenelius and Koutsopoulos, 2013).

Jenelius and Koutsopoulos (2013) developed a statistical model for travel time estimation using FCD on an urban road network. This model was applied to a case study in Stockholm, Sweden, and concluded that there is a significant impact on travel times based on roadway characteristics such as speed limits, functional classification, right turn lanes, and one-way streets. Li, Shi and Li (2013) used FCD to develop a location-speed method for the estimation of travel times on a signalised road network. They used the distribution of FCD upstream and downstream of a signalised intersection to more accurately estimate travel times at signalised intersections.

3.3 Determination of Traffic Conditions

Altintasi, Tuydes-Yaman and Tuncay (2017) used 1-min interval average speed values from FCD and compared these to the base free flow speed (FFS) to evaluate four scale parameters based on LOS for an urban road environment. In the absence of other traditional traffic data such as traffic flows and density, they were able to identify bottleneck positions and queue formations. Gühnemann *et al.* (2004) used taxi-FCD in Germany to demonstrate the benefits of several applications such as dynamic routing and navigation, traffic monitoring, traffic jam identification, and ways for using spatial traffic information for real-time monitoring environmental consequences of traffic congestion.

4. RESEARCH DESIGN

4.1 Methodology

The purpose of this research is to evaluate the improvements that can be achieved in operational conditions and congestion alleviation through the dualling of heavily trafficked single carriageway highways. The upgrade of Baden Powell Drive between Khayelitsha and Stellenbosch in the Western Cape from a single carriageway to a dual carriageway is used as a case study in this paper to investigate the research question. The analysis is conducted as a before and after study, considering traffic operations before and after the road was upgraded to a dual carriageway.

4.2 Study Area

The R310 (Baden Powel Drive) is a critical arterial road linking Stellenbosch to the National Route 2 (N2), Khayelitsha and Macassar. The Western Cape Government (WCG) is in the process of fully upgrading the R310 from a single carriageway road with two lanes per direction to a dual carriageway road with two lanes per direction and signalised intersections in three phases (EFG Engineers, 2011). Phase 1, between Annandale Road and the realigned Vlaeberg Road, was completed in 2015. Phase 2, from the realigned Vlaeberg Road to the N2 / R310 Interchange was completed in 2020. The Western Cape Government has completed the design stage of Phase 3 from Annandale Road to Stellenbosch Arterial (M12). The phasing of the project and the sections of road that comprise each phase are indicated in Figure 1.

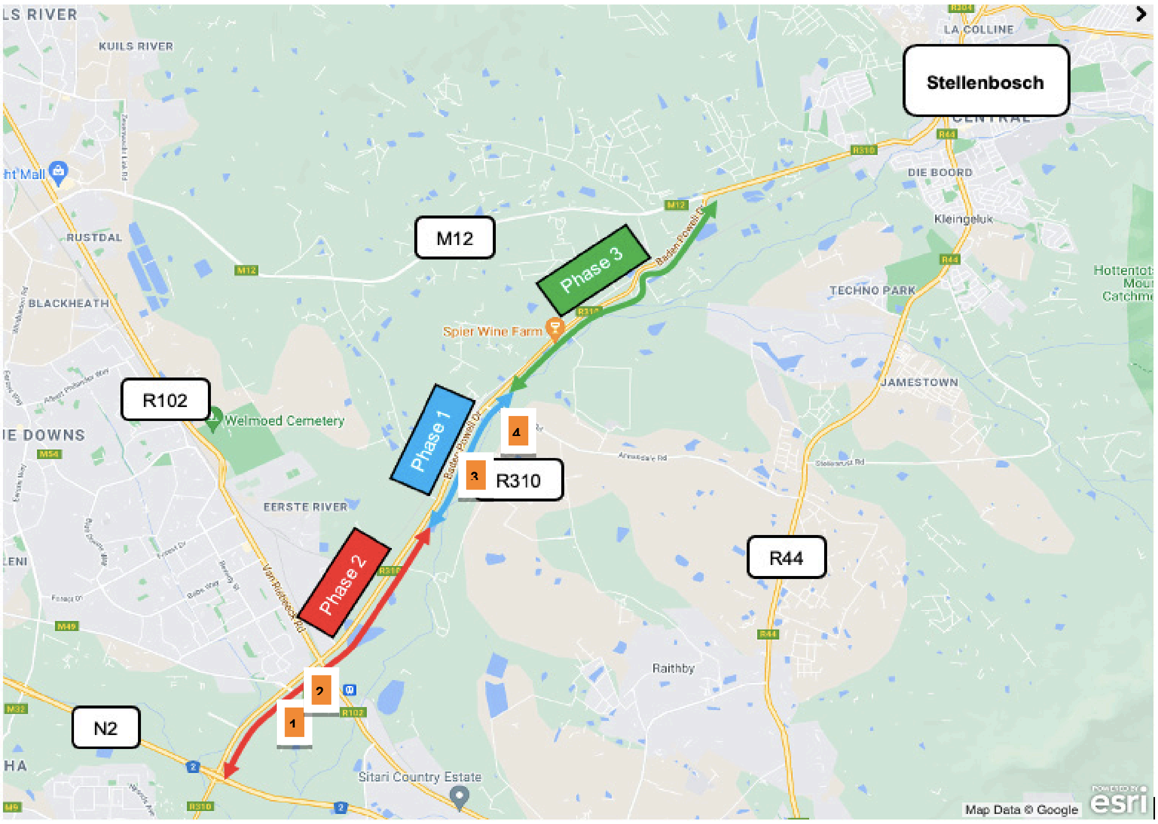

Figure 1: Study area

4.3 Data Sources

FCD for this study was acquired through TomTom on the TomTom Move portal using the *Traffic Stats* application. A route report was generated for the R310, collecting traffic data such as travel times and average speeds for various analysis periods. This route report contained both eastbound and westbound data. The analysis periods were based on the construction periods of Phase 1 and Phase 2. The data was collected for a full month (excluding weekends) before and after the road upgrade. The periods at which data was requested from TomTom for Phase 1 were May 2013 (before) and May 2016 (after) and May 2017 (before) and May 2021 (after) for Phase 2. The data was represented for each hour of the day, except between 00h00 and 04h00 where the data was combined to one Base Set which represented free flow conditions, due to limited probe activity during this time. The penetration rates for these datasets were, 0.4% in 2013, 1.3% in 2016, 2% in 2017 and 3.4% in 2021. The rate is lower than 1% in 2013 as there were not as many devices for collecting FCD as there are now.

This study also evaluated full day counts collected from existing counting stations at multiple positions within the study area. These counts were obtained from the Western Cape Government's Road Network Information System (RNIS) website and are collected using inductive loops. Data from four counting stations was obtained. Since the traffic data was from RNIS website, the dates that the data was collected could not be controlled. Traffic data was collected at station 1 and 2 in 2008, 2013 and 2016, and at stations 3 and 4 in 2009, 2015 and 2018. The positions of the four traffic counting stations along the study route are indicated in Figure 1.

5. RESULTS

5.1 Traffic Volumes

The traffic volumes at Station 3 for 2009, 2015 and 2018 are described in Figure 2 below.

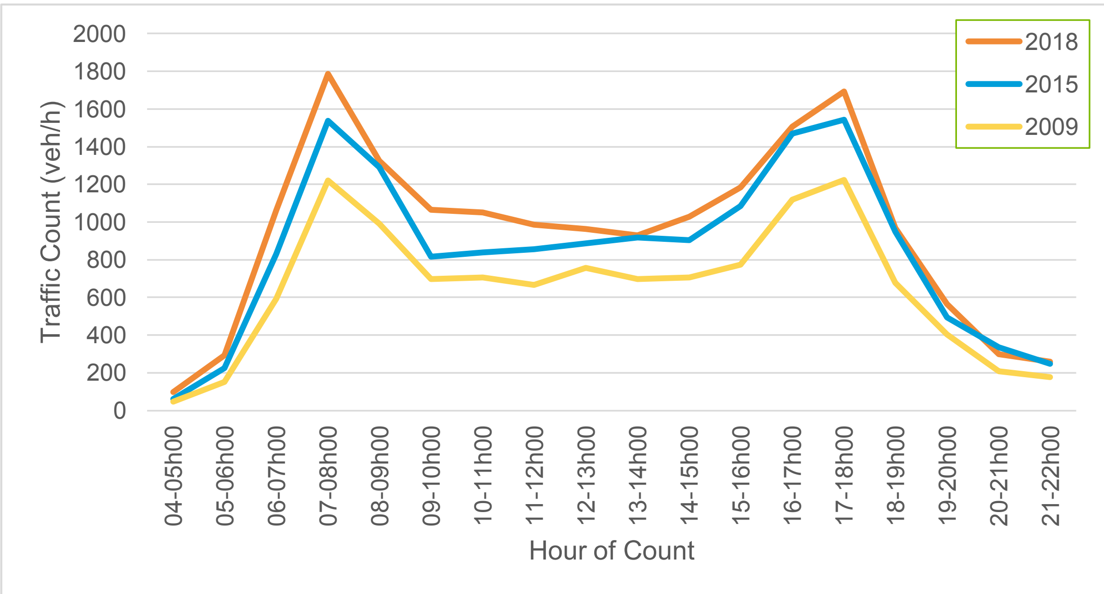

Figure 2: Station 3 traffic volume analysis

The AM and PM peak hours can clearly be identified at 07h00 to 08h00 and 17h00 to 18h00, respectively. There is significant growth in the traffic demand in the AM and PM peaks, as well as for daily traffic across the observed years. The Annual Daily Traffic (ADT) at Station 3 was 11813 veh/day in 2009, 15290 veh/day in 2015 and 17066 veh/day in 2018, indicating an annual growth in traffic volume of 4.4% per annum from 2009 to 2015, and 3.7% per annum from 2015 to 2018 (average annual growth of 4.2%). The traffic volumes observed at Station 3 in 2018 were collected after the road was upgraded to a dual carriageway.

5.2 Travel Time Analysis

The travel times were collected for every hour from 04h00 to 22h00. The travel times were averaged when traffic volumes were low between 00h00 to 04h00 and 22h00 to 24h00. The period between 00h00 to 04h00 was used to represent the Base Set where free flow conditions occur. A travel time analysis was conducted for over the Phase 1 zone and Phase 2 zone. The travel times of eastbound travelling vehicles (into Stellenbosch) were found to be the most critical, particularly in the morning peak, and are described below.

5.2.1 Changes in Travel Time Over the Phase 1 Zone

The Phase 1 zone extended from the Annandale Road / R310 intersection to the new Vlaeberg Road / R310 intersection. This section of road is approximately 1.8km in length. Variation in total travel time over a typical day in the eastbound direction for this route segment are presented in Figure 3 for May 2013 (before) and May 2016 (after the upgrade).

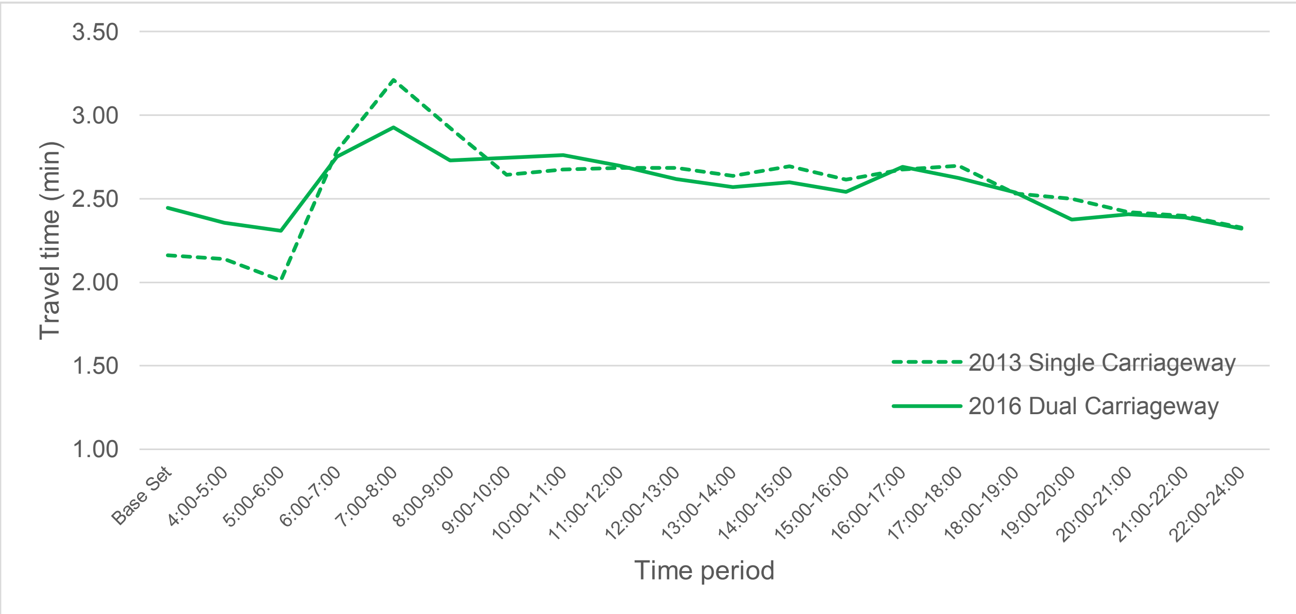

Figure 3: Total travel time eastbound for the Phase 1 zone

Figure 3 shows no clear difference in the total route travel times before and after the road was upgraded to a dual carriageway after 10h00 onwards. It was expected that travel times would be the same for both the single and dual carriageway during periods with free flow conditions. However, for the base set, the dual carriageway's travel time for the Phase 1 zone is about 20s more in 2016 (after the upgrade) than it was when the road was a single carriageway. This is likely due to the additional signalised intersection that was introduced at the new Vlaeberg Road / R310 intersection which would add to the travel time in the absence of heavy traffic.

Figure 3 also clearly indicates that the eastbound traffic experiences a morning peak in the direction towards Stellenbosch which is not identified in the afternoon (a one directional peak). In the morning peak, there is an improvement in the travel time by approximately 20s (11.4%) in 2016 compared to 2013. This could be accounted for by the additional capacity provided by the extra lanes and dual carriageway, reducing delays during the morning peak hour.

5.2.2 Changes in Travel Time Over the Phase 2 Zone

The Phase 2 zone runs from the R310 / N2 interchange to the new Vlaeberg Road / R310 intersection. The section of road in this phase is approximately 5.8km in length. Total travel time along this section of the route is illustrated in Figure 4.

Figure 4 demonstrates that traffic traveling eastbound through the Phase 2 zone experiences increased travel time during both the morning and afternoon peak periods. The distribution of total travel times throughout the day for both the single (2017) and dual carriageway (2021) present the same profile. Travel times along the upgraded route in 2021 are marginally longer than compared to the single carriageway travel times in 2017. The biggest difference is observed in the afternoon peak travel period when travel time on the dual carriageway is 40s (11.1%) longer than when the road was a single carriageway. The introduction of 4 signalised intersections as part of the Phase 2 zone upgrade would have added to the travel times. The operational delay caused by the addition of the traffic signals can be observed in the off-peak base set data. Higher travel times in 2021, when compared to 2017 observations, during the day, which are comparatively more than in the base set, are likely an indication of the impact of the higher traffic volumes in 2021 increasing travel times.

Considering the relatively high traffic growth rate along the corridor (4.2% per annum), it is anticipated that travel times along the original single carriageway route would have increased due to the increased traffic demand without the intervention to upgrade the arterial.

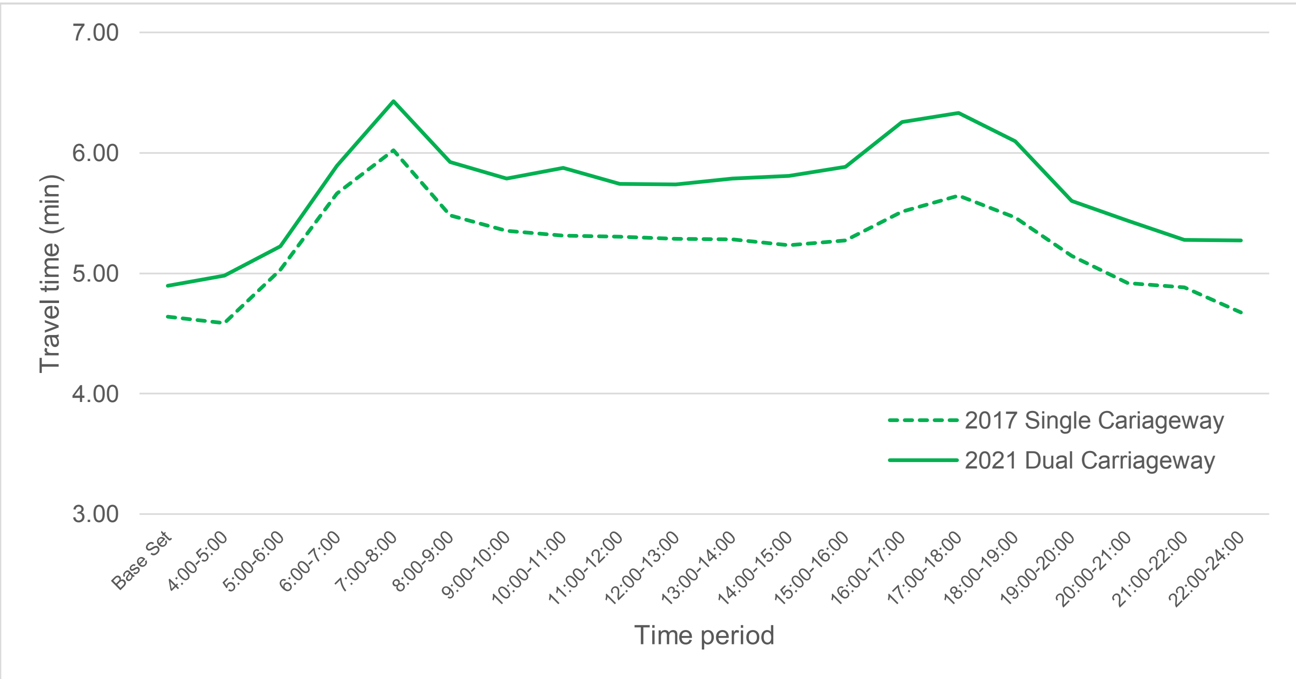

Figure 4: Total travel time eastbound for the Phase 2 zone

5.3 Average Speed Profile Analysis

FCD was used to develop speed profiles along the R310 during before and after periods. The speed profiles, describing average speed changes along the route, for the eastbound morning peak, which occurs between 07h00 and 08h00, are analysed below.

5.3.1 Eastbound AM Speed Profiles in the Phase 1 Zone

Figure 5 illustrates the base set and morning peak hour speed profiles in the eastbound direction for a single carriageway in 2013 and a dual carriageway in 2016.

In the segment of the Phase 1 zone between the old Vlaeberg Road / R310 intersection and the Annandale Road / R310 intersection, the AM peak speeds improved significantly from just over 60 km/h to about 80 km/h with the implementation of the dual carriageway. Contrastingly, the base set speed profiles for this same segment showed little difference between 2013 and 2016. It can therefore be concluded that the observed improvement in average speed during the peak hour is an indicator that there has been a reduction in congestion within the Phase 1 zone. The average speed at the new Vlaeberg / R310 intersection is less for the dual carriageway. However, this is consistent the average speed reduction observed during the free flow period as well, indicating that the decrease in speed is likely due to the implementation of the new signalised intersection at the New Vlaeberg Road / R310 intersection.

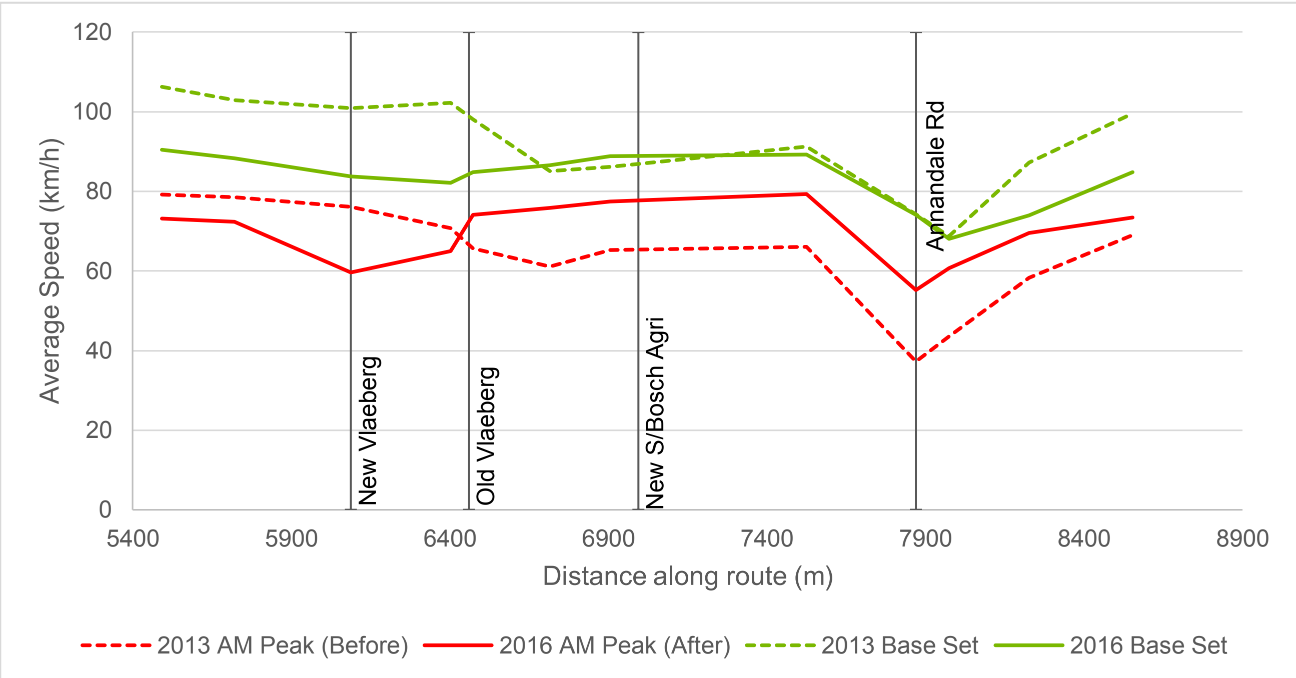

Figure 5: Eastbound AM peak speed profiles on Phase 1 zone

5.3.2 Eastbound AM Speed Profiles in the Phase 2 Zone

The eastbound AM peak speed profiles for the Phase 2 zone are presented in Figure 6. The speed profile indicates that traffic along the upgraded dual carriageway in 2021 experiences reduced speeds at localised intersections within the Phase 2 zone compared to the 2017 speed profiles before the upgrade, particularly at the northern ramp of the N2 / R310 interchange and the new R102 Quarterlink / R310 intersection. The northern ramp of the N2 / R310 interchange and the new R102 Quarterlink / R310 intersection, which have been signalised as part of the upgrade, appear to suffer localised congestion due to the forced delay imposed by the traffic signals. This is however expected in the morning peak period considering that the connecting roads, the N2 (Class 1) and R102 (Class 2), carry high volumes of traffic.

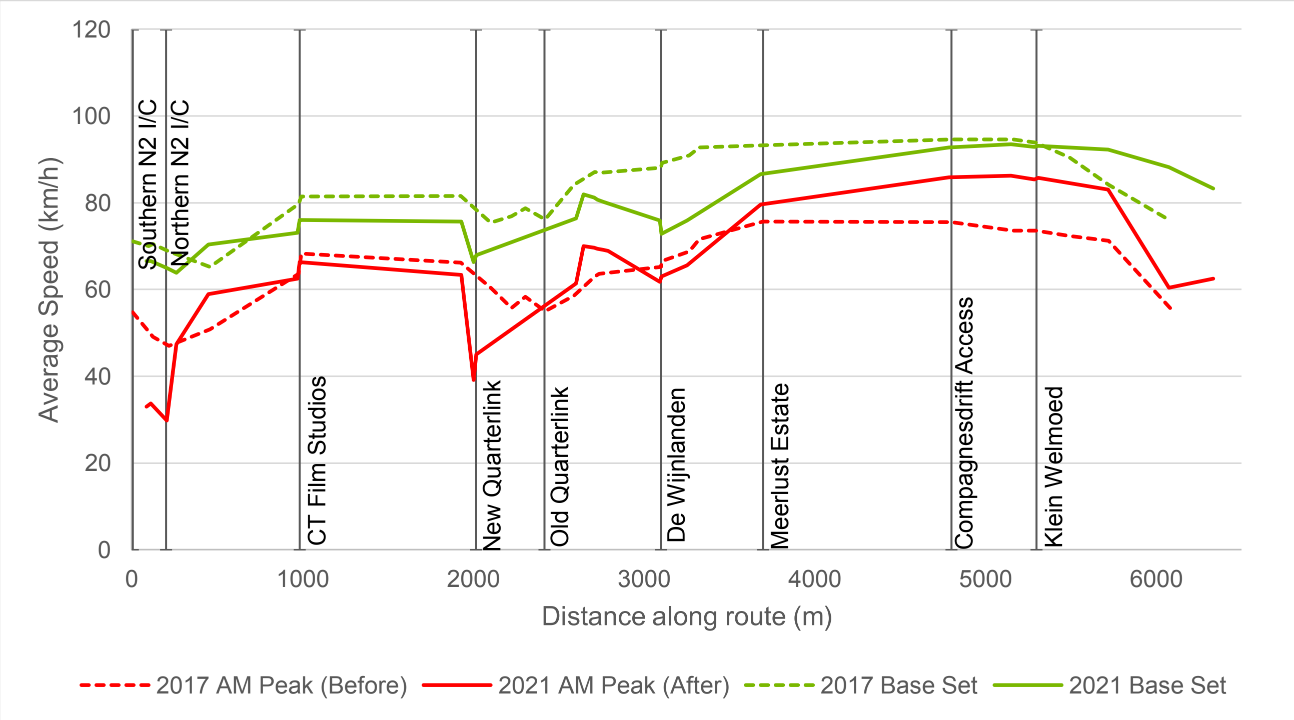

Figure 6: Eastbound AM peak speed profiles on Phase 2 zone

Improved speeds are observed in 2021 after the upgrade for the section of the Phase 2 zone from the Meerlust Estate / R310 intersection to beyond the Klein Welmoed / R310 intersection. Throughout the rest of the Phase 2 zone, apart from the localised instances discussed above, there is very little difference in the average speed profiles before and after the update in the peak period.

When comparing the before and after of the base set with the peak hour, it shows that there is a relative speed improvement as there is a decrease in free flow speeds in the base set. It can be concluded that in the AM peak, the upgraded dual carriageway road performs better than the single carriageway.

5.3.3 Effect of Access Management

The improvement in average speeds in the sections identified correlates with the improved access management strategy. An extract of the improvement of access management for the Phase 1 zone is represented in Figure 7 below.

There is an elimination of 4 driveway accesses on Phase 1 zone between the New Vlaeberg and Annandale Road improving the spacing of intersections. This improvement correlates with the improvement in average speeds on Phase 1 as demonstrated in Figure 5.

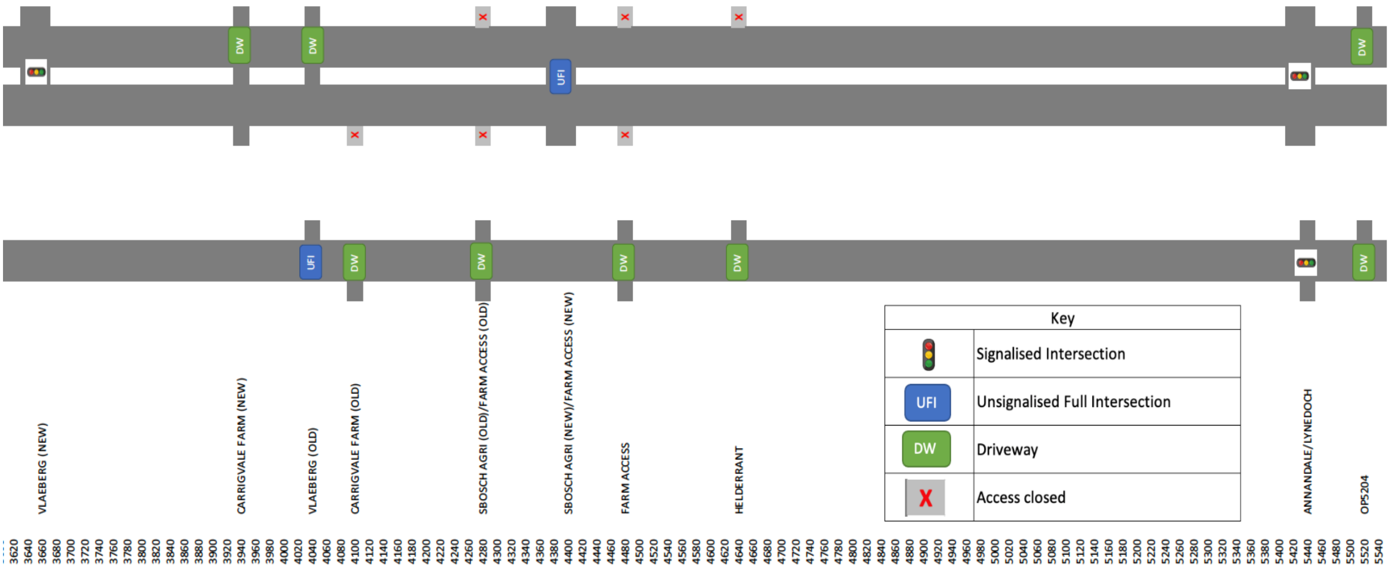

Figure 7: Phase 1 access management improvements

6. DISCUSSION

This study has demonstrated that the improvements in speed and operation conditions associated with upgrading a single carriageway, two-way, two-lane road to a dual carriageway can effectively be measured from FCD. At multiple locations throughout the study there were improvements in travel time and speed.

Along the Phase 1 zone segment, travel times after the road upgrade improved in the eastbound direction during the AM peak period. The travel times during the rest of the day in the eastbound direction were the same for single and dual carriageway. Along the Phase 2 zone segment, travel times were slightly longer after the upgrade to a dual carriageway was completed. This section however now has four additional traffic signal-controlled intersections which have introduced control delay, thereby increasing the travel times.

The speed profiles were analysed for the morning peak hour in the eastbound direction. The speed profiles for the morning peak hour demonstrates the benefit of FCD in that it can identify specific locations where the speeds are improved while still considering the route-wide operational conditions which can be evaluated for averaged travel time along the route. A correlation between with average speeds and access management improvements have also been observed. The improvement in the average speed along the upgraded dual carriageway in comparison to the single carriageway points to the alleviation of congestion and improvement of mobility along the upgraded road.

7. CONCLUSION

The use of FCD as a form of traffic data has provided the ability to evaluate past traffic conditions to determine the effect of a change in the operational conditions along a route before and after a geometric upgrade. Operational improvements can be determined through travel time and average speed profiles before and after an event. In this study, FCD was used to determine the impact of upgrading of Baden Powel Drive (R310) from a single carriageway, two-way, two-lane road to a dual carriageway on speed and operational conditions.

Travel times were noticeably improved in the Phase 1 zone in the morning peak period. The Phase 2 zone did illustrate marginally longer travel times however if the introduction of 4 signalised intersections is factored into the analysis, the travel times are improved.

The average speed profiles demonstrated that there was an improvement in the average speed in the AM peak on both Phase 1 and Phase 2 zones. Clearly indicating an alleviation in congestion along the route.

In conclusion it was found that through the use of FCD the dualling of single carriageway arterials does improve the operational conditions and reduce congestion.

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