MOBILITY PERFORMANCE ANALYSIS OF THE BEN SCHOEMAN FREEWAY: BEFORE AND AFTER GFIP

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ABSTRACT

The use of mobility performance measures is a practical way to evaluate congestion levels on highly trafficked roads, as it is based on parameters to which road users can relate such as travel time, delay and the reliability with these parameters can be estimated. A set of Mobility Performance Measures was formalised by the Texas Transportation Institute (TTI) between 2003 and 2005 to supplement the traditional Level of Service (LOS) approach [1] [2]. These performance measures are particularly useful as they are easy to interpret and require basic data as input which can usually be obtained from various sources. Because these measures are quantitative rather than qualitative, the improvement or deterioration of traffic conditions can be easily compared over time or between different road sections, corridors, road networks or even different transport modes.

The feasibility of using mobility performance measures to assess traffic congestion in South Africa was investigated in 2008 [3]. As part of this study the performance of the Ben Schoeman Freeway between the Brakfontein and Buccleuch interchanges was assessed. The study found that by 2007 the majority of this road section performed dismally with the AM peak period spreading from 6h00 to 9h00 and traffic conditions classified as “intolerable” based on mobility performance analysis.

Since then the Brakfontein-Buccleuch road section has been significantly upgraded as part of the Gauteng Freeway Improvement Project (GFIP) initiated by the South African National Roads Agency (SANRAL). The purpose of this paper is to assess the change in traffic conditions from before to after the implementation of the upgrades by calculating mobility performance measures from the latest traffic data.

Key Issues that are discussed as part of this paper as follows:

1. Impact of improvements to the Ben Schoeman Freeway on mobility performance measures;
2. Impact of implementation of e-toll on congestion levels of the Ben Schoeman Freeway.
3. Value of using mobility measures to assess change in traffic conditions over time.

A substantial improvement in traffic congestion levels are observed, although it is clear that congestion is still at significant levels and that continuing traffic growth will counter the advantages yielded by the road upgrades in due course. It is also observed that the e-tolling system initially led to a decrease in traffic volumes, but that this effect had already been phased out by mid-2014.
1. INTRODUCTION

Traffic congestion is an ever increasing global problem, adversely affecting the quality of life of billions of people on a daily basis. Many countries in the developing world also face extreme congestion due to rapid economic growth and a lack of the necessary infrastructural development and maintenance.

South Africa experienced significant economic growth after 1994 leading to a dramatic increase in gross national income per capita as can be seen in Figure 1. This leads to increased spending and credit generation patterns, resulting in the number of registered vehicles increasing linearly to the growing income/per capita.

![Figure 1: Gross national income per capita after 1994 (2005 Rands)](image)

Parallel to economic growth, metropolitan areas also experienced a massive population growth due to the influx of people from the countryside in search of better job opportunities. Unfortunately, for the first 20 years after democracy, upgrades in transport infrastructure did not keep up with pressures generated by these changes on the existing transport infrastructure. Subsequently, traffic on major arteries, such as the Ben Schoeman Freeway connecting Pretoria and Johannesburg became unbearable during peak periods which extended for more than three hours in the mornings as well as in the afternoons. To improve these conditions, SANRAL launched the extensive Gauteng Freeway Improvement Project (GFIP) in 2008; with the aim to increase the capacity of freeways and interchanges in the Gauteng area and thus the traffic conditions in the area as a whole.

In 2008 a study [3] was conducted on the most notorious road links with the aim to demonstrate the ability of mobility performance measures to quantify traffic conditions in a way that could be easily presented to the public and could be related to the economic impact of the traffic congestion in monetary terms. This paper revisits the 2008 study and calculates the same mobility indices six years later, after the implementation of the GFIP upgrades, in order to evaluate the improvement that has been achieved by this investment. The impact of the implementation of the controversial e-tolling system is also assessed. The advantage of using traffic mobility measures to quantify the performance of a corridor over time is demonstrated.
2. MOBILITY PERFORMANCE MEASURES

2.1 Definition of mobility performance measures

Mobility performance measures were first developed by the Texas Transportation Institute (TTI) and formalize as part of The White Paper: The Keys to Estimating Mobility in Urban Areas in 2005 [1]. The aim of this document and subsequent supporting documents were to assist road authorities and governing bodies in monitoring the status of traffic congestion and also to compare these indices on a countrywide level.

The main advantages of mobility performance measures over conventional methods of traffic performance assessment (e.g. Level of Service) are that:

- numeric values are produced that can be easily compared for different scenarios and study areas;
- transport related improvements are reflected better than conventional methods;
- corridor, route or network based analysis can be performed;
- the combined impact of all modes can be analysed;
- they are more easily understood by the public.

Mobility performance measures are calculated based on parameters such as travel time, travel distance, traffic flow, vehicle occupancy and calculate performance relative to a certain target speed, which is usually taken as free-flow speed or the speed limit. Non-recurring delays caused by incidents are incorporated into these measures and values are therefore calculated from real data observed over a long enough period.

Mobility performance measures are classified as either “individual” or “absolute”, in order to quantify the impact of the delays on each road user (individual measures) or on the study area as a whole (absolute measures). The complete set of mobility performance measures as defined by the White Paper is as follows:

Table 1: Mobility performance measures*

<table>
<thead>
<tr>
<th>INDIVIDUAL MEASURES</th>
<th>ABSOLUTE MEASURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Time Index (TTI)</td>
<td>Total Delay [Person-Hours].</td>
</tr>
<tr>
<td>Delay Per Person km [Person-minutes]</td>
<td>Congested Travel [km]</td>
</tr>
<tr>
<td>Delay Per Km [Person-hours]</td>
<td>Percentage of Congested Travel [%]</td>
</tr>
<tr>
<td>Buffer Index (BI)</td>
<td>Congested Travel [Person-kms]</td>
</tr>
<tr>
<td>Planning Time Index (PTI)</td>
<td>Congested Travel [Person-hours]</td>
</tr>
</tbody>
</table>

* Refer [1] for more detailed definitions of each mobility measure.

Every mobility measure focuses on a different aspect of congestion. The individual measures quantifies the intensity of congestion experienced by each commuter as well as the reliability of the trip (BI and PTI), whereas the absolute measures quantifies the extent of congestion and can also be used to calculate the economic impact.
The mobility performance measure most commonly employed is the Travel Time Index (TTI), which compares travel times during congested conditions to travel times during ideal conditions. The TTI essentially is a ratio that indicates the additional time needed to travel a distance during peak travel when compared to target conditions.

A TTI can be calculated for a road link, corridor or on an area-wide basis, as it is a weighted average ratio taking into account the different characteristics of each road section, for example:

\[
TTI = \left[ \frac{\text{Freeway Travel Rate}}{\text{Freeway Free-flow Rate}} \times \frac{\text{Freeway Peak Period VMT}}{\text{VMT}} \right] + \left[ \frac{\text{Arterial Travel Rate}}{\text{Arterial Free-flow Rate}} \times \frac{\text{Arterial Peak Period VMT}}{\text{VMT}} \right]
\]

Where VMT vehicle miles traveled (vehicle km traveled used in this study)

TTI values of less than 1 and are associated with congestion-free travel and is therefore desirable. Values of 2 or above are considered indicative of heavily congested conditions, with traffic breakdown occurring and conditions becoming intolerable. The evaluation of TTI values are demonstrated in Figure 2.

Figure 2: Evaluation of Travel Time Index (TTI)
2.1 Implementation of mobility performance measures

Since its introduction, many cities in the United States have adopted these measures to evaluate the impact of traffic congestion on an annual basis.

The 2008 study on the feasibility of using these measures in South Africa [3] also concluded that they are useful and feasible tools to assess and compare congestion in South African cities on an annual basis and that sufficient data sources are often available for major routes (e.g. data from electronic counting stations).

In 2010, TomTom began to publish annual mobility performance measure reports based on data obtained from their automobile navigation systems. These reports provide international coverage and also include values for South African cities such as Pretoria, Johannesburg, Cape Town, Durban, Bloemfontein and East London [6]. These reports therefore enable congestion levels of cities from around the world to be compared.

Although and excellent source of information, sufficient historic GPS data is not available in South Africa to enable a comparative studies spanning several years as required for the work presented here. For the moment the best data source for the analysis of major routes remains output from electronic counting stations.

3. GAUTENG FREEWAY IMPROVEMENT PROJECT (GFIP)

The Gauteng Freeway Improvement Project (GFIP) was launched by SANRAL, supported by the Department of Transport, in October 2007 after approval from the cabinet. It was to comprise several phases of which the first phase involved the upgrading of some 200 km of congested highways linking metropolitan areas in the Gauteng province of South Africa (refer to Figure 3).

The project aimed to improve the congested conditions on the road system of South Africa’s economic hub by:

- Widening freeways (addition of some 585 km lanes);
- Upgrading interchanges (34 significant upgrades);
- Cross roads improvements;
- Providing median lighting;
- Improving Intelligent transport systems (ITS);
- Open-road tolling system.
The majority of the upgrades planned as part of the first phase of the GFIP project were completed in 2012 and the controversial open road tolling of the freeway system commenced on 1 December 2013.

4. PERFORMANCE OF THE BRAKFONTEIN-BUCCLEUCH ROAD SECTION

4.1 Background

This paper focuses on the performance of the Ben Schoeman freeway between Pretoria and Johannesburg and more specifically the road section from the Brakfontein (N1/N14) to the Buccleuch interchanges. This road section is historically known for some of the worst congested conditions in the country. As SANRAL had already put into place permanent electronic counting stations along the route before the year 2000 to monitor traffic conditions, ample data was available to compare the change in traffic conditions over time for this road section.¹

In the 2008 study, data for the AM peak in the South bound direction (Brakfontein to Buccleuch) was presented as this was established to be the worst case peak travel time and travel direction. Mobility performance measures were calculated for 2000 to 2007.

Since the previous study, significant upgrades were implemented on the Brakfontein-Buccleuch road section, of which the most significant are demonstrated in Figure 4.

Upgrades to this road section forming the scope of this study was as follows:

- Up to two additional lanes to entire road section
- Additional lanes to interchange ramps at Brakfontein, Old Jhb Rd,
- Widened bridge crossing at Olifantsfontein Interchange
- Upgrade of Annandale interchange from diamond to cloverleaf

As part of the study presented here, updated mobility performance measures were determined for the same study area using an identical analysis procedure in order to compare congestion levels before and after these upgrades. The latest results presented in this document are based on data obtained for 2013, the first year for which a complete representative data set exists after the upgrades were implemented.

It needs to be noted that the electronic counting stations were relocated during the upgrades to be at the interchanges themselves, instead of mid-link as for the previous study (refer to Figure 5). Local influences on traffic flows and speeds resulting from ramp-data now forming part of the data-set are therefore reflected in the results. No attempt has been made to compensate for this effect and the results presented for 2013 can therefore be seen as a conservative indication of the improvement of congestion levels on this road section.

¹ Data provided by Syntell with the permission of SANRAL
Figure 4: Upgrades from Brakfontein to Buccleuch

**BRAKFONTEIN 2006**
- Additional lanes on N1
- Bride widening
- Auxiliary lanes on cross road

**OLIFANTSFONTEIN 2006**
- Additional lanes on N1
- Bride widening
- Auxiliary lanes on cross road

**OLD JHB ROAD 2006**
- Additional lanes on N1
- Bride widening
- Auxiliary lanes on cross road

**ANNANDALE 2006**
- Additional lanes on N1
- Reconstruction of complete intersection including 4 new bridges
The extent of the study area on the Ben Schoeman Freeway (N1) from the Brakfontein to Buccleuch interchanges are presented below, including the respective links forming part of this road sections and the positions of the electronic counting stations pre-upgrade and post-upgrade.

Adjacent to Figure 5 in Table 2 the Annual Average Daily Traffic (AADT) is presented for each road link for 2007 and 2013. It can be seen that the current average AADT for this road section is in the order of 180 000 vehicles per day. Traffic growth over this period is calculated as 3.44% per annum, which reflects the annual growth in GDP/capita as mentioned before.

### Table 2: Annual Average Daily Traffic for 2007 and 2013

<table>
<thead>
<tr>
<th>Length of link [km]</th>
<th>AADT [veh]</th>
<th>Annual Growth [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3</td>
<td>135,305</td>
<td>160,189</td>
</tr>
<tr>
<td>2.8</td>
<td>112,920</td>
<td>143,612</td>
</tr>
<tr>
<td>3.1</td>
<td>133,745</td>
<td>169,236</td>
</tr>
<tr>
<td>3.0</td>
<td>140,508</td>
<td>175,268</td>
</tr>
<tr>
<td>4.1</td>
<td>146,963</td>
<td>182,559</td>
</tr>
<tr>
<td>4.1</td>
<td>179,277</td>
<td>211,920</td>
</tr>
<tr>
<td>Weighted Average</td>
<td>144,019</td>
<td>176,472</td>
</tr>
</tbody>
</table>

#### Figure 5: Electronic counting stations

- **2007 electronic counting stations**
- **2013 electronic counting stations (south bound)**
4.2 Results and discussion

4.2.1 Raw data evaluation

Raw data was filtered to contain only traffic information for weekdays in the south bound direction. Simply looking at the resulting average hourly traffic flows and speeds already gives an indication of the advantages that had been gained through the upgrades between 2007 and 2013 (refer to Figure 6 and Figure 7).

When data for 2007 and 2013 is compared, significant increases in traffic flows are observed, particularly for the New Road - Annandale - Buccleuch links with increases during the AM peak hour of between 3500 and 4000 veh/h. This is due to the capacity provided by lane additions and the significant upgrade of the Annandale interchange. The increase in average hourly flows for each road link is shown in Figure 6.

![Figure 6: Annual average hourly traffic flows for (a) 2007 and (b) 2013.](image)

The average speeds for peak hour traffic have also increased significantly for the AM peak, with the most dramatic changes on the Old JHB – Samrand – Olifantsfontein road links. Average speeds have increased with between 20 and 30 km/h for these road links as can be seen in Figure 7.

![Figure 7: Annual average hourly speeds for (a) 2007 and (b) 2013.](image)
4.2.2 Travel time indices

Mobility performance measures were calculated respectively for the AM peak period and AM peak hour in the south bound direction. Peak time spreading in the study area have taken place to the extent that peak conditions spans a three hour period from approximately 6h00 AM to 9h00 AM. Mobility performance measures have therefore been calculated for two scenarios:

- **Scenario 1:** Peak period from 6h00 AM to 9h00 AM (south bound)
- **Scenario 2:** Peak hour from 7h00 AM to 8h00 AM (south bound)

Scenario 1 gives individual performance measures that are representative of the conditions experienced by the average traveler for the duration of the peak period and gives absolute measures that are indicative of the total delays and costs that are incurred. Scenario 2 gives individual measures that are indicative of the worst case conditions.

Firstly, travel time indices were calculated for 2013 and compared to those from the previous study (values from 2000 to 2007):

Firstly, travel time indices were calculated for 2013 and compared to those from the previous study (values from 2000 to 2007):

![Graph](image-url)  
**Figure 8:** Travel time indices for (a) Scenario 1: (6h00 to 9h00) and (b) Scenario 2: (7h00 to 8h00).

**Scenario 1:**

From the results it can be seen that the travel time indices for all road sections have been significantly reduced from 2007 to 2013. In 2007 all road sections, except for the Annandale - Buccleuch section reported average TTI's of above 2 for the entire three hour period from 6h00 to 9h00 (refer to Figure 8(a)), which are conditions associated with traffic breakdown (refer to Figure 2).

The results for 2013 show a significant improvement, with travel time indices having been reduced to values below those recorded for 2000 - the oldest available data-set.
Scenario 2:

It can be seen in Figure 8(b) that peak hour performance is in general poorer than peak period performance. In 2007 traffic completely broke down (TTIs exceeding 2 and even as high as 4) for a large portion of the road section. In 2007 peak hour performance was between 30 and 40% worse than for the peak period travel, whereas in 2013 the difference is less than 10% for the majority of road sections.

This indicates vastly improved road conditions, though it is noted that a TTI of 2 is already approached in 2013 for the Samrand-Olfantsfontein-New Road links, indicating that conditions are still close to an intolerable level.

Travel time forecasts:

As part of the GFIP project, a travel demand model (SATURN) was developed in 2006. Output from the “do nothing” hypothesis was used in 2008 to forecast the peak hour TTI values should no upgrades be implemented. In order to compare the originally forecasted values with actual observed values, the weighted average TTI over the entire road section from Brakfontein to Buccleuch are shown in in the Figure 9 for both peak scenarios. It is observed that 2006 forecasted TTI values were calculated to go “off the charts” (above 4) in 2012 in contrast to the actual values that are significantly below 2 in 2013-2014. This emphasizes the advantages gained from the GFIP upgrades.

It can also be seen that peak period TTIs (blue) and peak hour TTIs (red) are significantly closer to one another in 2013-2014 than before the upgrades, indicating that peak period travel is more stable over the peak period than before the upgrades.

Figure 9: Weighted average annual TTI for Scenario 1 (peak period) and Scenario 2 (peak hour), as well as projected values calculated in 2006 (peak hour) for a “no improvement scenario”.

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2 Goba Consulting Engineers
4.2.3 Other mobility performance measures

Other mobility performance measures were also calculated in order to compare the changes between 2007 and 2013. Results were obtained as shown in Table 3.

Table 3: Comparison of mobility performance measures for AM peak period for 2007 and 2013.

<table>
<thead>
<tr>
<th>Mobility Performance Measure</th>
<th>Unit</th>
<th>Average over road section</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2007</td>
<td>2013</td>
</tr>
<tr>
<td>Individual</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delay per hour driven/veh</td>
<td>Vehicle-minutes</td>
<td>63</td>
<td>28</td>
</tr>
<tr>
<td>Total Delay</td>
<td>Vehicle-Hours</td>
<td>2,856</td>
<td>1,829</td>
</tr>
<tr>
<td>Total Delay</td>
<td>Person-Hours</td>
<td>3,427</td>
<td>2,194</td>
</tr>
<tr>
<td>Delay Per Person km</td>
<td>Person-Minutes</td>
<td>3.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Delay Per km</td>
<td>Person-Hours</td>
<td>1,025</td>
<td>631</td>
</tr>
<tr>
<td>Absolute</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Congested Travel</td>
<td>Person-km</td>
<td>390,364</td>
<td>560,697</td>
</tr>
<tr>
<td>Congested Travel</td>
<td>Person-Hours</td>
<td>6,680</td>
<td>6,867</td>
</tr>
<tr>
<td>Congested Travel</td>
<td>km</td>
<td>20.3</td>
<td>20.3</td>
</tr>
<tr>
<td>% of Cong. Travel</td>
<td>Percent</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

* Performance measures were calculated based on a conservative vehicle occupancy rate of 1.2.

The results show that the delay per hour driven in 2013 is less than half of what it was in 2007, whilst all other individual measures have also improved significantly. However, absolute measures, which serve as indication of “total wasted time”, have increased due to increased traffic volumes. Travel is still classified as congested for 100% of the peak time period for this road section.

Using the delay per person km and the person-kms of congested travel, the economic impacts of delays can be estimated. For this the cost of time must be determined, which should be calculated taking into account vehicle occupancy, light/heavy vehicle split, value of working time, value of cargo etc. Since some of these parameters were not available for this specific road section at the time of this study, an estimated average economic time cost of R112/hour (in 2013 Rands) [7] was assumed in order to demonstrate the economic impact of delays. If the annual economic cost of delay during the AM peak period on the Brakfontein- Buccleuch road section is thus calculated, it amounts to approximately R255 Million for 2007 vs R163 Million for 2013. This excludes other economic costs, such as vehicle running costs, accident costs etc.

4.2.4 Impact of e-tolling on congestion levels

The e-tolling system was implemented on 1 December 2013. The available traffic data was assessed to investigate the impact of e-tolling on traffic flows and speeds.

AM peak hour data for January to July 2014 was compared to data for the same period in 2013. Data for the electronic counting station at the Brakfontein interchange was used, being the most complete data-set available for these time periods.
Average monthly flows and speeds can be seen in Figure 10(a) and (b) respectively.

When 2013 and 2014 is compared, it is observed that traffic flows decreased with approximately 1000 veh/h year-on-year for the first 4 months of 2014. Thereafter the 2014 traffic volumes caught up to the 2013 values and surpassed them by May 2014. Similarly, the traffic average monthly speeds for 2014 are higher for the first part of the year and then returns to previous levels after May.

Although not presented here, data for the other counting stations support this trend and it is therefore clear that although e-tolling initially had an impact on traffic due to a reduction in traffic volumes, this impact had been phased out by mid-2014.

5. CONCLUSION

This study compares traffic conditions on the Brakfontein-Bucleuch road section between Pretoria and Johannesburg before and after the implementation of upgrades as part of the Gauteng Freeway Improvement Project.
To investigate the performance of this road section, mobility performance measures were used, with particular focus on Travel Time Indices (TTI). Indices were calculated for the AM peak in the south bound direction, representing the worst congested conditions.

Based on the results from the data presented here the following conclusions were made:

- Average hourly peak flows and speeds for the AM peak have significantly increased due to the increased capacity provided by the upgrades;
- Travel time indices for the AM peak period as well as the AM peak hour have improved to levels of below 2 and are now at levels corresponding to those recorded for the year 2000;
- The difference between AM peak period and AM peak hour values have decreased, indicating more stable traffic conditions over the peak period;
- E-tolling initially had an effect on traffic volumes, but this effect had been phased out after only 4 months of operations.

This study therefore demonstrates the significant advantages gained by the GFIP project based on mobility performance measures. However, conditions over the peak period are still classified as congested, with peak hour TTIs for certain road links values of 2, which is regarded as intolerable conditions.

ACKNOWLEDGEMENTS

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REFERENCES


