Accessibility and Social Welfare: A study of the City of Johannesburg

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Keywords:
Accessibility; Social Welfare; Well-being; Quality of Life; Johannesburg, Public transport; Exclusion

Classification codes:
I3; R2; C3

ABSTRACT

Within the corpus of accessibility measures is the Net Wage After Commute which describes the potential wage earnable less the transport costs incurred to commute to work from a particular location. This paper explores the time-series developments of accessibility, using this poverty-relevant metric, in low-income residential areas of the City of Johannesburg, biennially from 2009 to 2013 when accessibility patterns were altered as a result of major investments in the Bus Rapid Transit (BRT) system. Furthermore, a difference-in-differences approach was adopted to explore the effects of access to the BRT on the well-being of lower-income households, investigating the premise that transport related benefits brought about by such investments translate to social welfare improvements. The results suggest that significant time-series changes in accessibility patterns are driven by affordability against the backdrop of decentralisation, particularly for low-income areas in the peripheries of the city. The difference-in-differences model reveals that the BRT did not improve the well-being of residents, however, likely users of the service are better off in terms of well-being than non-users. This suggests that that BRT in Johannesburg is beneficial as a transport project, but not as a general urban intervention able to improve the overall amenity of served communities.

1. Introduction and background

Transport and planning policy is prioritising the improvement of transport accessibility and equity across various regions in the world; it is no different in the Gauteng province (GPG, 2012, CoJ, 2013). Located in the polycentric province is the City of Johannesburg (CoJ) which is South Africa's largest and most dynamic economy (Todes, 2012). However, despite its economic success, the CoJ grapples with relatively high levels of poverty, unemployment and inequality (Todes, 2012, CoJ, 2013). During the apartheid era, non-white groups were relocated to residential areas which are predominantly located in the peripheries of the CoJ (Todes, 2012). This resulted in low-income groups residing in areas that were politically excluded from receiving adequate funding, therefore, these residents suffered from poor infrastructure and service delivery (Todes, 2012).

The Reconstruction and Development Programme (RDP) was introduced in 1994 as a poverty alleviation strategy which involved, amongst other things, providing housing to the urban poor. However, RDP housing continues to be developed within or close to these low-income residential areas due to escalating land prices in the city (Todes, 2012, CoJ, 2013), perpetuating the spatial exclusion and the financial and travel time burden experienced by low-income groups. To combat this historic spatial exclusion, the CoJ introduced the "Corridors of Freedom" as an initiative to drive spatial integration through land-use and transport interventions (Venter, 2016). The first of these corridors of freedom was introduced during the study period (2009 – 2013) through the introduction of the Bus Rapid Transit (BRT) system dubbed Rea Vaya (CoJ, 2013, Gotz et al., 2014). The Rea Vaya Phase 1A corridor operates between Soweto (a low income residential area) and the Johannesburg CBD. Since its implementation, Rea Vaya Phase 1A has resulted in 10% - 20% travel time savings for its users and it has assisted in the transition of minibus taxi drivers from informal employment to formal employment with Rea Vaya, doubling their annual income (Carrigan et al., 2014). However, the poorest residents of the CoJ are not significant beneficiaries of this project, only receiving 4% of the project benefits (Carrigan et al., 2014).

The question of whether BRT systems deliver equitable and pro-poor outcomes is closely related to the extent to which they enhance the accessibility of poverty populations (Venter et al., 2017). Despite the body of theoretical and empirical work that has been done on accessibility, there still appears to be a poor understanding of the social meaning of accessibility benefits and how such benefits translate into social welfare improvements across different groups of a population. The use of accessibility measures to better understand the wider social benefits of transport investments is hampered by a shortage of empirical studies that examine the relationships between accessibility and social outcomes. Accessibility, its social benefits, and the various forms of exclusion are dynamic concepts which should be thoroughly assessed over time, individually and interactively. This study will attempt to fill this gap by unpacking the effects of the introduction of the Rea Vaya BRT and its associated accessibility on the well-being of Soweto residents. Through a case study of selected low-income residential areas, the study aims to: a) measure the time-series development of accessibility, using a poverty-relevant metric, over a time period when public transport changed, b) identify and measure the extent to which investment in public transport, particularly BRT, contributed to these changes in the accessibility patterns of the urban poor, and c) attempt to identify wider social benefits, in terms of subjective well-being, of accessibility improvements driven by public transport investment.

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

(QoL) (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). Accessibility is rarely measured over time; some recent examples of such studies include those of El-Geneidy and Levinson (2006) and Foth, Manaugh et al. (2013). El-Geneidy and Levinson (2006) stress the importance of time-series measurements of accessibility as a tool to assess the performance of land-use and transportation planning policies.

2.1 Accessibility measures

Geurs and van Wee (2004) highlight a number of accessibility measures in their evaluation and review, amongst which two of the most commonly used measures are gravity-based measures and threshold type measures. Both of these measures have been applied in the South African context by Venter and Mohammed (2013) to explore a possible relationship between transport energy consumption and accessibility in the Nelson Mandela Bay (gravity-based measure) and van Dijk, Krygsman et al. (2015) to explore the effects of tolls on the public transport and private vehicle accessibility across various income groups in the Cape Town metropolitan region (threshold type measure).

2.1.1 The Access Envelope Technique

Venter and Cross (2014) identified two main shortcomings of gravity-based measures and threshold type measures, 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.
- **Walking times:** The time required to walk from the origin to the first public transport mode and the time required to walk from the last public transport mode 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.

- **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 obtained from the CoJ Public Transport Record, these fares were adjusted for inflation to determine the fares across all analysis years. These fares were calibrated using fare data from the various public transport mode websites. The minibus taxi [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.
- **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. 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 come 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). The NWAC is computed as follows:

$$NWAC_{ij}^{m} = I_j - Fare_{ij}^{m} - \delta . v_3 \quad (1)$$

$$If\ t_{ij}^{m} > T: \delta = 1\ and\ v_3 = [(t_{ij}^{m} - T)/H] . I_j \quad (2)$$

$NWAC_{ij}^{m}$ is the NWAC from zone *i* to *j* using mode *m,* expressed in Rands. I_j is the daily wage for all jobs in zone j, expressed in Rands. $Fare_{ij}^{m}$ is the fare incurred to travel from zone *i* to zone *j* using mode *m*, expressed in Rands. t_{ij}^{m} is the travel time, in minutes, from zone *i* to *j* using mode *m.* T is the travel time budget, which is approximately 60 minutes per direction, and H is the working time per day in minutes. 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. The computation of this travel time penalty is described by equation 2.

2.2 Accessibility and exclusion of the urban poor

In various studies, transport accessibility has been linked to QoL and social exclusion (Kenyon, 2003, Preston & Rajé, 2007, Delbosc & Currie, 2011, Venter & Cross, 2014). Transport-related social exclusion refers to the inability of residents to participate in the social or economic spheres of the communities in which they reside due to reduced accessibility to opportunities caused by insufficient provision of transport means and/or facilities (Kenyon et al., 2002). According to Tithridge et al. (2014), low-income groups endure the most adverse effects of poor provision of transport facilities and/or transport barriers such as high transport fares. Due to the combination of being located in the peripheries and the lack of sufficient opportunities within their immediate neighbourhoods, low-income households are more prone to experience limited access to essential opportunities and the consequences thereof (Combs, 2017). This is evident in the CoJ, where low-income residents 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). This provides strong rationale for investing in new PT systems to reduce exclusion. Recent research in Colombia questions whether public transport investment in BRT systems has reached the desired effect of reducing social exclusion and allowing low-income households to reach their mobility needs [see (Jaramillo et al., 2012, Combs, 2017)].

Bocajero & Oviedo (2012) stress that transport affordability is a critical element to consider as a means to improve accessibility. Transport affordability is a key transport challenge in Gauteng; the 2011 QoL 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). The resulting inadequate transport accessibility leads to social and/or economic exclusion and compromises the QoL of residents.

3. Data and methodology

The methodology covers a time-series and cross-sectional analysis of accessibility in select regions of the CoJ, as well as a difference-in-differences approach used to estimate the effects of the BRT implementation on the social welfare of Soweto residents.

3.1 Public transport services

The public transport services in the CoJ are the minibus taxi, Metrobus, Metrorail and Rea Vaya BRT. The minibus taxi is an informal service which has a nearly ubiquitous network. This mode is the second most expensive mode in the CoJ after the Metrobus which has a widespread network in the CoJ with average route lengths of 27.2km (CoJ, 2013). Despite being subsidised by the government, it is still the most expensive mode operating in the city. The Metrorail is the lowest cost public transport mode in the city, however, it does not serve most of the decentralised economic nodes and residential areas to the north (CoJ, 2013). Due to three decades with no investment in the service, it is dilapidated and offers uncompetitive travel times (CoJ, 2013). The first phase of Rea Vaya (Phase 1A) became fully operational in February 2011 and it operates between Soweto and the Johannesburg CBD. Rea Vaya Phase 1A constitutes of 22km of bi-directional busways, 25km of mixed traffic lanes used by complimentary buses, 29km of mixed traffic lanes used by feeder buses and 31 stations. Annual passengers in 2011/2012 were 8.8 million, which increased to 10.2 million in 2012/2013 (CoJ, 2013). The public transport routes and associated fares for all operational modes in the CoJ were sourced for the years 2009, 2011 and 2013.

- <u>2009:</u> Only three modes were considered; namely, the minibus taxi, Metrorail and Metrobus.
- <u>2011:</u> Four modes were considered; namely, the minibus taxi, Metrorail, Metrobus and the Rea Vaya BRT (Phase 1A). 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 in 2012.

3.2 Net Wage After Commute

The access envelope technique computes the accessibility from a selected origin to all other points on a study surface. The NWAC metric seeks to reflect the objective of a worker or work seeker that trades off travel time and cost in such a way as to maximise their take-home pay at each given location. Doing so might require selecting a combination of modes by which to travel to the destination. In practical terms, this will typically be achieved through the lowest cost mode (including walking); however, once the travel time budget (in the present case 60 minutes per direction) is exceeded, higher cost but faster motorised modes may be used in order to avoid encroaching onto the available working time for the day. To compute the NWAC, the CoJ was divided into roughly 19000 zones and the output is a GIS NWAC surface graphically displaying the access levels from the selected origin to surrounding job locations. Figures 1 and Figure 2 display the output for a selected zone in Orange Farm for 2009 and 2013, respectively.

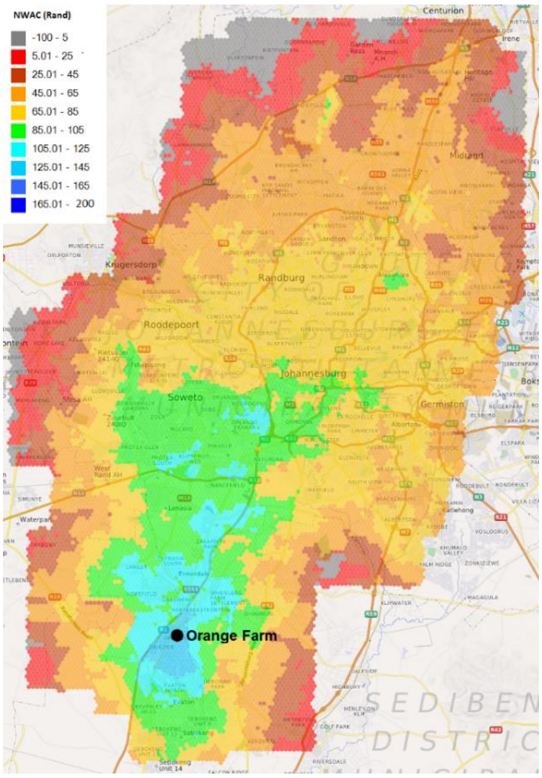

Figure 1. NWAC surface 2009

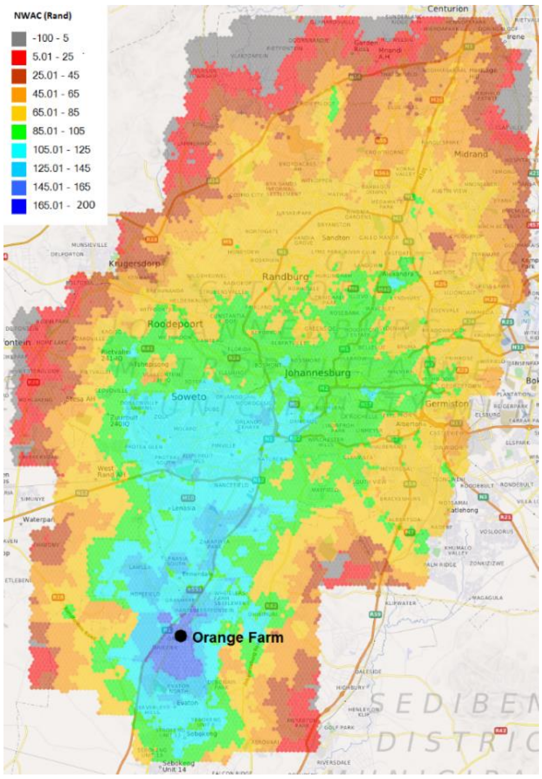

Figure 2. NWAC surface 2013

The following summary measures were determined for ease of comparison between different origin zones and to capture the effects of transport affordability, job location and travel times on job accessibility:

- **The number of jobs accessible with NWAC greater than R85/day:** This gives 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 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 gives 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 served by faster modes of public transport.
- **Average NWAC of the closest 200,000 jobs:** This gives 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.

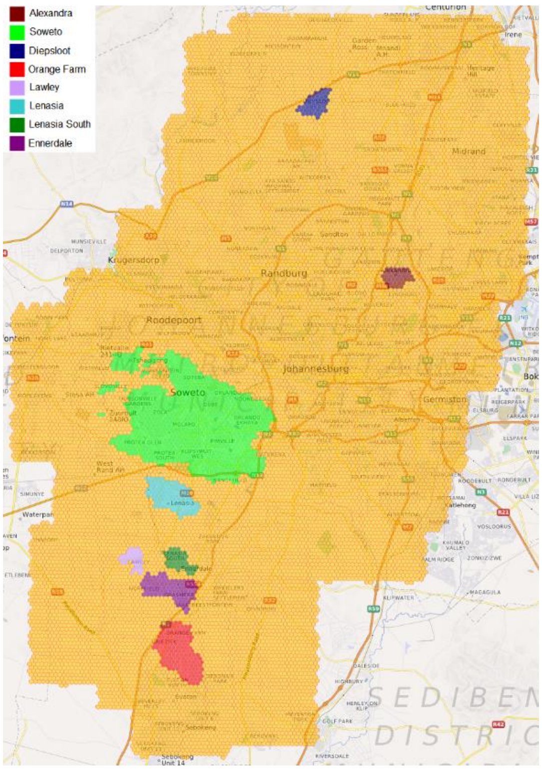

Figure 3. Analysis regions in the CoJ

The residential areas selected for the case study were: Alexandra, Soweto, Diepsloot, Orange Farm, Lawley, Lenasia, Lenasia South and Ennerdale (see Figure 3). Non-white groups were forcefully relocated to these areas, with the exception of Alexandra, during the apartheid era. Alexandra residents were successfully able to resist relocation (Todes, 2012), however, like all the other areas, Alexandra still suffered from poor infrastructure and service delivery. These regions accommodated and continue to accommodate predominantly low-income households, which is the main premise for their selection. An additional reason for the selection of Soweto, in particular, is the increased likelihood of observing the changes brought about by the BRT implementation in that region. From each of the selected analysis regions, 30 or more sample zones were randomly selected and the NWAC surface computed for each origin. For each of these selected regions, average summary measures were determined and compared over time.

3.3 Time-series developments and cross-sectional analysis of accessibility

A time-series analysis of accessibility, defined by the abovementioned summary measures, was conducted to determine the changes of accessibility over time in the various low-income regions. A four quadrant plot was used to understand the interaction between two of the accessibility summary measures as well as the changes of that interaction over time. The x-axis is defined by the number of jobs accessible with NWAC>R85 (NWAC index) and the y-axis is defined by the number of jobs accessible within 60 minutes of travel time (TT index). Each summary measure was standardized about the overall average which was taken across all regions over all three analysis years. Therefore, a value of 0 on the plot indicates that the average accessibility measure for that region is equal to the overall average and a value of 1 indicates that the average accessibility measure for that regions is 100% greater than the overall average. A schematic of the four quadrant plot is displayed in Figure 4, detailing the accessibility attributes of the various quadrants. A cross-sectional analysis was conducted to illustrate the effects of geographical location on the distribution of accessibility amongst region residents. This was done through a cumulative distribution plot where the x-axis recorded the percentage of jobs accessible with NWAC>R85 on the entire study surface and y-axis recorded the cumulative percentage of zones in each region. This provides an indication of the total number of opportunities available on study surface as well as the extent to which these are accessible within the various regions.

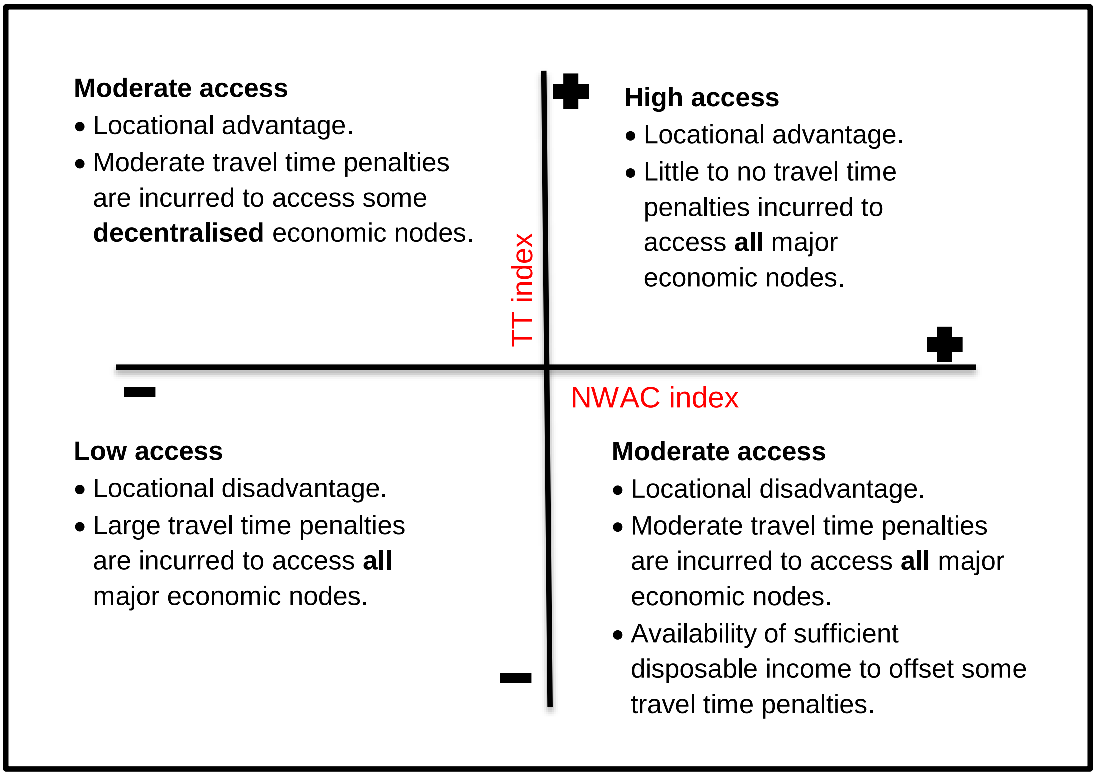

Figure 4. Four quadrant plot schematic of accessibility summary measure indices

3.4 Impact of BRT implementation on social welfare

To unpack the effects of accessibility on social welfare, a difference-in-differences approach was adopted to determine the effect of the implementation of the BRT in Soweto on the social welfare of Soweto residents. This acknowledges that social welfare is determined by a number of factors including finances, relationships, leisure time or activities and possibly the improvement of transport accessibility.

The time considered before and after BRT implementation is 2009 and 2013, respectively. The treatment group comprises of Soweto QoL survey respondents residing within 800m of feeder and/or trunk route stations while the control group comprises of Soweto QoL survey respondents further than 800m from the stated stops and/or stations. Biennially, since 2009, the Gauteng City Region Observatory (GCRO) conducts a QoL survey in an attempt to evaluate the social welfare of residents of the Gauteng City-Region (GCR). Survey respondents were sampled from the adult population to be representative at the electoral ward level (Mushongera et al., 2015).

Each QoL survey has a personal well-being section which asks a number of questions, relevant to the section, across various areas of the respondent's life, for which responses are provided on an ordinal scale from 1 ("Very satisfied") to 5 ("Very dissatisfied"). For difference-in-differences, a count regression model, specifically Poisson regression, was used. The dependent variable was the number of questions in the abovementioned section of the survey for which respondents were either "Dissatisfied" or "Very dissatisfied". The basis for this was to ensure equidispersion or over-dispersion of the count variable; selecting "very dissatisfied" as the only count variable criteria resulted in an under-dispersed count variable which is not as readily modelled. However, only 9 of the questions in the well-being section were common to both the 2009 and 2013 QoL surveys, therefore the Poisson regression model was right truncated at 9 (refer to equation 3). It should be noted that any measurement of subjective well-being is imperfect due to the inability to capture all person-specific factors, and the possibility of large error terms due to day-to-day variations in latent phenomena.The count variable was modelled using the following Poisson regression model:

$$Pr\{y_i = y|\mu_i; y_i \leq 9\} = [(\exp(y_i) \cdot \mu_i^{y_i})/\, y!] \,/\, (\Pr\{y = 0\} + \cdots + \Pr\{y = 9\}) \quad (3)$$

$$\ln(\mu_i) = \beta_0 + \beta_1 \cdot year + \beta_2 \cdot BRT + \beta_3 \cdot PT\,user + \beta_4 \cdot SEI + \beta_5 \cdot Acc + \beta_6(year \cdot BRT) + \beta_7(year \cdot BRT \cdot PT\,user) + \beta_8(year \cdot BRT \cdot AccBRT) + \varepsilon \quad (4)$$

$$where\ \mu_i = E(y_i|x_i)$$

The count variable y_i is described by individual variables as well as interactions between them. Three of the explanatory variables in equation 4 are dummy variables, namely; *year*, *BRT* and *PT user*. *year* takes on the value of "0" for pre-BRT respondents (2009) and a value of "1" for post-BRT respondents (2013). *BRT* takes on the value of "0" for Soweto respondents located more than 800m away from BRT route stations and/or stops, and a value of "1" for respondents within 800m of the BRT route stations and/or stops. *PT user* takes on the value of "1" if the respondent is a frequent public transport (PT) user and a value of "0" if the respondent is not a frequent PT user. *SEI* is a social exclusion index (SEI) computed for each respondent based on selected variables from the QoL survey; its purpose is to capture a range of other social factors that might influence a respondent's subjective welfare perception. *Acc* is the TT accessibility summary measure computed for each household. The coefficient β_6 describes the effect of the implementation of the BRT in 2013 on the count variable. The coefficient β_7 describes the effect of the implementation of the

BRT in 2013 for frequent public transport users on the count variable, and β_8 describes the effect of the BRT and its associated accessibility in 2013 on the count variable.

3.4.1 Social Exclusion Index

The SEI was constructed from selected indicator variables in the QoL surveys which were grouped into seven dimensions, namely: employment, education, infrastructure, food security, transport, connectivity and health limitations. The selection of dimensions and indicators was predominantly informed by Wright's report (2008) which was part of the *Indicators of Social Exclusion and Poverty Project* listing indicators of poverty based on socially perceived necessities and it was limited by the questions set out in the QoL surveys. The index construction was partly informed by the work done by Mushongera et al. (2015) in which the authors constructed a Multidimensional Poverty Index (MPI) for the Gauteng province.

The selected indicator responses were recorded on various scales, therefore, to reduce all the responses to a common scale they were recoded (based on selected cut-off points for each indicator) such that "0" indicated a "favourable" response and "1" indicated an "unfavourable" response for each indicator. Each dimension of the SEI was given an equal weight, which in this case was a weight of 1/7. Each dimension comprised of one or more indicators. Equal weights, based on the dimension weights, were given to each indicator of a dimension (see Table 1). Each weight was multiplied with the corresponding recoded indicator value and the algebraic sum of the weighted indicators gave the SEI for each respondent, which was rescaled to be expressed as a value between 0 and 10. Due to the recoding methodology, the SEI was constructed in such a way that the higher the index, the more socially excluded a respondent is deemed to be. The SEI was computed for Soweto in 2009 (2.82), 2011 (3.22) and 2013 (3.15).

Table 1. SEI dimensions, indicators and weights

Dimensions	Indicator	Weights
1. Employment	Employment status	0.143
2. Education	Highest level of education	0.143
3. Infrastructure	Sanitation	0.036
	Refuse removal	0.036
	Water source	0.036
	Electricity supply	0.036
4. Food security	Adult skips meal	0.143
5. Transport	Closest public transport stop	0.071
	Travel time	0.071
6. Connectivity	Cell phone	0.143
7. Health limitations	Health prevents daily work	0.143

4. Results

4.1 Changes in Accessibility

The four quadrant plot displayed in Figure 5 reflects the accessibility levels for all eight selected regions throughout the three analysis years. 2009 is the left most reading, 2013 is the right most reading and the 2011 is the centre reading for each region. It is immediately evident for each region that the NWAC index increases from one analysis year to the next, while the TT index decreases from one analysis year to the next, with Soweto being the only exception to the latter. The increase in the NWAC index is predominantly driven by an increase in potential wages earnable, which translates to increased relative affordability of public transport to either commute using a faster mode or over longer distances using the same mode. The decrease in the TT index, which is proportionally lower than the corresponding increase in the NWAC index, is predominantly driven by the increase in fares from one year to the next, which results in a slight increase in the distance over which walking maximises the NWAC, decreasing the overall number of jobs accessible within one hour of travel time. The study regions in the high accessibility quadrant are Alexandra, Soweto and Lenasia. Figure 3 shows that these are the most centrally located regions that boast shorter distances to the Johannesburg CBD than other regions. Alexandra, however, reflects the highest accessibility due to its close proximity to not only the CBD but also key activity nodes with ample economic opportunities to the north of the CBD such as Sandton, Midrand and Randburg, which can all be accessed within the travel time budget from Alexandra. Subsequently, Alexandra also reflects the highest accessibility in terms of the average NWAC of the closest 200,000 jobs (R123 on average), see Figure 5. However, the effect of increasing wages is not as evident in Alexandra as it is in the other regions. Alexandra is predominantly served by the minibus taxi, therefore an increase in wages allows for longer commutes towards the south of the CoJ while retaining a reasonable NWAC. With fewer job opportunities located in the South, this only has a minimal effect on accessibility, in terms of the NWAC index. This illustrates that, in a polycentric region like the CoJ, proximity to the CBD no longer results in the highest accessibility levels, vividly illustrating the effects of job decentralisation on access to opportunities. Over and above that, improved accessibility to regions with limited economic activity will have an equally limited effect on the accessibility patterns of a region.

Majority of the selected regions (Diepsloot, Lenasia South, Lawley, Orange Farm and Ennerdale) all fall within the low and/or moderate accessibility quadrants in the lower half of the four quadrant plot. Orange Farm recorded the lowest accessibility values; located in the southern peripheries of the CoJ (see Figure 3), it is the region that is furthest away from the Johannesburg CBD and decentralised economic nodes to the north of the CBD. An increase in wages from one analysis year to the next allowed for a shift from the low-fare and low speed Metrorail 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 1 and Figure 2). This reinforces the observations made for Alexandra in that Orange Farm and the other low accessibility regions demonstrate that accessibility patterns are largely altered by improved accessibility to regions of high economic activity. The low-fare Metrorail, which predominantly runs in the East-West direction and towards the South and South-West of the city, serving Orange Farm, could act as a buffer against fare increases on other modes, particularly due to its low fares. However, with its relatively low operating speed over long distances such as those encountered from Orange Farm to the Johannesburg CBD, large travel time penalties are incurred, significantly reducing the NWAC. Low-cost public transport modes can play a role in improving accessibility patterns, however, this is only possible if they offer their service at competitive speeds; which is what the Rea Vaya BRT provided, though at a slightly higher fare than the Metrorail.

The BRT was introduced to the city during the analysis period and Soweto became the only one of the eight regions well served by all 4 public transport modes in the city. Figure 5 reveals that Soweto is the only region for which the number of jobs accessible within 60 minutes travel time increased, though minimally, from 2011 (0.27) to 2013 (0.28). This is attributed to the BRT and the speed improvement it provides (over Metrorail and NMT) at a lower cost than the minibus taxi and Metrobus. Therefore, the BRT ensures that even as fares rise, access (in terms of the travel time index) does not decline as it provides a lower cost alternative to the minibus taxi and Metrobus while maintaining similar travel times. The effects of the BRT Phase 1A, although fully operational from 2011, only became notable in 2013. This can be attributed to the change in the BRT fare structure from 2011 to 2013 in tandem with increasing fares of other modes with similar operating speeds. Rea Vaya Phase 1A operates parallel to pre-existing services that have a significantly larger catchment area than the BRT and it provides a limited service by only giving access to one major economic node which is the Johannesburg CBD, creating challenges in leveraging this investment.

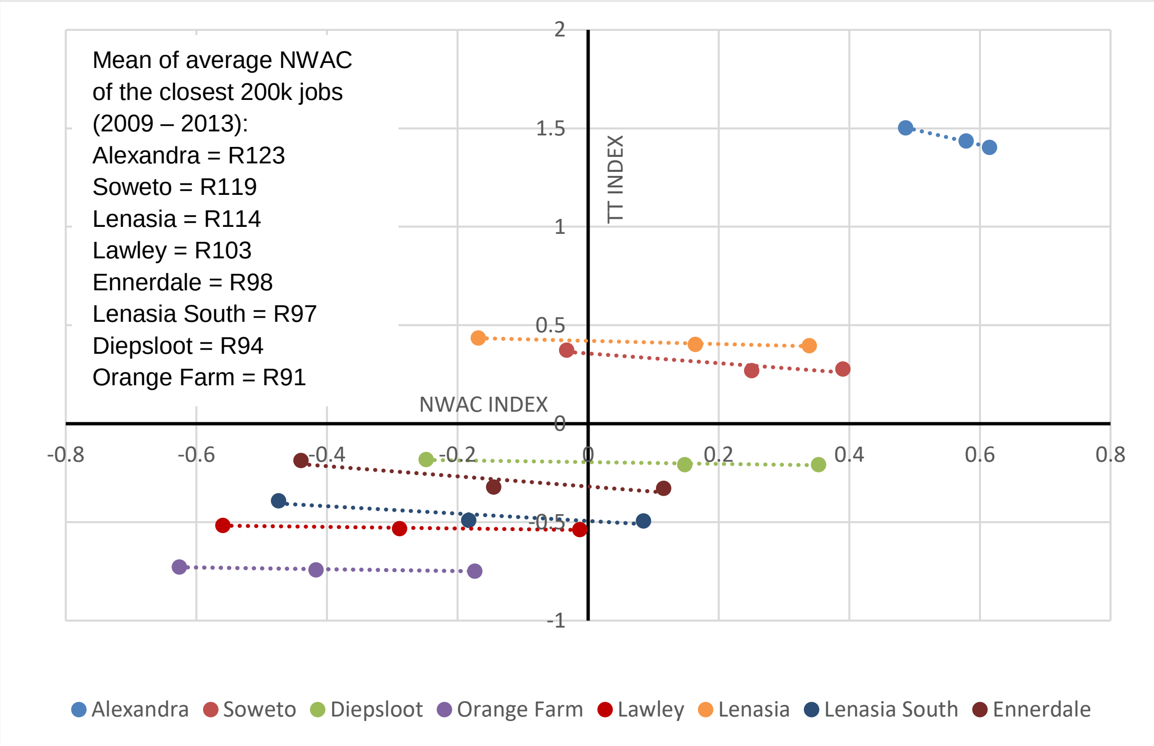

Figure 5. Four quadrant plot of accessibility summary measure indices

Figure 6 illustrates the distribution of accessibility in the selected regions as well as the change in this distribution from 2009 to 2013 to illustrate the impact of geographical location on accessibility distribution within a region. There were roughly 3.3 million jobs on the study surface for all three analysis years. The accessibility distributions of the regions located to the West and the North of the CBD (Soweto, Lenasia, Dieplsoot and Alexandra) tend to become more uniform from 2009 to 2013; yet again highlighting the value of proximity to decentralised economic nodes. Diepsloot, a region located in the northern peripheries of the CoJ and primarily served by the minibus taxi, illustrates the value of this proximity clearly in Figure 6, as the accessibility distribution within the region becomes more uniform as affordability of public transport improves; this effect is not observed for regions located to the south of Lenasia. Decentralization allows for similar levels of accessibility throughout a region, irrespective of the size of that region, without any major transport investments, simply by virtue of improving relative affordability of public transport.

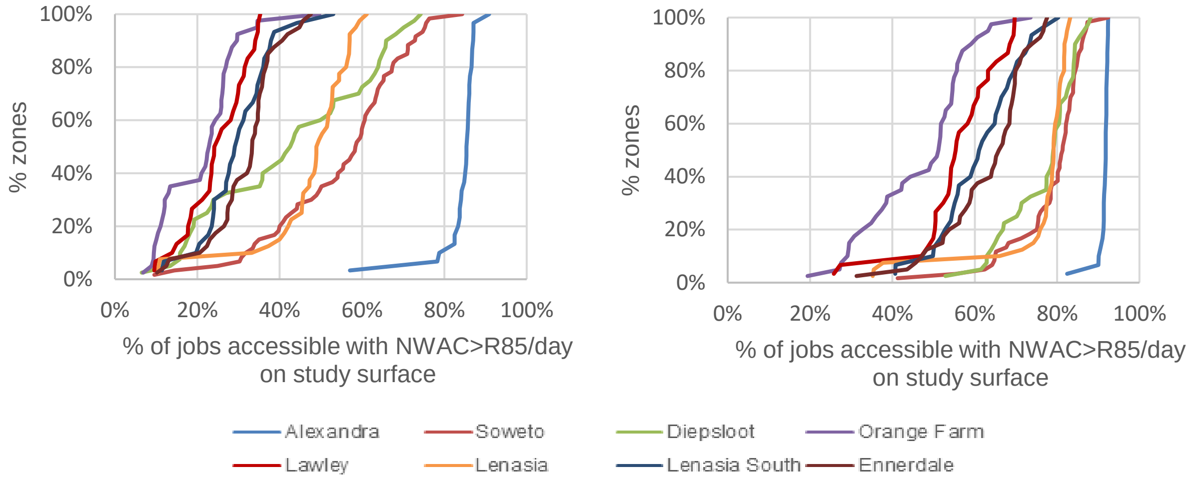

Figure 6. Accessibility distribution within regions for 2009 and 2013

4.2 Social welfare outcomes

Table 2 reflects the 2009 and 2013 average dissatisfaction for the treatment group and the control group. Dissatisfaction decreases from 2009 to 2013 for both groups. In 2009, respondents within the BRT region were more dissatisfied than those outside the BRT region, but this observation is reversed in 2013. Table 3 displays the results of the Poisson regression model which reflects the estimated effect of BRT implementation on these observed changes in the well-being of residents.

Table 2. Changes in dissatisfaction measure from 2009 to 2013

	Treatment group					Control group				
	2009		2013		% change	2009		2013		% change
	Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Dissatisfaction	2.79	1.94	1.66	1.41	- 40.5	2.63	2.25	1.75	1.59	- 33.5

The incidence rate ratio (IRR in Table 3) is interpreted as follows: A positive effect on the count variable will be indicated by an IRR greater than 1, while a negative effect is indicated by an IRR less than 1. For example, the estimate of the SEI coefficient of 1.12 implies that a unit increase in SEI results in a 12% increase in the count variable; while the estimate of the PT user coefficient of 0.89 implies that the count variable of PT users is 11% less than that of non-PT users. The results reveal that *BRT* and *PT user* had no statistically significant relationship with the count variable. Soweto residents were already well served by existing services at the advent of the BRT Phase 1A, which was implemented in such a way that it duplicated existing services which had much larger catchment areas, therefore, the lack of a significant effect of having access to the BRT on the well-being of Soweto residents is expected. As stated previously, low-income public transport users in the CoJ do not consider the public transport services affordable, and sometimes resort to NMT or no travel at all.

Giuliano (2005) states that when low-income households transition to vehicle ownership, it requires the sacrifice of some essentials in order to afford the vehicle trips. Therefore, both frequent PT users and those who are not frequent PT users in the lower income bracket suffer some sort of financial burden as a result of their mode of transport or lack thereof; perhaps this is the reason that PT user is not a statistically significant variable.

According to the β_1 IRR, respondents in 2013 are better off in terms of well-being than respondents in 2009, reaffirming the findings in Table 2. As expected, an increase in the SEI resulted in a decrease in the well-being of respondents. The β_5 estimate, on the other hand, initially appears counterintuitive as it indicates that a unit[1] increase in the number of jobs accessible within one hour of travel time results in a 2% increase in dissatisfaction. Given the unit increase required to result in the 2% increase, this result is considered negligible.

Table 3. Poisson regression results

	Independent variable	Results	
		IRR	**SE**
β_0	Intercept	1.50	0.18**
β_1	Year	0.67	0.11***
β_2	BRT	1.16	0.12
β_3	PT user	0.89	0.09
β_4	SEI	1.12	0.02***
β_5	Acc	1.02	0.01**
β_6	year*BRT	1.48	0.19**
β_7	year*BRT*PT user	0.59	0.15***
β_8	year*BRT*AccBRT	0.93	0.03**
	AIC	1467	
	BIC	1503	
	N	423	

** $p < 0.05$ *** $p < 0.01$

β_6 is the main coefficient of interest as it indicates the effect of the treatment, holding constant for effects of location in the pre-treatment year, and all other variables. This result is unexpected as it indicates that the treatment results in a decrease in the well-being of respondents. Perhaps this is a consequence of the limitations of the BRT stated above. Unlike the TransMilenio BRT in Bogotá, Colombia which, upon implementation, resulted in the reorganisation of existing transport routes and fares across the city (Combs, 2017), the Rea Vaya Phase 1A had no significant impact on existing transport services and their operations which could have had beneficial implications for the well-being of residents. The β_7 IRR reflects that although the treatment does not result in an increase in well-being overall, frequent PT users are 41% better off (in terms of well-being) with the treatment than those who are not frequent PT users. β_8 IRR reveals that a unit[1] increase in the accessibility afforded by the BRT results in an increase in well-being in the treatment year for the treatment group.

5. Conclusions and recommendations

The Access Envelope Methodology was applied to: a) measure accessibility changes over time in selected low-income regions in the CoJ, b) measure the effect of the BRT on accessibility patterns and c) assess the impact of transport investments on the well-being of Soweto residents. The results revealed that in a polycentric region, the highest levels of accessibility are observed for regions within close proximity to all economic nodes, not only

[1] The accessibility variable was scaled down by 100,000 for the model, therefore a unit increase for the variables Acc and AccBRT is equivalent to an increase of 100,000.

the CBD. Therefore, in polycentric regions which grapple with poor modal integration, fixation on providing increased accessibility to an already well accessible CBD could potentially be futile in terms of significantly improving accessibility to jobs. This notion is supported by the computed accessibility levels after the advent of the Rea Vaya BRT, which revealed that the BRT improved travel time accessibility for Soweto residents to the CBD, but only minimally from 2011 to 2013. The results also revealed the value of decentralization, which allows previously disadvantage groups in the peripheries access to key economic areas without the need for any considerable transport investment, simply by improving the affordability of the existing higher speed, widespread transport modes.

The regression model revealed that there is no evidence of any significant increase in well-being brought about by a general increase in accessibility alone. Furthermore, merely being located near BRT trunk and feeder lines does not result in welfare improvements; however, those who actually use the BRT are better off in terms of well-being as opposed to those who do not use the service. Improvement to job accessibility via the BRT also results in a statistically significant, but small increase in the welfare of residents within close proximity to the service. It appears the welfare benefit of the BRT is associated with actual use of the BRT system, and not simply a spill-over of the intervention to the community regardless of whether or not they use the service. This suggests that BRT in Johannesburg is beneficial as a transport project, but not as a general urban intervention able to improve the overall amenity of served communities. This is consistent with findings in Bogotá and Santiago de Cali in Colombia, in which the BRT transport-related advances did not translate to social and/or mobility benefits or improvements (Jaramillo et al., 2012, Combs, 2017). Perhaps more effort related to land use, property value, and urban design changes in areas served by the BRT is required to leverage non-user benefits. The results suggest that in terms of metrics, proximity to public transport type of accessibility measures (such as distance to a BRT station) are not likely to adequately reflect benefits as experienced by communities; accessibility measures taking the actual generalised travel cost and distribution to opportunities into account are more powerful in this regard.

Further work is required to refine the computation of the accessibility measure and summary measures for a time-series analysis, some suggestions include adjusting what is deemed the reasonable NWAC from one analysis year to the next and imposing a stricter penalty on walking trips. The methodology should be calibrated to validate its use as a transport and land-use planning tool. With regards to the regression model, perhaps the use of more transport orientated indicators of well-being will produce the expected results.

Acknowledgements

The work of Willem Badenhorst and Johan du Toit from Mapable in assisting with software development is greatly appreciated. The data used in this paper is taken from the Quality of Life survey commissioned by the Gauteng City-Region Observatory, a partnership of the University of Johannesburg, the University of the Witwatersrand, Johannesburg, and the Gauteng Provincial Government.

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