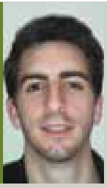
Articulated density

a study of its potential effects on the financial sustainability of South African BRT corridors



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INTRODUCTION

Many cities in the 'global south' face mounting pressures from rapid urbanisation, population growth and rising income inequality. The successful integration of public transport and land development planning is likely to be central in determining how effectively these cities manage these pressures. Some research – associated with the advent of bus rapid transit (BRT) systems – into how best to integrate public transport and land development planning has been undertaken in Latin America and Asia. While a number of sub-Saharan African cities, particularly in South Africa, have commenced large-scale public transport reform, little research has been undertaken to date on appropriate public transport / land use integration in these contexts.

The initial phases of BRT corridor implementation in South African cities have highlighted the importance of supportive urban forms in facilitating public transport services that are not dependent on unsustainable operating subsidies. The City of Cape Town's latest review of its Comprehensive Integrated Transport Plan (CITP), for instance, states that "*... the operational requirements to run road-based public transport at the levels of service required by the CITP 2013–2018, in the current urban form of Cape Town, are proving to be financially unsustainable and could lead to significant long-term implications for the future roll-out of road-based public transport ... Dispersed urban form leads to passenger numbers being low along many routes, resulting in demand best met by small vehicle sizes and longer headways.*" (CCT 2014) The City of Johannesburg has come to similar conclusions in its Rea Vaya Phase 1C Sustainability Study (CoJ 2013). Clearly a better understanding of the prerequisite land use conditions for high-quality BRT systems is required, and technology choices should be made with due regard to the prevailing urban form (Del Mistro & Bruun 2012).

Population density has been widely accepted by South African city planning authorities as an important land use prerequisite, resulting in the formulation of density targets and densification policies. However, the effects associated with the spatial distribution of this density on the viability of adjacent public transport services has not been investigated.

STUDY METHOD

Due to scarce empirical data on South African land use characteristics and public transport operating costs, simulation research was chosen to study the public transport / urban form relationships. A public transport corridor operating cost model was therefore developed to simulate the effects of varying land use environments on public transport systems. The model expands an earlier version developed by Del Mistro and Bruun (2012). This article focuses on just the simulations involving population density, density articulation and mode technology related to a BRT service.

Given the radial nature of many South African public transport networks, the model represents a triangular transport corridor terminating at a Central Business District (CBD), as illustrated in Figure 1. The model comprises one trunk service route (thick black line) and ten feeder service routes (thin red lines). The length of the trunk route is 20 km, which is comparable to the 15 km of Cape Town's Phase 1A, and 25.5 km of Johannesburg's Phase 1A.

The model analyses public transport service viability through authority cost, which represents the total cost of the service to the transport authority and includes:

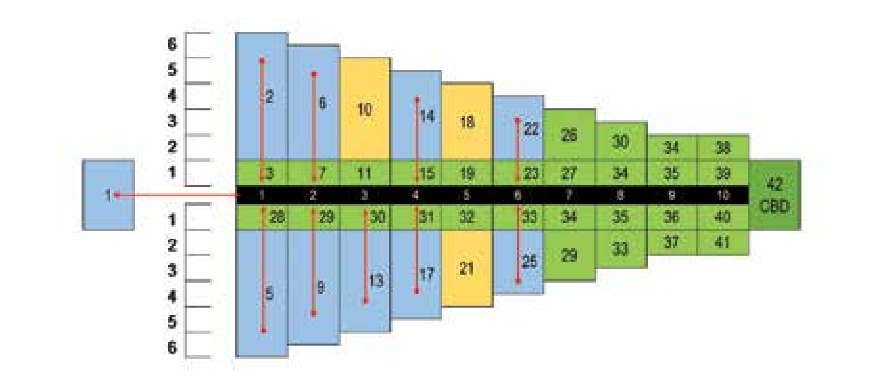

Figure 1: Layout of the simulated transport corridor

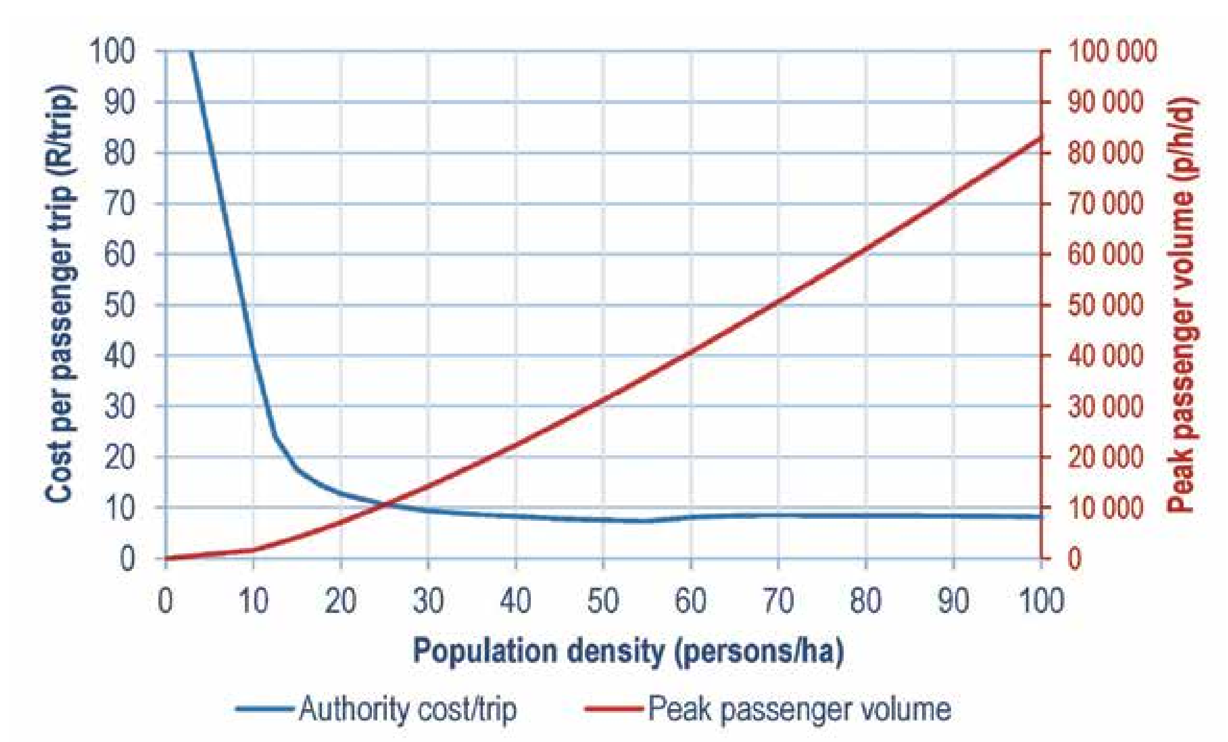

Figure 2: Effect of varying population density on a 20 km corridor

Table 1: Densification targets in selected South African cities (after Jones 2014)

Targeted Areas	South African City / Municipality				
	Cape Town (CoCT 2012)	Tshwane (CoT 2012)	Johannesburg (CoJ 2010)	Nelson Mandela Bay (NMBM 2007)	eThekwini (eThekwini 2013)
Entire urbanised city area (persons/ha)	83	-	-	78	79
Activity spines (persons/ha)	393	150	-	340	209
Development / public transport trunk corridors (persons/ha)	208	150	232	238	209

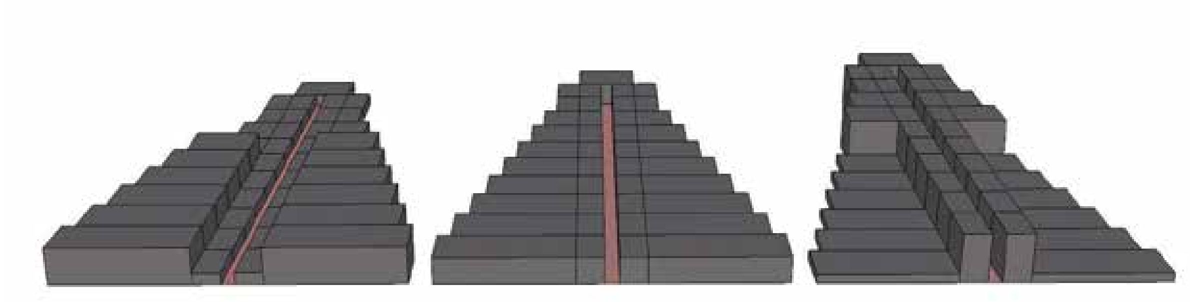

Figure 3: Orthographic projection of 20%, 43% and 80% density articulation on the simulated corridor representing population density as height

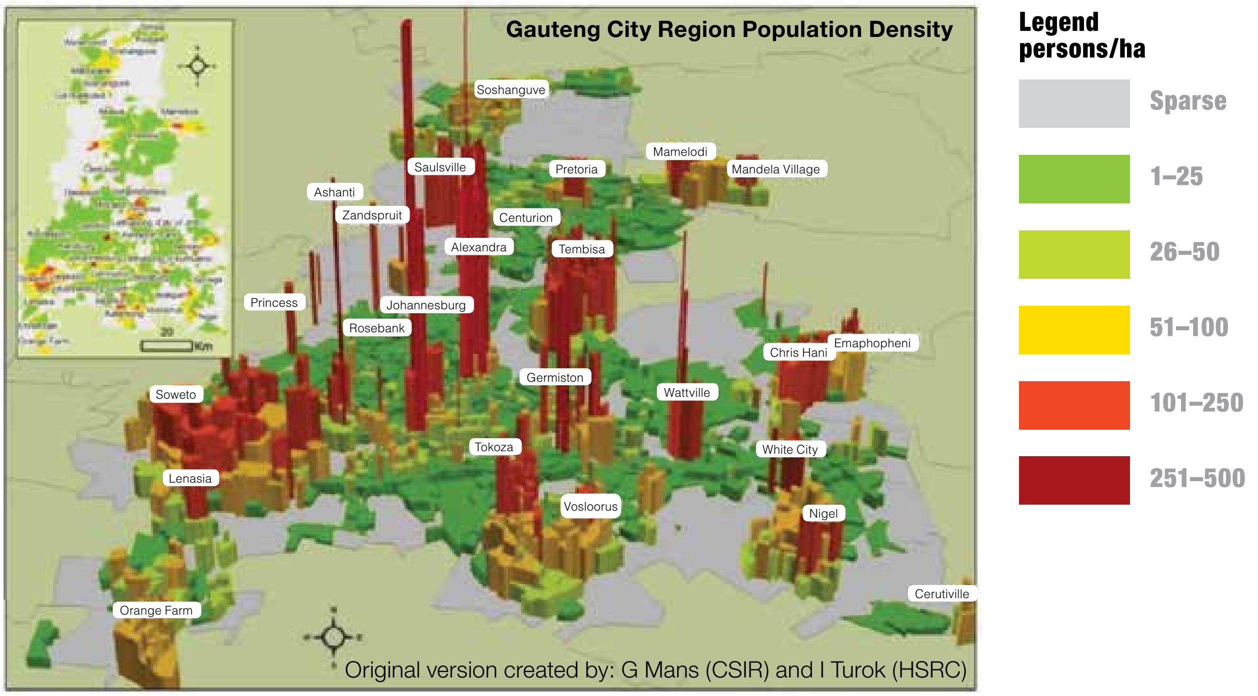

Figure 4: Population density distribution of the Gauteng city region (SACN 2011)

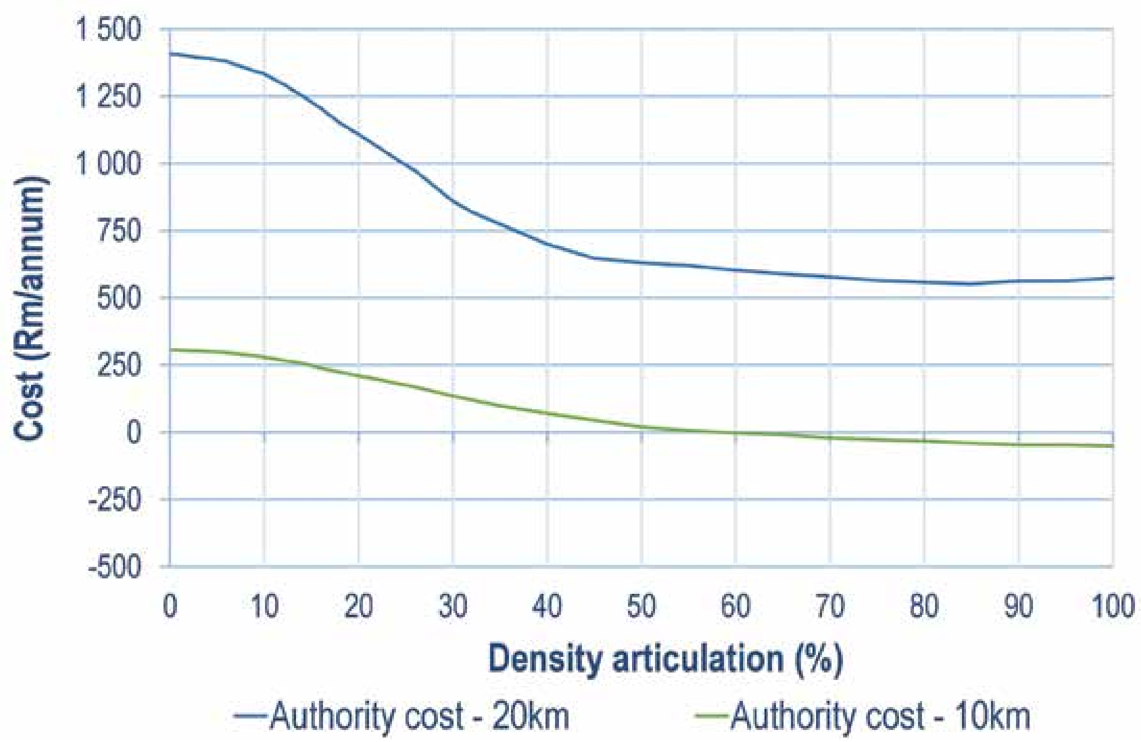

Figure 5: Effect of varying density articulation on a 20 km corridor at 50 persons/ha and on a 10 km corridor at 100 persons/ha

- Capital investments
- Operation and maintenance costs
- Operator profit
- Contracting costs
- Loan repayments
- Fare revenue.

POPULATION DENSITY

Population density is defined in this study as the number of people residing within a specified gross area, per unit area. Population density affects the volume of passengers who utilise a public transport service. Density has garnered much of the attention in the land use / transport interaction research and the majority of studies are in agreement that population density is the most significant spatial factor in determining the viability of public transport services. It is said that density puts the 'mass' in mass transit. Density thresholds for viable public transport are offered by various authors, and international empirical evidence suggests that urban gross population densities in the range of 140–190 persons per hectare (p/ha) are required.

Various South African cities have developed densification policies that set density targets in relation to both the entire city area and public transport corridors.

In the population density simulation, the aim was to analyse the direct causal effect of gross population density on public transport system viability. The population density was distributed evenly across the corridor and the non-residential land use distribution approximated a generic South African city with a strong CBD. The land use activity increased with population density to balance the trip origins and destinations. As the costs of the system naturally increase with the number of users, the authority cost is represented as a monetary value per passenger trip served.

Figure 2 illustrates that, apart from an initial sharp decline in authority cost, population density does not significantly affect the viability of the BRT system in this case. This contradicts the consensus held by the majority of authors of relevant literature, challenging the common proposition that achieving high population density targets and thresholds will lead to viable public transport. The contradiction may arise from the fact that, in empirical studies, high-density cities also have a generally more supportive land use environment, including a favourable density distribution pattern. Therefore, population density as a determinant is not being analysed in isolation, as it is in this case. An empirical example of unsupportive density, or 'dysfunctional density', is the city of Los Angeles. A relatively high, evenly distributed population density exacerbates congestion and the negative externalities associated with car travel (UN Habitat 2013).

A further problem with 'dysfunctional density' is its effect on peak passenger volume. If this representation of a South African transport corridor were to attain the city area gross population density target of Cape Town, 83 p/ha, it would result in a peak passenger volume of 64 377 persons per hour per direction (p/h/d). The observed ridership of the highest capacity BRT systems is significantly below this, at 25 000 – 35 000 p/h/d, even utilising express services (Grey & Behrens 2013). Therefore, if one of the new BRT corridors resembles the one simulated in this model, the BRT system will reach capacity well before the density target is reached.

DENSITY DISTRIBUTION

The distribution of density across space is a recent addition to the group of urban form indicators. Strategically distributed density with regard to public transport trunk service proximity is referred to as 'articulated density' (Suzuki *et al* 2013). The distribution of population density can impact upon service viability by increasing the proportion of public transport users within walking distance of the trunk route, which decreases the reliance on less viable feeder services. At the time of writing, no study could be found that simulates the effect of articulated density on public transport service viability. The density distribution simulation varies the distribution of the population, while keeping the distribution of other land uses the same as the previous scenario. Population density was set at 50 p/ha, as the peak passenger volume is just within the operating capacity of a BRT system.

As of yet, there is no metric for how strategically the population density is distributed over the city area with regard to public transport trunk service proximity. 'Density articulation' is proposed as this metric and was created by examining the distribution of density across different cities. The suggested measure for density articulation is the percentage of the urban area's total population that lives within walking distance of the trunk service route, given a specified gross population density. At a percentage of 100, no person lives outside of the walking catchment areas of the trunk service stations, sometimes called the transit oriented development (TOD) areas. These TOD areas are represented by the green zones in Figure 1. At a percentage of zero, every person requires a feeder service to reach a trunk service station. The concept of density articulation is illustrated in Figure 3 using the model's generic 20 km South African corridor. When the density is evenly spread over the catchment area, the density articulation is approximately 43%. The illustration on the right in Figure 3 has an 80% level of density articulation, a possible target for South African cities. To the left, a density articulation of 20% is applied, which, due to the prevalence of suburban housing and peripheral townships, has a close resemblance to the current South African context, illustrated in Figure 4, using Gauteng as an example.

Figure 5 illustrates that density articulation has a larger effect on authority costs than urban gross population density. As density articulation increases, the reliance on feeder services diminishes until the minimum allowable level is reached, leading to a halving of the authority cost across the range of values. However, due to the BRT's operational capacity limits, the highest possible population density that can be achieved in the TOD areas is 100 p/ha, well below the public transport trunk corridor density targets of the South African cities presented in Table 1 (which range between 150 and 238 p/ha). In this scenario, peak passenger volume limits the analysis of density articulation at higher values of population density and possible further improvements to public transport service viability. By decreasing the length of the corridor, and therefore the catchment area, higher gross population densities can be realised before the operational capacity limits are reached.

The second density distribution simulation in Figure 5 analyses a 10 km corridor with an overall population density of 100 p/ha. The total corridor population is two thirds of the previous scenario, but due to the higher density increasing the public transport mode share, the average number of passenger trips served is 6% higher. The decrease in authority cost is not as steep as that of the 20 km corridor, which is due to a higher proportion of the corridor being within the TOD areas. As a result, the effect of leveraging density articulation to increase the gross population density of the TOD areas is greatly diminished. Despite this, the shorter corridor and higher gross population density create a system that, at worst, costs one fifth of the previous system and at best generates a healthy profit. The peak passenger volume is maintained within the capacity limits of the BRT mode.

CONCLUSION

Gross population density can have very little effect on the viability of a public transport system and many of the empirical studies done on the relationship attribute the effects of corridor length and density articulation to population density. These effects are correlated with population density, but not caused by it. As a result, the South African population density targets could lead to negative impacts on viability if densification occurs in the wrong areas.

Density articulation appears to have a much stronger relationship with public transport viability. Prioritising this metric in South African BRT corridors could have substantial positive impacts on public transport operations, even at low gross population densities. Density articulation would be especially effective in South Africa's long public transport corridors, but viability improvements are limited by the operational capacities of the services. Shorter corridors and smaller catchment areas are more supportive of public transport, despite density articulation being less effective. This means that the planning and policy focus needs to change, depending on the catchment area of the corridor.

To achieve a high public transport modal split and sustainable BRT service requires high densities, high articulation, small catchment areas and minimal feeder services. However, this study only analysed population density and distribution. Other land use characteristics, such as employment distribution, land use mix and polycentrism can also be leveraged to optimal levels to improve the financial viability of the South African public transport services. A detailed land use development plan should be created for each major public transport corridor, with unique land use targets. These plans would need to be integrated with those of the Integrated Rapid Public Transport Network plan and implemented proactively.

ACKNOWLEDGEMENT

The lead author acknowledges the scholarship funding received from the Department of Transport's Southern Transportation Centre of Development, which supported the research activity upon which this article is based.

REFERENCES

The full list of references is available from the editor. □