MEASURING THE IMPACT OF ROADWORKS ON TRAFFIC PROGRESSION USING FLOATING CAR DATA

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ABSTRACT

Roadworks projects, while necessary to upgrade and maintain our transport networks, are loathed for their presumed negative impact on our daily commute. The purpose of this study is to investigate how Floating Car Data (FCD) can be used to assess the influence of a work zone on traffic progression. The effective change in speed and travel time was examined within and around a work zone of the recently completed upgrade of the N1 in Cape Town, particularly during the lane closure of the inbound section of the N1 between Durban Road and Jip de Jager Drive. The use of FCD to assess the impact of work zones provided unprecedented insight into traffic patterns such as the change in position of bottlenecks during roadworks. FCD was shown to improve our understanding of traffic movement within work zones. This can provide input to strategies for safer traffic accommodation during roadworks, going some way to improve the daily commute of road users.

1. INTRODUCTION

Roadworks result in roadway capacity constraint because of lane closure or lane narrowing, causing increased congestion and reducing the efficiency of the road network. While every effort is made to safely accommodate the traffic demand during roadwork projects, traffic progression will usually be compromised. This research is interested in the observation of traffic disturbances to monitor the impact of roadworks on traffic patterns.

A number of transportation agencies worldwide (including SANRAL) are using technology applications for “smart work zone monitoring” to make travel through and around work zones safer and more efficient (FHWA, 2019). Intelligent Transport Systems are being applied in work zones to monitor and measure work zone activity during construction by utilising CCTV, Vehicle Detection Stations and Floating Car Data (FCD) to increase operational awareness during the time of construction. FCD is a relatively new source of traffic data that provides speed information along the trajectory of vehicles from GPS enabled probes. FCD is therefore uniquely able to observe the location of speed changes along a route, which can in turn be used to infer information about queue formation and the position of bottlenecks. By comparison, traditional roadside traffic sensors are not able to observe traffic patterns spatially because they report traffic conditions at a single location where installed.

The objective of this research is to investigate the use of FCD to evaluate the impact of lane closure at a roadworks site on aggregated long-term traffic patterns. Speed reduction, queue formation and bottleneck location will particularly be evaluated before, during and after a long-term lane closure event at a work zone. The recently completed N1 upgrade in Cape Town is used as a case study, specifically the lane closure of the inbound carriageway of the N1 between Durban Road and Jip de Jager Drive. The right lane was closed on this section of the N1 for 11 months from February 2017 to January 2018.

2. EFFECT OF ROADWORKS ON TRAFFIC

Roadworks are obviously anticipated to cause traffic delays. Three main factors have been identified that induce delays at roadwork zones (Bourne et al., 2008):

1) Capacity constraints caused by roadworks resulting in queuing.
2) Reduction in normal speeds because of reduced speed limits in work zones.
3) Incidents at roadworks sites made more likely or aggravated by the roadworks.

Queues form when traffic demand exceeds roadway capacity (Bourne et al., 2008). Capacity constraints at roadworks are caused by lane closures and the narrowing of lanes necessary to safely accommodate the workspace on the side of the road. Closing lanes severely constrains road capacity. Additionally, the narrowing of lanes through work zones may result in 15% lower vehicle throughput than conventional lanes (Bourne et al., 2008) (Stromgren & Olstam, 2016). Capacity reductions can also be caused by more than simplistic physical lane configuration and geometry. A study by Maze and Bortle (2005) found that the remaining lanes adjacent to a closed lane have less capacity than before the lane closure. For example, if a three lane road is reduced to two lanes, then the capacity of the remaining two lanes can be reduced by 25% per lane from normal capacity (Calvert & Walker, 2013).

Other factors that influence the capacity of a road affected by road works include traffic composition, weather and work zone activity. Higher percentages of heavy vehicles decrease road capacity due to the limited acceleration ability of heavy vehicles after passing through a bottleneck (Maze & Bortle, 2005) (Bourne et al., 2008) and the increased driving load on other drivers when lanes are narrowed (Stromgren & Olstam, 2016). Rain has been found to further reduce road capacity in work zones by around 10% (Bourne et al., 2008). With regard to work zone activity, an active work site can result in road capacities of between 5 and 10% lower than work sites where no work was taking place or where work was not visible (Stromgren & Olstam, 2016). Lastly, the duration of roadworks can influence capacity, with short-term roadworks creating lower roadway capacity than long term roadworks (Maze & Bortle, 2005) (Stromgren & Olstam, 2016). This is likely due to the adjustment of driver behaviour over time as commuters become accustomed to the local road conditions within the work zone, reducing headways and increasing flow.

3. USING FCD TO OBSERVE TRAFFIC PATTERNS

Floating Car Data (FCD) is reported by probe devices in vehicles from within the traffic stream measuring vehicle trajectory information (Vandenberghe et al., 2012). Trajectory data, also called Lagrangian data, provide time-based location, heading and speed of discrete vehicles (Yuan et al., 2012) (Herrera & Bayen, 2010). Probe devices usually incorporate GPS tracking and can include smart phones with navigation applications, personal navigation devices and vehicle tracking devices. Various studies have determined a penetration rate (proportion of vehicles reporting FCD along a specific route) of between 1 and 3% to be adequate to report accurate traffic information on higher order roads (Vandenberghe et al., 2012). Aggregated Lagrangian data provide average speed and travel time of the traffic stream, allowing analysis of speed variation along a route.

Vandenberghe et al. (2012) proved that FCD can accurately determine the location of a traffic incident and the position of the back of the queue, while also monitoring queue formation over time by considering FCD reported speeds along a route. Another study has shown that FCD is able to reliably detect locations of recurrent daily congestion (Adu-Gyamfi & Sharma, 2015). A South African study considered the use of FCD to evaluate the impact of partial road closure caused by a stationary vehicle obstructing one lane. The study observed the time for traffic flow to return to normal after the incident was cleared and quantified the delay on the surrounding road network (Olivier et al., 2017). The ability to detect the location of a traffic incident and congestion is specific to FCD because speed is reported along the entire trajectory of a trip, rather than at certain geographic locations, as is the case for data reported by road-side traffic sensors. This makes FCD particularly useful in analysing the effects of events such as roadworks on the traffic stream.

4. RESEARCH DESIGN

4.1 Study Area

The lane closure under investigation was located on the N1 inbound carriageway (direction towards Cape Town CBD) between Durban Road and Jip De Jager Drive. The right lane was closed for a distance of approximately 2.3 km from February 2017 to January 2018. The lane closure was implemented from the merge point of the N1 inbound and the onramp from Durban Road. The study area incorporates this work zone and extends a further 5 km to either side along the N1 from Brackenfell Boulevard east of the work zone to Vasco Boulevard to the west (total length 12.8 km). The study area is presented in Figure 1. The N1 inbound under investigation is highlighted by the black line, the section of lane closure is in red and the main intersecting roads are highlighted in orange. The N1 in this area has a speed limit of 120 km/h with a reduced speed limit of 80 km/h through the work zone.

Prior to the lane closure, both the N1 mainline and the Durban Road onramp comprised two lanes. After the onramp merge point, four lanes were maintained for 550 m before the left lane was dropped. Three inbound lanes then continued to Plattekloof Road. During road closure, the right lane was closed in the zone demarcated in red in Figure 1.

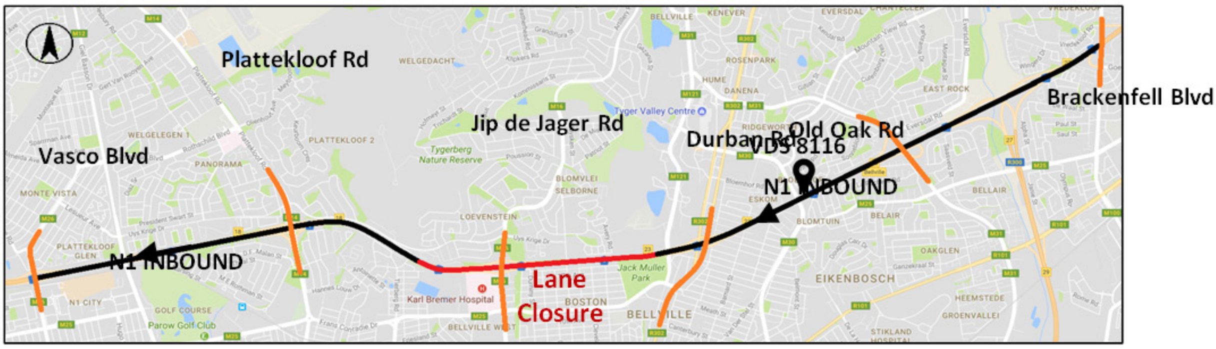

Figure 1: Study Area

The N1 mainline was maintained at 2 lanes in the inbound direction by changing the road markings along the Durban Road onramp to reduce the onramp to 1 lane just before the merge point. After the merge, the N1 had 3 lanes instead of the original 4 for 550 m up to the existing left lane drop, thereafter continuing with 2 lanes for the remaining 1.75 km of the work zone. After completion of the roadworks, lane markings upstream of the road closure area were revised to three lanes on the N1 inbound direction from Old Oak Road and the Durban Road onramp was reinstated to two lanes. At the Durban Road onramp merge point, the onramp right lane merged immediately with the N1 mainline to result in four lanes on the N1 inbound, reducing to three lanes 550 m downstream, as per the original lane configuration.

4.2 Data Sources and Analysis

FCD was obtained from TomTom International BV. using the TomTom Move online portal. TomTom collects and stores historical probe data dating back to 2008 in South Africa from anonymous probe sources. FCD was obtained for the full study area (12.8 km). FCD does not provide traffic volume because it is reported by a sample of probe vehicles. Traffic volume information was therefore obtained from the SANRAL Cape Town Traffic Management Centre from roadside Vehicle Detection System (VDS) devices that form part of the Cape Town Freeway Management System. Data from VDS 8116, located midway between Durban Road and Old Oak Road was sourced because it was operational throughout the study period and is close to the area of lane closure.

FCD and VDS data were obtained for three periods, before (2016), during (2017) and after (2018) the lane closure period. All data was collected for the same period between 1 and 16 March in 2016, 2017 and 2018 allowing a period of 1 month for traffic pattern adjustment after lane closure and opening. This timeframe provided two full work weeks (Monday to Friday) while excluding any holiday periods. Weekday data was aggregated for each hour of the day to provide representative traffic information. A “Base Set” was defined to which other hourly time periods are compared. The Base Set describes Free Flow traffic conditions between 00:00 and 04:00 when very few vehicles are on the road. Aggregating data over this period improves accuracy by increasing the number of probes, which is very low during this early morning period due to the low number of vehicles using the road.

5. DATA ANALYSIS

5.1 Traffic Volume

Traffic volumes observed at VDS 8116 (inbound direction) in March in 2016, 2017 and 2018 are presented in Figure 2. The general direction of peak travel is towards Cape Town CBD in the morning and out of Cape Town CBD in the afternoon.

According to Figure 2, the 2016 traffic demand remains relatively constant throughout the day (from 06:00 to 18:00) with no clear morning peak in the inbound direction. This is likely due to significant capacity constraints on the N1 downstream of VDS 8116, influencing both travel demand and throughput during the morning peak. Traffic demand in 2017 was the same during for the first part of the peak hour (up to 07:00), and then reduced to less than the 2016 hourly volumes for the remainder of the day indicating that the roadworks influenced travel behaviour along this route. In 2018, after completion of the roadworks, the morning peak was more clearly defined, with higher traffic than in 2016 and 2017 and spread over four hours (05:00 to 09:00) while traffic during the rest of the day remained similar to 2017 volumes. This traffic flow increase could indicate latent demand on this section of the N1 which could be accommodated with the improved capacity after the roadworks project.

Annual Daily Traffic (weekday) for March was 56 130 veh/day in 2016, 49 040 veh/day in 2017 and 49 300 veh/day in 2018. This points to a significant reduction in traffic demand

(7000 veh/day) on the N1 inbound between 2016 and 2017. This could be due to adjustments in travel behaviour by commuters due to the roadworks, with this change being maintained in 2018. Investigation of the reason for this severe decrease in travel demand is outside the scope of this study and could be considered in further research.

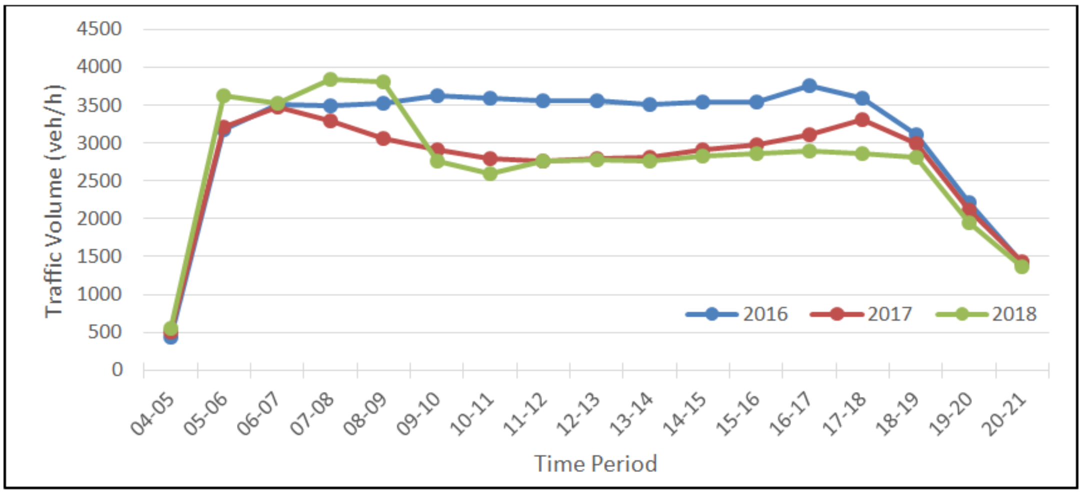

Figure 2: VDS 8116 Inbound Traffic Volume Analysis

5.2 Total Travel Time Over the Study Area

The time to traverse the full study area (12.8 km) at different times of the day was obtained from TomTom FCD. The total travel time is compared in 2016, 2017 and 2018 in Figure 3. Travel time remains relatively constant at 8 minutes throughout the off-peak period (20:00 to 05:00) over all three years and is observed to peak significantly between 06:00 and 08:00. In 2016, the average travel time during the morning peak period (06:00 to 08:00) increased sharply to 36 minutes. In 2017, the period of roadworks, average travel time between 7:00 and 8:00 increased to 45 minutes and remained consistently higher throughout the day than in 2016. After the roadworks was completed, travel time during the morning peak period reduced to 30 minutes between 06:00 and 7:00 and 25 minutes between 7:00 and 8:00.

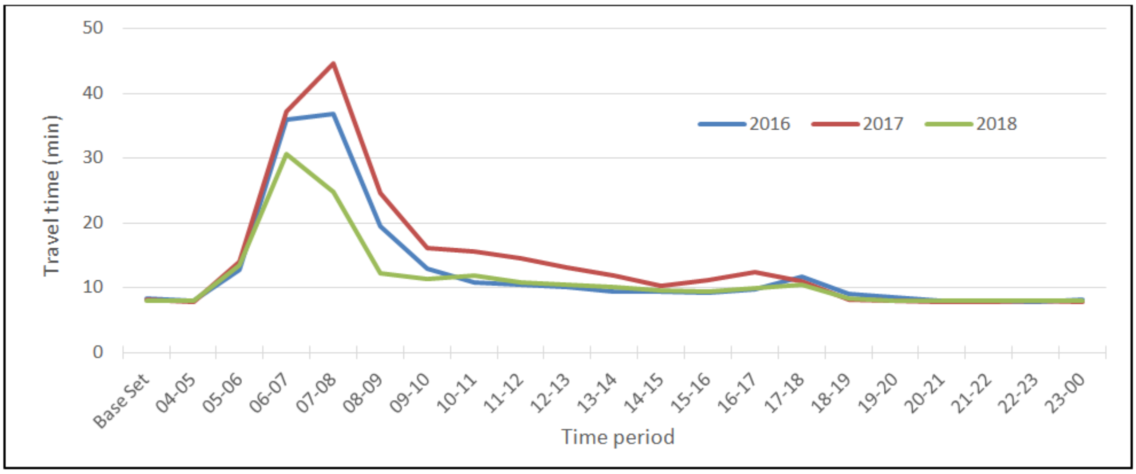

Figure 3: Total travel time over study area

The significant increase in travel time during the morning peak period cannot be explained by considering traffic volume at a discrete location (Figure 2). The limited variation in traffic volume through the day, particularly in 2016 and 2017, should not trigger this drastic change in travel time. Further investigation of FCD will attempt to describe this travel time variation.

5.3 Temporal and Spatial Speed Analysis

Figure 4 graphically displays average speed patterns throughout the day within the study area. Red blocks indicate segments with the slowest average speeds (1-10 km/h) and dark green blocks high speeds (>120 km/h) according to a colour scale. Roads crossing the N1 and the location of road works are indicated at their respective positions.

Figure 4: Temporal and spatial speed analysis

5.3.1 Upstream of Roadworks Section

According to Figure 4, speeds were constrained in 2016 from the R300 onramp to 500 m before Durban Road. Significant speed reduction in this zone continued from 5:00 to 12:00, while speeds remained below 80 km/h until 18:00. The congestion patterns were disrupted in 2017 during the period of roadworks. Very low speeds (<10 km/h) were observed for a longer distance but still upstream of Durban Road in the morning peak period, while a new area of congestion formed closer to Durban Road during the rest of the day. In 2018, significant improvement to the morning congestion was observed in the zone between the R300 and Durban Road compared to 2016 indicating the success of the addition of a third inbound lane from Old Oak Road. Traffic in the first section of the study area remains relatively fast flowing in the morning peak hour (>70 km/h). Interestingly, the period with the worst traffic is transferred to the period after the peak between 09:00 and 11:00, possibly due to continued roadworks on the side of the N1 in this area during 2018 (without lane closure), in line with other research that has proven that visible construction can reduce roadway capacity (Stromgren & Olstam, 2016).

5.3.2 Roadworks Section

The impact of the lane closure in 2017 is clear from Figure 4, with uncharacteristically low speeds of below 20 km/h for the full workday period (06:00 to 17:00) in 2017 in the first stretch of the workzone. The slowest speeds occurred at or just upstream of the point of lane closure, with speeds gradually increasing through the work zone. By comparison, the work zone area maintained high speeds in 2016 and 2018, except during the morning peak.

5.3.3 Downstream of Roadworks Section

Speed patterns downstream of Jip De Jager Drive remained similar in 2016, 2017 and 2018. The morning peak period experienced significantly low average speeds of below 10km/h for long sections, clearing after 9:00. Traffic queues are clearly visible (associated with these low speeds denoted by red segments) giving an indication of the queue length. The queue was the longest between 06:00 and 07:00, getting shorter until it dissipated after 9:00. This queue of vehicles is caused by insufficient capacity downstream of the study area. The queue stayed constant through 2016, 2017 and 2018 between 06:00 and 07:00, however is shorter in 2018 than 2016 between 07:00 and 08:00. This could indicate that the peak period is shifting earlier, reinforced by the higher 2018 traffic volume before 07:00 in Figure 2 and lower speeds between 05:00 and 16:00 in Figure 4.

5.4 Speed Profile Analysis

5.4.1 Morning Peak Hour

The average speed profile through the study area during the morning peak hour (06:00 to 07:00) is presented in Figure 5. Speeds during the Base Set remained constant at 100 km/h for the entire study area for the three years of analysis (only 2018 is presented in Figure 5). The speed profiles through the study area during the morning peak hour were found to be similar before (2016) and during the roadworks period (2017). Speeds decreased sharply 600 m before the R300 onramp to 20 km/h. This low speed was maintained up to 1.3 km past Old Oak Road, coinciding with the position on the road where three lanes merged to two (the two lanes of the Old Oak Road onramp were accommodated by increasing the N1 inbound carriageway to three lanes after the merge point). This merge zone can be identified in Figure 5 as a significant bottleneck creating a 2.5 km long queue. Average speed doubled downstream of the bottleneck up to Durban Road, after which speeds decreased due to downstream congestion.

After completion of the roadworks, resulting in an additional lane from Old Oak Road, the 2018 speed profile for the morning peak hour indicates that the merge point bottleneck between Old Oak Road and Durban Road has been eliminated and speeds remain acceptably high (close to 80 km/h) all the way to Durban Road, where traffic slows similarly to earlier years. Some additional capacity on the section between Durban Road and Jip De Jager is evident from isolated, local increases in speed, however the overall traffic pattern is still heavily influenced by downstream congestion.

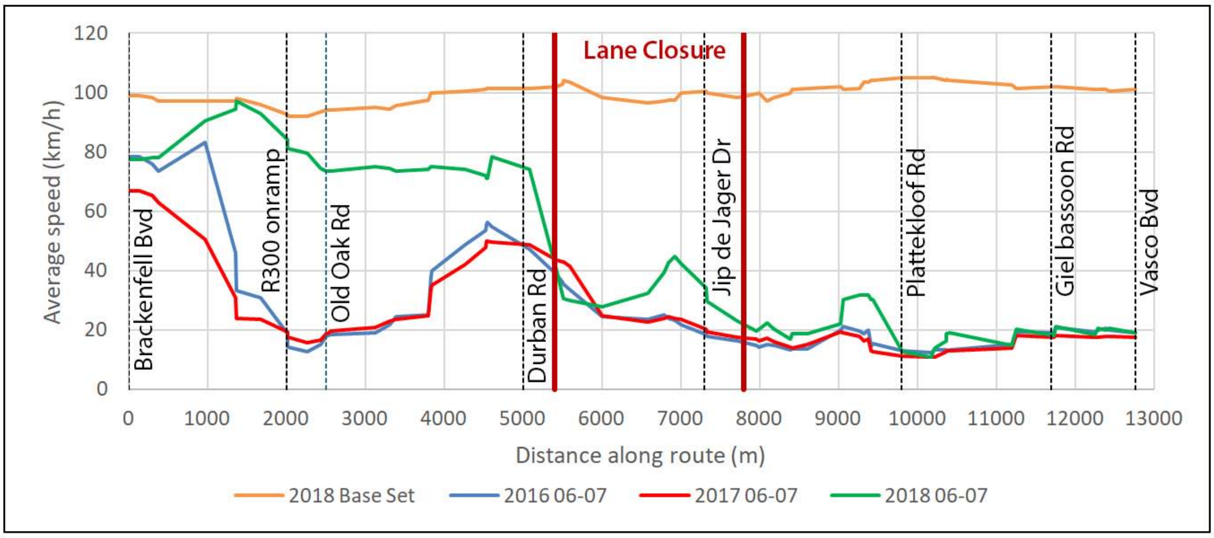

Figure 5: Speed Profile Analysis: AM Peak

5.4.2 Mid-Morning Period

The influence of the lane closure in 2017 (which was not clear in the morning peak hour due to downstream congestion) becomes obvious during the mid-morning period. The speed profiles for the period between 10:00 and 11:00 are presented in Figure 6. 2017 speeds decrease significantly up to the point of lane closure. This bottleneck is evident from the sudden decrease in speeds followed by maintained speed increase. Vehicles gradually increase their speed through the work zone to 60 km/h and then increase speed again to 80km/h after the work zone.

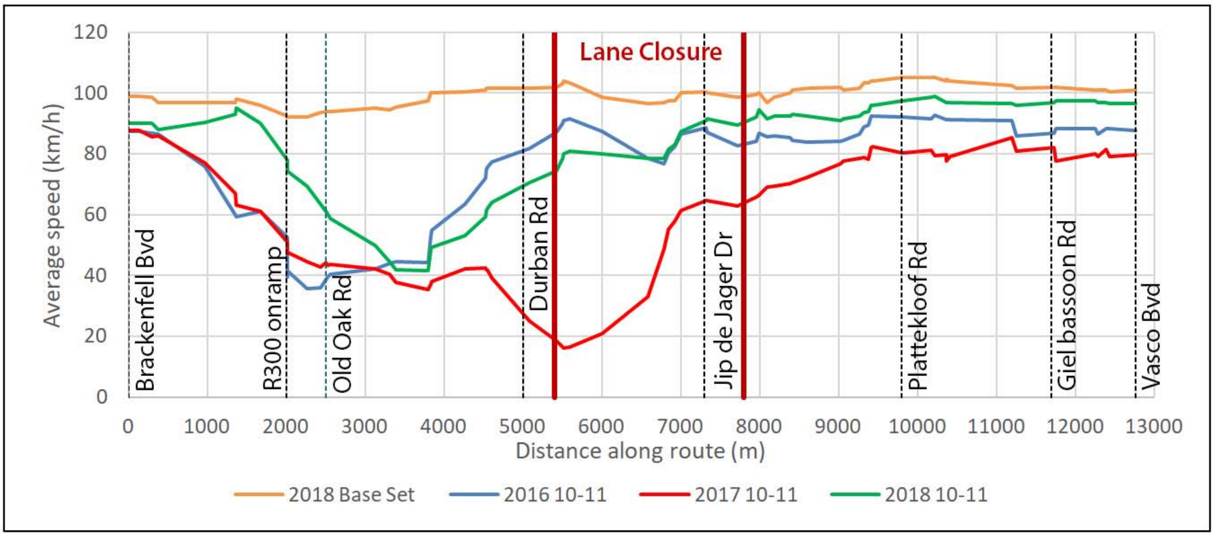

Figure 6: Speed Profile Analysis: Mid-Morning Period

The bottleneck 1.3 km downstream of Old Oak Road continued to influence traffic during the mid-morning period in 2016 and 2017. It is clear from Figure 6 that this bottleneck also affects traffic progression during the mid-morning period in 2018 (however not during the morning peak hour, as seen in Figure 5) after the addition of the third lane. This location is still a merge point, where the N1 now merges from four lanes to three lanes to accommodate the Old Oak Road onramp. As identified in Figure 4, this could be due to continued roadworks on the side of the N1 in this area during 2018.

5.4.3 Afternoon Peak Hour

The area of lane closure influenced travel speeds during the afternoon peak similarly to the mid-morning period in 2017 with a clear bottleneck forming at Durban Road, as visible in Figure 7. The peak direction of travel during the afternoon is outbound from Cape Town CBD, and so, as would be expected, the study area has relatively free-flowing traffic during this period.

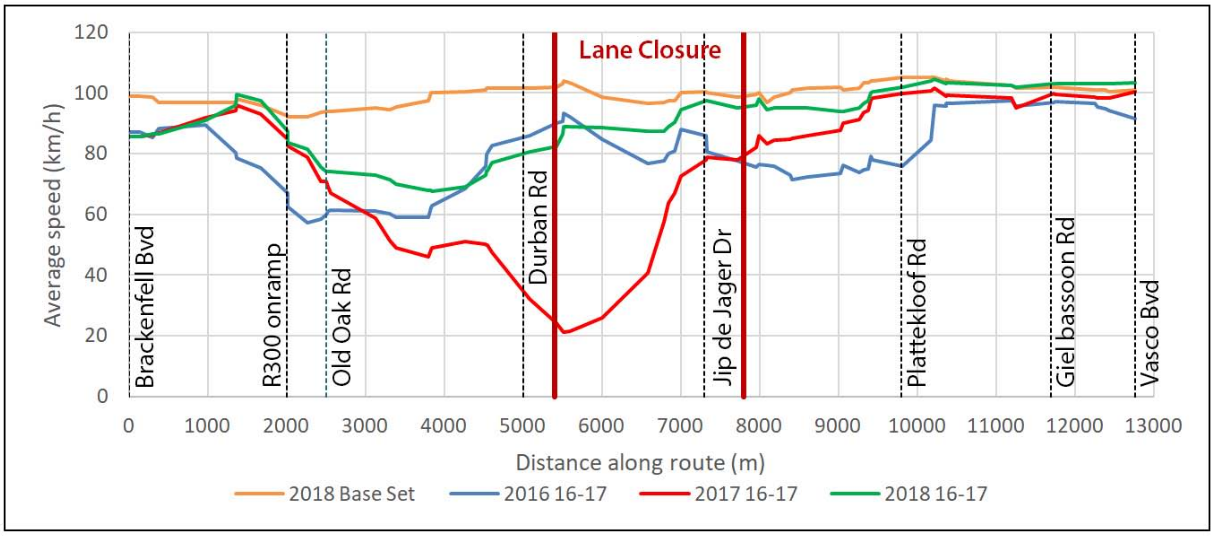

Figure 7: Speed Profile Analysis: PM Peak

5.5 Discussion

FCD has been shown to provide a detailed picture of traffic movement along the N1 inbound in this study and allowed changes in travel time along the route to be assessed. Three main locations causing congestion in the study area can be identified, as described below.

The first bottleneck in the study area was detected at a merge point where the N1 dropped a lane between Old Oak Road and Durban Road. This merge point was found to influence speeds throughout the day before and during the roadworks period. This bottleneck was eliminated in the morning peak hour in 2018 by the addition of a lane along the N1 inbound carriageway from Old Oak Road, significantly improving travel time. This location continued to influence traffic during the middle of the day and afternoon peak, possibly due to continued roadworks on the side of the road in this area in 2018.

Secondly, the roadworks zone between Durban Road and Jip De Jager Drive acted as a significant bottleneck in 2017, except during the morning peak period. During the midday and afternoon peak periods, traffic slowed to 20 km/h at the point of lane closure after which speeds increased quickly through the work zone.

Through all years of analysis, the morning peak period travel pattern is significantly affected by the third cause of congestion: capacity constraints downstream of the study area. This congestion caused traffic to back up through the work zone during the morning peak period, which is why the construction zone did not influence traffic patterns early in the day.

The increase in travel time during the morning peak period in 2017 was not induced by the roadworks activity. The profile of speeds through the work zone during the morning peak were similar in 2016 and 2017. It appears that the increase in travel time can be attributed to decreased speeds upstream of the R300 (requiring further investigation not included in this study). The improvement in travel time during the morning peak period in 2018 can however certainly be attributed to the capacity improvements made to the N1, even though downstream congestion remains a significant issue.

6. CONCLUSION

FCD is a relatively new source of traffic data that allows speed patterns to be observed continuously along a route. This Lagrangian type data has various benefits in observing traffic patterns, including the ability to determine the location of a bottleneck causing recurrent congestion and the position of the back of the resulting queue. These benefits have been applied in this research to evaluate the impact of roadworks on traffic patterns along the N1 in Cape Town. The positions of bottlenecks before, during and after completion of the roadworks projects were compared. This highlighted the benefits derived from the completed road upgrade project, particularly during the morning peak period, as well as the impact of significant downstream congestion on the evaluated road section. This information is not readily available if only considering traffic volume and overall travel time.

Temporal and spatial speed comparison charts obtained from FCD, such as Figure 4, give an overview of the change in speeds throughout the day along a route. This allows for comparison of general speed trends and provides an indication of areas affected by congestion. Detailed analysis of speed profiles along a route for specific hours of the day (Figures 5 to 7) allow the identification of bottleneck locations and queue lengths. Together these figures provide a much clearer view of traffic conditions than traditional location-based traffic information, allowing comparison at different periods of a roadworks project. FCD is therefore shown to provide important insight into traffic trends in work zones, augmenting our understanding of how traffic patterns are influenced by roadworks.

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