TIME-SERIES ANALYSIS OF ACCESSIBILITY IN THE CITY OF JOHANNESBURG

N LIONJANGA and C VENTER*

Department of Civil Engineering, University of Pretoria, Hatfield 0002, South Africa,
Tel: 083 894-6497; Email: nlionjanga@gmail.com
* Department of Civil Engineering and Centre for Transport Development, University of Pretoria, Hatfield 0002, South Africa,
Tel: 012 420-2184; Email: christo.venter@up.ac.za

ABSTRACT

Accessibility, a concept that has been extensively studied and developed since the late 1950s, describes the ease or difficulty of reaching a destination from a particular location. Within the corpus of accessibility measures is the Net Wage After Commute (NWAC) which describes the potential wage earnable less the transport costs incurred to commute to work from a particular location. The NWAC explicitly accounts for transport costs as a measure of impedance which is crucial in a province like Gauteng with low transport affordability. This study explores the evolution of accessibility for poor, public transport captive households in the City of Johannesburg (CoJ) by calculating accessibility to jobs from a select group of locations biennially from 2009 to 2013. A time-series analysis of accessibility reveals that accessibility improves from one analysis year to the next primarily due to increases in the potential wage earnable. Although fully operational since 2011, the analysis reveals that the Rea Vaya BRT (Phase 1A) only makes a notable addition to job accessibility from Soweto in 2013. However, its limited catchment area relative to existing services, amongst other things, limits its effects on accessibility. Development of economically vibrant corridors along BRT routes could assist in leveraging this service.

1 INTRODUCTION

Johannesburg was founded in 1886 when gold was discovered in the southern part of Gauteng, formerly known as the South Transvaal (Hart, 1984). For the first five years of its existence, Johannesburg was a compact pedestrian town, a stark contrast of the metropolitan city experienced today which is the economic hub of the Gauteng province and South Africa as a whole (Hart, 1984; Todes, 2012; Gotz et al., 2014). The population of the CoJ grew at an annual average growth rate of 3.2% from 2001 to 2011, resulting in a population growth of approximately 1.2 million in 10 years (CoJ, 2013). It is estimated that by 2040 the population of the CoJ will be approximately 7 million (CoJ, 2013). Due to the relative success of the city, it acts as a magnet for migrants from other areas in South Africa as well as other countries in Southern Africa (Landau & Gindrey, 2008). In 2011,

only 52% of CoJ residents were born in Gauteng compared to 93% in 2001 (CoJ, 2013). Despite its perceived relative success, the CoJ is one of the most unequal cities in the world, with high levels of poverty and unemployment (CoJ, 2013; Todes, 2012).

During the study period (2009 to 2013) the CoJ underwent two key public transport interventions; namely, the introduction of the Gautrain and the Bus Rapid Transit dubbed Rea Vaya (CoJ, 2013; Gotz et al., 2014). This large investment in transportation infrastructure was made in an attempt to solve some of the public transport challenges that the CoJ residents grapple with on a daily basis, one of which is poor transport accessibility (CoJ, 2013). The 2011 Quality of Life Survey revealed that one of the greatest concerns facing public transport users in the CoJ was the cost of service (Gotz et al., 2014). In fact, most low income groups resort to non-motorised transport (NMT) modes, not by choice, but because public transport is not affordable and/or it is not easily accessible (Gotz et al., 2014). Low-income residents of the CoJ residing in the peripheries of the city travel more than 25km on average to look for work, suffering a significant financial and travel time burden (Gotz et al., 2014). Transport and planning policy is prioritising the improvement of transport accessibility and affordability for all Gauteng residents (GPG, 2012; CoJ, 2013). In various studies, transport accessibility has been linked to quality of life and social exclusion (Kenyon, 2003; Preston & Rajé, 2007; Delbosc & Currie, 2011; Venter & Cross, 2014). Inadequate transport accessibility compromises the quality of life of residents and leads to social and/or economic exclusion.

Accessibility and exclusion are dynamic concepts, and should properly be assessed over time. This study aims to do so through a time-series analysis of accessibility in selected low-income locations in the CoJ, specifically Alexandra, Orange Farm and Soweto. This case study allows for the observation of accessibility changes brought about by the implementation of the BRT as well as changes in the fare structure of the BRT. The objective is to further our understanding of the social impact of transport investments on low-income user groups.

2 ACCESSIBILITY

Accessibility, a concept that has been extensively studied and developed since the late 1950s, describes the ease or difficulty of reaching a destination or opportunity from a particular location. In most studies, opportunities refer to job opportunities and ease or difficulty is measured in units of distance or time (Venter & Cross, 2014).

There is significant social value in accessibility both as a theoretical construct and as a potential spatial planning tool; as Martens (2017) puts it, “the distinct social meaning of the transport good lies in the accessibility it confers to persons”. Accessibility can aid in the identification of areas subject to transport disadvantage subsequently answering questions of transport equity (Morris et al., 1979; Cervero, 2005) , and it can act as a social indicator by identifying the level of accessibility to essential activities necessary to provide persons with a high quality of life (Geurs & van Wee, 2004). Ultimately, monitoring projects from a perspective of accessibility provides a more holistic view (Cervero, 2005), hence the

increased interest in accessibility amongst academics (Venter & Cross, 2014). To the authors' knowledge, accessibility is rarely measured over time, particularly in the South African context. Time-series measurements of accessibility can be used as a tool to assess the performance of land-use and transportation planning policies (El-Geneidy & Levinson, 2006).

2.1 Accessibility measures

Geurs & Wee (2004) highlight a number of accessibility measures in their review, amongst which are two of the most commonly used measures; namely, gravity-based measures and threshold type measures (Cervero, 2005). Hansen (1959) is one of the pioneers of accessibility measurements (Martin & van Wee, 2011); he defined accessibility as "the potential of opportunities for interaction". His research that aimed to further understand the relationship between land-use and accessibility resulted in the development of a land-use model that was based on a gravity-based accessibility measurement (Hansen, 1959). Although gravity-based models are one of the most commonly used methods of measuring accessibility (Iacono, Krizek, & El-Geneidy, 2010), one of the shortcomings of these models is that they are not easily interpreted and communicated (Geurs & van Wee, 2004; Venter & Cross, 2014). This is primarily due to the unclear determination of the impedance function (Venter & Cross, 2014), which can take on a wide range of values depending on trip length, trip purpose etc. (Hansen, 1959). Consequently, the accessibility measure is not always easily understood by policy and decision makers (Hansen, 1959; Cervero, 2005; Venter & Cross, 2014). The gravity-type model was applied by Venter & Mohammed (2013) to explore a possible relationship between transport energy consumption and accessibility in the Nelson Mandela Bay.

The threshold type accessibility measure specifies an arbitrary cut-off point (whether in travel time or travel distance) and only considers potential opportunities that fall within the specified threshold (Burns & Golob, 1976; Cervero, 2005; Venter & Cross, 2014). A shortcoming of this model is the necessity to specify an arbitrary cut-off point (Venter & Cross, 2014), however, it is widely used and it was applied by van Dijk, Krygsman et al. (2015) to explore the effects of tolls on public transport and private vehicle accessibility across various income groups in the Cape Town metropolitan region.

2.1.1 Access Envelopes

Venter and Cross (2014) identified two main shortcomings of the above mentioned accessibility measurements, that together prompted the development of the access envelope technique for accessibility mapping. The first shortcoming is the simplistic manner in which travel impedance is typically accounted for, often on the basis of travel time or travel distance estimated on the road network, without taking actual public transport routes and frequencies into account (Venter & Cross, 2014). The second shortcoming is the failure of these measures to explicitly account for travel costs when estimating travel impedance (Venter & Cross, 2014). The access envelope technique is implemented using a Geographic Information System (GIS), a common tool for mapping accessibility (see Miller & Wu, 2000; Delamater et al., 2012; Ford et al., 2015).

Venter and Cross (2014) describe the access envelope technique as, “a planning tool for measuring the impact of both transport and job or housing delivery on the location-specific affordability of job access at a community level for poor households”. The following is a list of the input data required to determine the level of accessibility to employment opportunities (Venter & Cross, 2014):

- **Spatial distribution of jobs:** These jobs must suit the typical education level and/or skill level of residents in the locations of origin. The spatial distribution of jobs in the CoJ was obtained from the Gauteng Transport Model job location data.

- **Potential wage levels:** This is the typical potential daily wage earnable across various employment sectors for low income groups in the CoJ. The wage is increased from one analysis year to the next and it can range anywhere between R100/day to R190/day. Consequently, the NWAC does not exceed values of R190/day.

- **Walking times:** The times required to walk to the first public transport mode of choice and the time required to walk from the last public transport mode of choice to the place of employment.

- **Waiting times:** The time spent waiting for a mode of transport to arrive. The average waiting time was accepted as half the headway of the mode of choice.

- **Public transport costs:** The public transport fares and associated fare structures. The fares considered were the daily trip fares, which are slightly more expensive than the fares offered through purchasing weekly, monthly or yearly tickets. The fare structure adopted for all the modes was a linear distance-based fare structure (with the exception of the Rea Vaya BRT in 2011 which had a flat fare structure).The public transport fares were increased from one analysis year to the next.

- **Speed of transport mode:** For road based modes, this was expressed as a percentage of the speed limit of the road section along which the mode travels.

The accessibility measure is dubbed the Net Wage After Commute (NWAC) and it describes the potential wage earnable less the transport costs incurred to commute to work from a specific location on any given day. By explicitly including transport costs as a form of travel impedance, this technique becomes sensitive to these costs as well as operational shortfalls that force commuters to transfer, which usually comes in tandem with payment of an additional fare and travel delay (Venter & Cross, 2014). Previous applications of Access Envelopes have examined access patterns for taxi, bus and rail in Tshwane (Venter & Cross, 2014), and compared various BRT feeder strategies in Johannesburg (Venter, 2016).

3 ACCESS ENVELOPE METHODOLOGY

Ingram (1971) defined two types of accessibility, namely, relative accessibility and integral accessibility (Dalvi & Martin, 1976). Relative accessibility determines the extent to which two points on the same surface are connected, whereas, integral accessibility determines the extent to which a single point is connected to all other points on the same surface (Dalvi & Martin, 1976). The access envelope technique is an integral accessibility measure calculating the accessibility, from a selected origin, to all other points on the study surface, which in this case is the CoJ. The output is a GIS surface graphically displaying the access levels from the selected origin to surrounding job locations.

The public transport routes and associated fares for all operational modes in the CoJ were sourced for the years 2009, 2011 and 2013.

- 2009: Only three modes were considered; namely, the minibus taxi, Metrorail and Metrobus. Rea Vaya Phase 1A implementation began in 2009 but only became fully operational in February 2011, thus it was excluded from the 2009 analysis.

- 2011: Four modes were considered; namely, the minibus taxi, Metrorial, Metrobus and the Rea Vaya BRT (Phase 1A) which became fully operational in February 2011. In 2011, Rea Vaya used a flat fare structure which was as follows: The cost of using a feeder route was R4,50; the cost of using a trunk route was R8,50; and the cost of using both the feeder and trunk route was R12,00.

- 2013: The same four modes in 2011 were considered in 2013. Rea Vaya Phase 1B only became operational in October 2013 and was thus excluded from the analysis. In 2013, Rea Vaya BRT used a distance-based fare structure following the introduction of the Rea Vaya smartcard, thus commuters travelling longer distances using this mode incurred higher costs than they did in 2011.

The NWAC expresses accessibility in monetary terms by assessing the potential impact of extended travel time on the potential wage earnable. Based on travel behaviour literature, it is assumed that commuters have a travel time budget of 60 minutes per direction; 120 minutes per day (Venter & Cross, 2014). If commuters exceed the travel time budget, it is assumed that this reduces working hours and subsequently decreases the potential wage earnable.

Computation of the NWAC requires relatively extensive and accurate public transport spatial data; fares, routes and speed, across all modes in the CoJ. Public transport fares were obtained from the CoJ Public Transport Record and inflated accordingly to determine the fares across all the analysis years. The inflated fares were calibrated using current fare data available online for most of the modes. For the minibus taxi, which is the most widely used mode in the CoJ (CoJ, 2013), fares were calibrated through field data collection, specifically surveys conducted with various taxi operators in the CoJ regarding fares. With accurate transport routes available, it is possible to determine walking times to and from

the public transport modes utilised. The NWAC combines job income, travel cost and travel time into an intuitive and easily interpretable measure that incorporates both land-use and transport.

3.1 Summary measures

Summary measures are defined to allow comparison across the analysis years and across different areas of the CoJ. Three summary measures are used that address the issue of transport affordability, travel times and job location.

- **The number of jobs accessible with an NWAC greater than R85/day:** This will give an indication of the number of jobs a commuter can access while retaining a reasonable NWAC (assumed to be R85/day). This amount of R85 is based on the assumption of a single breadwinner and a household size of four (the average household size in the Gauteng City-Region based on the 2009, 2011 and 2013 QoL surveys). A sole breadwinner in such a household will have to take home R85 a day to ensure that each individual in the household of origin lives above the lower bound poverty line (ignoring equivalence scales). The lower bound poverty line, as defined by StatsSA (2014), is the line below which food items are sacrificed to afford other non-food goods such as transport.

- **The number of jobs accessible within 60 minutes of travel time:** This will give an indication of the spatial distribution of jobs within 1 hour of travel time from the origin. Origins that score high are either within close proximity to economic nodes and/or are confined to faster modes of public transport.

- **Average NWAC of the closest 200,000 jobs:** This will give an indication of the distribution of the NWAC in the immediate surrounding of the origin location while controlling for the number of jobs. Origins that score high are either surrounded by high paying jobs or low transport costs in conjunction with shorter travel times.

The following chapter illustrates the application of this methodology in three townships in the CoJ; namely, Soweto, Alexandra and Orange Farm.

4 RESULTS

4.1 Supply of Transport

The access envelope methodology considers the closest cheapest mode or combination of modes, and makes a trade-off between travel time and travel cost when selecting the mode or combination of modes to maximise the NWAC. What remains consistent in the results across all three townships is the dominance of the minibus taxi as the mode that maximises the NWAC; more than 50% of the trips from the selected origin zones are completed using this mode. The findings of the computations appear to be consistent with the 2009 QoL survey travel behaviour findings that low-income households are heavily dependent on the minibus taxi mode (Gotz et al., 2014). The dominance of the minibus

taxi as the mode that maximises the NWAC for trips made from Alexandra is particularly high, simply because the Metrorail does not serve this township. In the CoJ, the Metrorail predominantly runs in the East-West direction and towards the South and South-West of the city, serving both Soweto and Orange Farm. Rail is the cheapest mode of transport in the CoJ, however, it is not as readily accessible and adaptable as the minibus taxi, and it does not extend to key economic nodes such as Rosebank, Sandton and Midrand, thus, using the NWAC methodology, it is not the leading mode of choice for commuter trips. The results reveal that the Metrobus trips are low, in comparison to the other public transport modes, regardless of its widespread network, due to the high fares associated with this mode. The Gautrain is not considered as a mode of transport in this study as it predominantly caters for middle-income and high-income groups.

Rea Vaya BRT Phase 1A, which became fully operational in February 2011, was introduced offering lower fares than the Metrobus. Despite the change of the Rea Vaya fare structure from 2011 to 2013, the percentage of trips made using this mode was not compromised. In 2013, Rea Vaya was the second cheapest mode after the Metrorail and the average distance covered using this mode (according to the NWAC calculation) was 17km resulting in a fare of approximately R9. For such relatively short distances, the 2011 flat fare structure works out to be more expensive, particularly when using a combination of the BRT trunk and feeder. However, the Rea Vaya duplication of the Metrorail service and lack of access provided to regions outside of the Johannesburg inner city is a contributing factor to its low number of trips from Soweto.

4.2 Accessibility: A Temporal And Township Comparison

Table 1 reflects the three summary measures computed for a single zone from each township. All jobs accessible within 60 minutes of travel time return a reasonable NWAC (greater than R85/day) thus they are also expressed as a percentage (values in red in Table 1) of the number of jobs accessible with NWAC greater than R85/day. It is evident that the number of jobs accessible with NWAC greater than R85/day increases from 2009 – 2013 for all origins, this could be due to increased potential wage levels. Wages increase with a monetary increment that is higher than that of the fare increase, thus wage increases could lead to the use of faster and generally more expensive modes (such as the minibus taxi, Metrobus and BRT) and the fare increase is offset by an increase in wages in order to retain a reasonable NWAC.

Alexandra is the region that can access the largest pool of jobs within a reasonable NWAC, followed by Soweto and finally Orange Farm. From Alexandra, more than 65% of these jobs can be accessed within 1 hour of travel time for all three years, which is significant compared to the percentages observed for Soweto (31% - 65%), and more especially Orange Farm (5% - 16%). It is evident from Figure 1 that Alexandra, compared to Soweto and Orange Farm, is within close proximity to key activity nodes with ample economic opportunities, such as Randburg, Sandton and Midrand, hence it reflects the highest values for the average NWAC of the closest 200000 jobs in 2011 and 2013 (R127 and R137 respectively). Over and above that, the results reveal that more than 90% of trips originating from Alexandra are completed using the minibus taxi, which offers faster

travel times and is more widespread than a cheaper mode such as rail, thus allowing accessibility within a reasonable NWAC to majority of the CoJ. In the apartheid era, residents of the Alexandra township successfully resisted relocation to the CoJ peripheries (Todes, 2012) and the current residents of this township could possibly be reaping the benefits of that resistance in terms of accessibility.

Orange Farm, located on the Southern peripheries of the CoJ, is the furthest away from the Johannesburg inner city as well as the CoJ's northern decentralised economic nodes; therefore the number of jobs accessible within an hour of travel time from Alexandra is more than 20 times greater than the jobs accessible from Orange Farm within the same travel time. An increase in wages in 2011, allowed for a shift from the low-fare Metrorial to the minibus taxi which significantly increased the number of jobs accessible with a reasonable NWAC from Orange Farm, particularly towards the North of the CoJ (See Figure 2 and Figure 3). The low-fare Metrorail could act as a buffer against fare increases on other modes, particularly due to its low fares, however, over long distances such as those travelled from Orange Farm to the Johannesburg inner city, large travel time penalties are incurred, significantly reducing the NWAC. Alexandra, although located close to the CBD, is the region with little to no access to rail services and thus did not have this buffer and experienced the lowest annual growth rate of the number of jobs accessible with a reasonable NWAC.

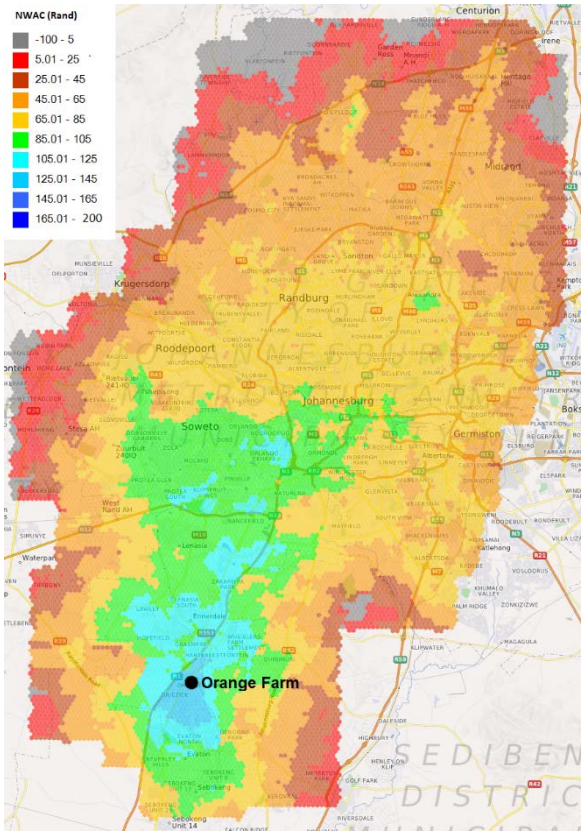
Soweto, which underwent the dawn of the BRT intervention during the analysis period, is particularly interesting. Comparing Soweto 2011 and 2013 including and excluding BRT, it is notable that the additional accessibility provided by the BRT only became evident in 2013 and even so, it was relatively insignificant (see Figure 4 and Figure 5). This is due to the fact that the Rea Vaya BRT Phase 1A operates parallel to the Metrorial route and only offers access to the Johannesburg inner city. Perhaps the implementation of the subsequent phases of the BRT will improve its catchment area and thus its effect on accessibility.

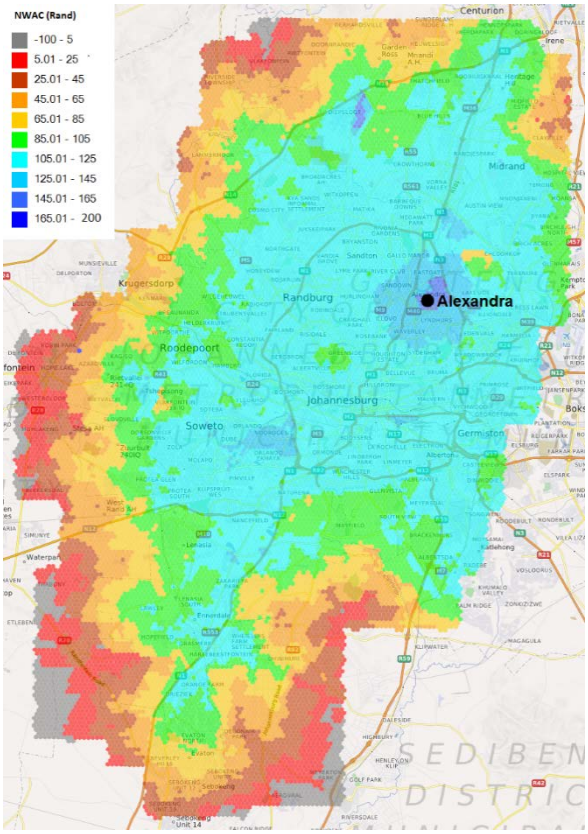
Despite the number of jobs accessible within a reasonable NWAC increasing biennially from 2009, the number of jobs accessible within one hour of travel time is decreasing (see Table 1). This is indicative of a shift to slower and usually more affordable modes such as rail and/or NMT from one analysis year to the next as fares increase. However, Soweto displays a deviation from the trend from 2011 to 2013 as the number of jobs accessible within a 60 minute travel time increases (only for the scenario including BRT) reflecting the speed improvement provided by the BRT at a lower cost than the minibus taxi and Metrobus. Therefore, the BRT ensures that even as fares rise, access does not decline as it provides a lower cost alternative to the minibus taxi and Metrobus while maintaining similar travel times.

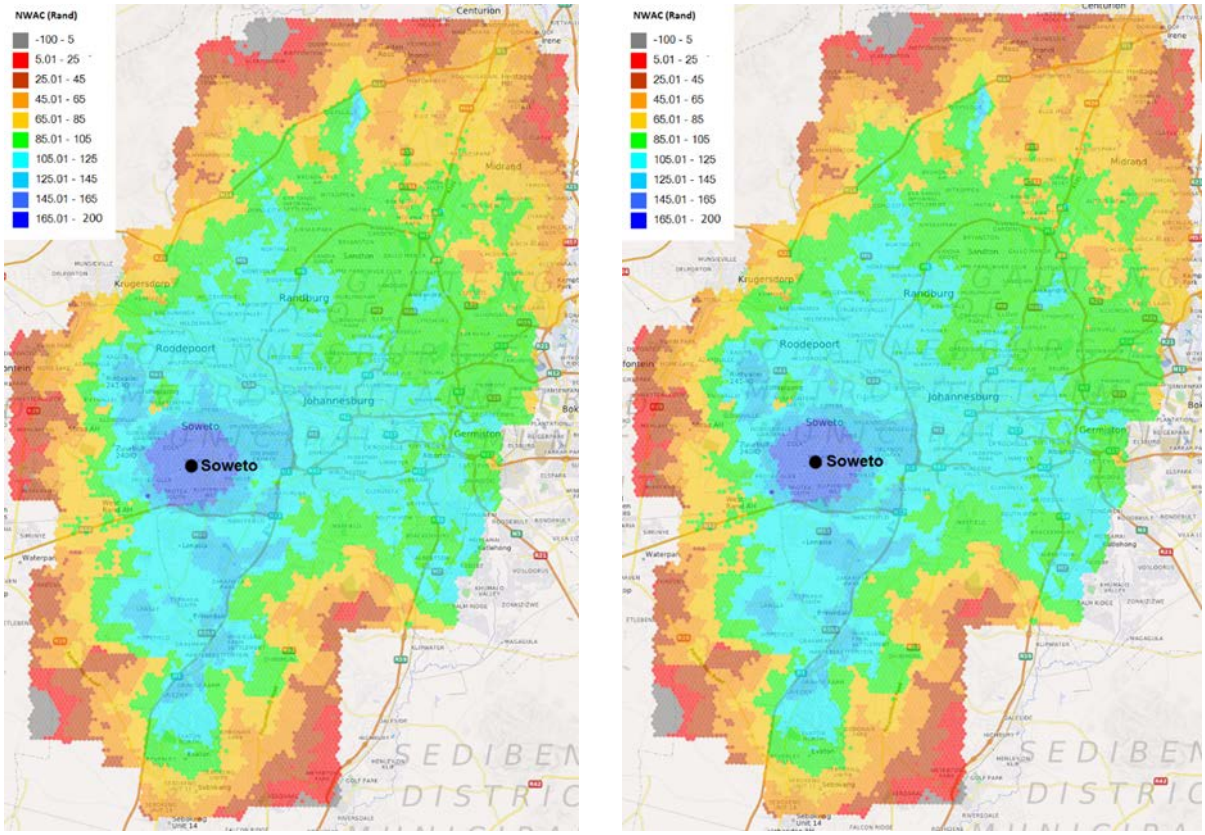
Table 1: Summary measure of the access envelope methodology

Origin	Number of jobs accessible with NWAC > R85	Number of jobs accessible within 60 minute travel time	Average NWAC of the closest 200000 jobs
Alexandra 2009	2,856,172	2,147,933 (75%)	R114
Alexandra 2011	3,001,864	2,095,962 (70%)	R127
Alexandra 2013 (Fig. 1)	3,057,583	2,054,566 (67%)	R137
Orange Farm 2009 (Fig. 2)	566,693	90,954 (16%)	R82
Orange Farm 2011	1,067,069	82,573 (8%)	R90
Orange Farm 2013 (Fig. 3)	1,520,253	77,942 (5%)	R95
Soweto 2009	1,894,806	1,153,821 (61%)	R114
Soweto 2011 including BRT	2,389,384	742,800 (31%)	R124
Soweto 2011 excluding BRT	2,392,059	1,064,582 (45%)	R124
Soweto 2013 including BRT (Fig. 4)	2,669,232	946,634 (35%)	R133
Soweto 2013 excluding BRT (Fig. 5)	2,667,509	1,055,874 (40%)	R132

Figure 6: Distribution of accessibility in the townships







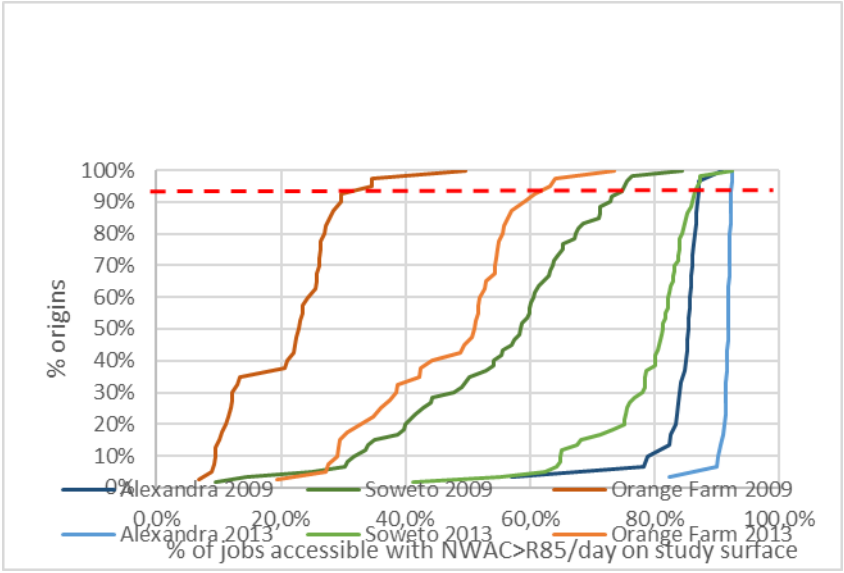


Figure 6: Distribution of accessibility in the townships

The study also explored the distribution of accessibility within these townships: thirty or more sample zones (also referred to as origins) were selected from each township and the summary measures for each origin computed for each analysis year. Figure 6 reflects the distribution of accessibility across these townships in 2009 and 2013. Alexandra not only displays the highest accessibility levels but also the most uniformly distributed; from 50% of the origin zones one can access 80% to 92% of the jobs on the entire study surface with an NWAC of R85/day in 2013. Soweto displays a shift to a more uniform distribution of accessibility across the township from 2009 to 2013, however, the BRT accounts for less than 1% of the growth in accessibility from 2009 to 2013. Orange Farm displays a more

widespread distribution of accessibility in 2009 and 2013, and it reflects strikingly low results in 2009; from 50% of the origin zones one can only access 5% - 25% of the jobs on the entire surface with an NWAC of R85/day, this increases by approximately 20% between 2009 and 2013.

5 CONCLUSIONS

The Access Envelope methodology developed by Venter and Cross (2014) was utilised to assess the time-series accessibility to job opportunities from three townships in the CoJ, namely, Alexandra, Soweto and Orange Farm. The accessibility measure is dubbed the NWAC and describes the potential wage earnable at a job opportunity less the transport costs incurred to reach that opportunity. The main challenge encountered is the lack of sufficiently accurate public transport operational and spatial data (fares, routes, transfer points). This is particularly a challenge for the minibus taxi, which should not be the case as it is the most widely used mode in the CoJ.

The time-series analysis revealed that Alexandra offers the highest levels of accessibility, primarily due to its close proximity to key economic nodes in the CoJ and its dependence on the nearly ubiquitous minibus taxi. However, the lowest annual growth rate of accessibility was observed for trips originating from Alexandra. The absence of low-fare Metrorail and/or high speed, low-fare BRT services that are readily accessible within the township, restricts commuters to the minibus taxi resulting in the payment of high fares and limits the growth of accessibility. In Orange Farm and Soweto, it was found that as wages increase, commuter trip modes shift to higher fare modes such as the minibus taxi or BRT (only in Soweto). The shift to the minibus taxi in Orange Farm significantly increased the accessibility, particularly towards the North of the CoJ. The Rea Vaya BRT was introduced to connect Soweto to the Johannesburg inner city, however, due to its duplication of the Metrorail service (which is more affordable and provides reasonable travel times over shorter distances), the Rea Vaya BRT failed to make a significant impact on job accessibility for low-income users from Soweto. For shorter travel distances, using both the BRT trunk and feeder, the distance based fare structure of 2013 is more affordable than the flat fare structure of 2011, as a result, in 2011 the BRT failed to make any notable improvements in accessibility for trips originating in Soweto. Interventions like Transit-Oriented Development (TOD) policy in CoJ to create economically vibrant corridors dubbed “Corridors of Freedom” will assist in deriving increased accessibility from the operation of the BRT. Orange Farm, which displays the lowest levels of accessibility, appears to be subject to transport disadvantage in the form of significantly high travel times as 84% to 95% of the jobs accessible with a reasonable NWAC (greater than R85/day) will take more than one hour to access. The minibus taxi could be incorporated as a feeder mode to the Metrorail, thus reducing the taxi fare, allowing for a more affordable transfer and faster travel times. The CoJ could consider “Corridors of Freedom” extending to the South of the city to bring opportunities closer to those in the south-end peripheries.

This study held the reasonable NWAC of R85/day constant throughout the study period, however, if all costs and wages increase by inflation then there is a monetary increase in the wage earnable but not in purchasing power. Moving forward, the reasonable NWAC of R85/day could also be adjusted from one analysis year to the next which could potentially provide a revised view of the access condition. The number of job opportunities on the study surface could also be adjusted from one analysis year to the next to assess the impact of job location and availability on the access condition. The incorporation of forced transfer points along the public transport routes, particularly for the minibus taxi, will provide a clear indication of how the additional fare and delay of a transfer affects accessibility. The methodology should be calibrated to validate its use as a transport and land-use planning tool.

ACKNOWLEDGEMENTS

The work of Willem Badenhorst and Johan du Toit from Mapable in assisting with software development is greatly appreciated.

REFERENCE LIST

Burns, L.D. & Golob, T.F. 1976, "The role of accessibility in basic transportation choice behavior", *Transportation,* vol. 5, no. 2, pp. 175-198.

Cervero, R. 2005, *Accessible Cities and Regions: A Framework for Sustainable Tranport and Urbanism in the 21st Century*, UC Berkeley Center for Future Urban Transport: A Volvo Center of Excellence, California.

CoJ 2013, *Strategic Intergrated Transport Plan Framework for the City of Joburg*, CoJ, Johannesburg.

Dalvi, M.Q. & Martin, K.M. 1976, "The measurement of accessibility: Some preliminary results", *Transportation,* vol. 5, no. 1, pp. 17-42.

Delamater, P., Messina, J., Shortridge, A. & Grady, S. 2012, "Measuring geographic access to health care: raster and network-based methods", *International Journal of Health Geographics,* vol. 11, no. 15.

Delbosc, A. & Currie, G. 2011, "The spatial context of transport disadvantage, social exclusion and well-being", *Journal of Transport Geography,* vol. 19, pp. 1130-1137.
El-Geneidy, A. & Levinson, D. 2006, "Mapping accessibility over time", *Journal of Maps,* , pp. 76-87.

Ford, A., Barr, S., Dawson, R. & James, P. 2015, "Transport accessibility analysis using GIS: Assessing Sustainable Transport in London", *ISPRS International Journal of Geo-Information,* vol. 4, pp. 124-149.

Foth, N., Manaugh, K. & El-Geneidy, A.M. 2013, "Towards equitable transit: Examining transit accessibility and social need in Toronto, Canada, 1996-2006", *Journal of Transport Geography,* vol. 29, pp. 1-10.

Geurs, K.T. & van Wee, B. 2004, "Accessibility evaluation of land-use and transport strategies: Review and research directions", *Journal of Transport Geography,* vol. 12, no. 2, pp. 127-140.

Gotz, G., Wray, C., Venter, C., Badenhorst, W., Trangoš, G. & Culwick, C. 2014, *Mobility in the Gauteng City-Region*, GCRO, Johannesburg.

GPG 2012, *Gauteng 2055: A discussion document on the long-term development plan for the Gauteng City-Region*, GPG, Johannesburg.

Hansen, W.G. 1959, "How Accessibility Shapes Land Use", *Journal of the American Planning Association,* vol. 25, no. 2, pp. 73-76.

Hart, G.H.T. 1984, "Urban transport, urban form and discrimination in Johannesburg", *South African Geographical Journal,* vol. 66, no. 2, pp. 152-167.

Ingram, D.R. 1971, "The concept of accessibility: A search for an operational form", *Regional Studies,* vol. 5, no. 2, pp. 101-107.

Kenyon, S. 2003, "Understanding social exclusion and social inclusion", *Proceedings of the Institution of Civil Engineers: Municipal Engineer,* vol. 156, no. 2, pp. 97-104.

Landau, L. & Gindrey, V. 2008, *Migration and population trends in Gauteng Province 1996-2055*, University of Witwatersrand, Johannesburg.

Martin, J.C. & van Wee, B. 2011, "Guest Editorial: What Can We Learn from Accessibility Modelling?", *ETJIR,* [Online], vol. 11, no. 4, pp. 21/01/2016-346 - 349. Available from: www.ejtir.tbm.tudelft.nl. [21/01/2016].

Miller, H. & Wu, Y. 2000, "GIS Software for measuring space-time accessibility in transportation planning and analysis", *GeoInformatica,* vol. 4, no. 2, pp. 141-159.

Morris, J.M., Dumble, P.L. & Wigan, M.R. 1979, "Accessibility indicators for transport planning", *Transportation Research Part A: General,* vol. 13, no. 2, pp. 91-109.

Preston, J. & Rajé, F. 2007, "Accessibility, mobility and transport-related social exclusion", *Journal of Transport Geography,* vol. 15, no. 3, pp. 151-160.

Todes, A. 2012, "Urban growth and strategic spatial planning in Johannesburg, South Africa", *Elsevier,* , no. 29, pp. 158-165.

van Dijk, J., Krygsman, S. & de Jong, T. 2015, "Toward spatial justice: The spatial equity effects of a toll road in Cape Town, South Africa", *Journal of Transport and Land Use,* vol. 8, no. 3, pp. 95-114.

Venter, C. & Cross, C. 2014, "Access envelopes: A new accessibility mapping technique for transport and settlements planning", *SSB/TRP/MDM,* , no. 64, pp. 43-52.

Venter, C.J. & Mohammed, S.O. 2013, "Estimating car ownership and transport energy consumption: A disaggregate study in Nelson Mandela Bay", *Journal of the South African Institution of Civil Engineering,* vol. 55, no. 1, pp. 2-10.