THE RELATIONSHIP BETWEEN TRANSIT-ORIENTED DEVELOPMENT, ACCESSIBILITY AND PUBLIC TRANSPORT VIABILITY IN SOUTH AFRICAN CITIES: A LITERATURE REVIEW AND PROBLEM FRAMING

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ABSTRACT

South African cities are facing multiple challenges, including low, inequitable accessibility, and financially unviable formal public transport services. Transit-Oriented Development (TOD) has been posited as a method to improve accessibility in Cape Town, and other South African cities, by simultaneously increasing the proximity of opportunities and services for residents, as well as strengthening the financial viability of the public transport systems. In this paper, literature is reviewed regarding four characteristics of the built environment (density, diversity, design and distance to transit), that are purported to have a significant impact on travel behaviour, accessibility, and financial viability. However, the spatial segregation created by Apartheid urban planning, the low property market participation rates, and the public transport-dependence of most South Africans are among the reasons that TOD may have a different relationship with accessibility and financial viability in this context than the literature describes. The need for a deeper, contextualised understanding of this relationship is explored, and a method for its investigation in Cape Town is proposed. The broader aim of this research is not to identify optimal solutions to these challenges, but to propose a spatial decision support system that guides the myriad choices that need to be made in order to develop more accessible and financially viable cities.

1. INTRODUCTION

South Africa has urbanised in the past few decades, which has led to a strong trend toward suburbanisation by the wealthy, with vast low income settlements developing on the cheaper land at the urban periphery. In addition, the forced relocation of working-class families from the older, better located neighbourhoods during Apartheid has exacerbated the spatial dislocation of the majority of residents from the available opportunities in the economic nodes. The (racialised) inequity in access and income that characterises South African cities may foretell similar trends for other rapidly developing African cities. The suburbanisation trend has now started to reverse in some South African cities, with wealth returning to the inner suburbs and gentrification gaining momentum; this could further intensify the disparity in the distribution of access (Lees, Shin & López-Morales, 2015; Hwang & Sampson, 2014). This movement of wealth back to city centres has also been observed in many Global North metropoles in recent years (Dodson et al., 2006). The spatial fragmentation and large travel distances experienced by most residents of South African cities highlights flaws in the traditional planning for mobility rather than for accessibility. The primary goal of the combined land use-transport system is to provide access to key opportunities and services for its population. Due to the spatial fragmentation in South African cities, the land use

system has not been able to provide access through proximity; consequently, access is largely dependent on mobility. Furthermore, low incomes have limited private vehicle ownership, which means that the accessibility of the average South African is dependent upon the quality and coverage of the public transport system. Concurrently, the unequal spatial distribution of opportunities and services creates transport network inefficiency, which undermines the financial viability of the public transport system; in particular, the formal public transport systems incur unsustainable levels of operating subsidisation and are restricting the ability of South African cities to finance the necessary improvements in accessibility.

Transit-Oriented Development (TOD) has been posited as a way to improve accessibility in Cape Town by simultaneously increasing the proximity of opportunities and services for residents, and strengthening the financial viability of public transport services. This paper interrogates this proposition by reviewing the literature that describes the relationships that TOD has with accessibility and public transport financial viability through the influence that the built environment has on travel behaviour.

The next section will introduce the topic of accessibility in relation to public transport, and the concept of 'transport justice'. The section that follows analyses the different facets of public transport finance and the challenges associated with achieving viability. The paper then highlights certain characteristics of the built environment, linked to TOD, that have been identified as having a significant influence over travel behaviour by many academic studies. These characteristics are then explored to try explain the potential impact that TOD can have on the distribution of access within a city, and on the financial viability of its public transport services. The paper will highlight the specific challenges that a TOD planning approach will face when aiming to improve access and public transport finance in South African cities. Finally, the paper will conclude by setting out a proposed research method for an upcoming study on this multifaceted relationship.

2. ACCESSIBILITY

Accessibility is a complex issue that has been at the core of much transport and urban planning research in recent years (Martellato, Nijkamp & Reggiani, 1998; Geurs et al., 2010; Páez, Scott & Morency, 2012). Van Wee, Annema & Banister (2013:13) define accessibility as "the extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s) at various times of the day (perspective of persons), and the extent to which land-use and transport systems enable companies, facilities and other activity places to receive people, goods and information at various times of the day".

Golub and Martens (2014:1) suggest that accessibility is "the most appropriate measure of benefits from transportation plans and investments, and thus should be the focus of any effort to understand and measure the impacts of transportation investment programs." This stems from the growing body of research proposing accessibility as the basis for transport planning, leading to the ideal of achieving 'transport justice' (Martens, 2016). Achieving a just transportation system means creating a just distribution of access in a metropolitan area through strategic transport investments or programmes (Golub & Martens, 2014). There are many factors that affect a resident's level of access, see Litman (2015), but chief among them are the distribution of land uses or activities that one is trying to access and the quality or coverage of the mobility system providing that access that can be financially sustained (Geurs & van Wee, 2004).

3. PUBLIC TRANSPORT FINANCIAL VIABILITY

Sclar, Lönnroth & Wolmar (2016) suggest that the principal sources of finance for an urban public transport system can be categorised into three broad groups: users, beneficiaries, and the general public. 'User financing' describes the revenue derived from the public transport users, typically in the form of fares. Very few public transport systems rely solely on user financing, as there is usually justification for some form of subsidisation (Ubbels et al., 2001; Kenworthy & Laube, 2001). The primary objective of Transit-Oriented Development (TOD) has often been framed as the promotion of public transport use and a shift of mode share away from the private vehicle, especially in the context of the United States (Renne & Wells, 2002). Hence, some of the initial discussions around TOD and public transport finance arose from the theoretical ridership and fare revenue increases that TOD would produce (Belzer & Autler, 2002).

'Beneficiary financing' encompasses contributions from individuals and businesses that are deemed to benefit from public transport services irrespective of whether they are users. The most common contributors to beneficiary financing arrangements are the owners of the property around the public transport stations. The complementary value creation by the co-location of TOD and public transport investment provides financing opportunities for both public transport agencies and property owners. Beneficiary financing has played a prominent role in the TOD planning approach. Public transport agencies have developed a toolbox of financing mechanisms to capture the value that the property market allocates to the utility of public transport services; the toolbox ranges from passive mechanisms, such as property taxes, betterment charges and tax increment financing, to more active interventions, such as the direct sale of land and air rights, see Suzuki et al. (2015). A promising option has been Transit Joint Development (TJD), which has been described as "[a] public-private partnership designed to decrease the costs of operating or constructing public transportation systems, stations or improvements through creative public-private financing arrangements" (Murphy & Gillen, 1989). An interesting form of beneficiary financing is the '*versement transport*' in France, a company tax levied on paid salaries, which accounts for approximately half of the revenue of most urban transport authorities in the country (Fouchet & Brandsen, 2016; Halpern & Le Galès, 2016).

'Public financing' represents the subsidies provided to a public transport service from a general fund, which is related neither to the users nor to the beneficiaries of the service. Public financing for public transport is ubiquitous in Global North cities, but less so in Global South cities where the fiscus is more constrained and paratransit services are dominant (Del Mistro & Behrens, 2014). As cities in the Global South, including those in South Africa, scale up their formal public transport systems, it becomes increasingly important to minimise operating subsidies. The magnitude of public financing, or subsidisation, is often dependent on the financial liquidity of the national government or the local transport authority (Mees, 2010). Therefore, the concept of public transport financial viability is variable. Cities in the Global South have a larger proportion of poor, public transport-dependent users, which means higher levels of subsidy are required. But the transport authorities suffer from a poverty of funding that they can allocate to subsidisation, whether the subsidies are warranted or not. Minimising the level of subsidy required is therefore equally, if not more, important in these cities than those of the Global North. Moreover, because public financing is rarely linked to operational performance, services with high levels of public financing may inadvertently conceal or reinforce network inefficiencies and access inequity (Sclar, Lönnroth & Wolmar, 2016).

4. SOUTH AFRICAN CONTEXT

South Africa is known for having particularly high wealth inequality, but often overlooked is a similar inequity in access (Piketty et al., 2017). The inequitable distribution of access to opportunities and services in South African cities are in large part due to the segregationist planning policies of the Apartheid regime that fragmented the urban form (Visser, 2001). The national and local governments of South Africa have taken on the responsibility of transforming the urban form of the cities to reduce racial and income segregation, as well as improve the lives of those that suffer a dearth of access; i.e. those living in 'access poverty'.

South Africa's formal bus and rail networks have been hindered by aging infrastructure and underinvestment. The majority of South Africa's residents are reliant on the paratransit industry for their access needs, which in 2014 conveyed 66% of all daily public transport trips in South Africa's six largest cities (Hunter Van Ryneveld, 2014). However, as the operations of the paratransit services are not actively controlled nor subsidised by public or beneficiary finances, local governments have seen limited leverage to utilise them to actively target access improvements. Furthermore, without subsidisation or economies of scale, paratransit services remain more expensive for the urban poor than many rail and bus services. In Cape Town, for those of a low income, 27% of household expenditure is on public transport services to work, on average (City of Cape Town, 2013). In order to overcome the Apartheid legacy of access inequity and address the challenges of affordability, the South African national and local governments believed a coordinated and structured public transport system was required. Hence, a public transport reform agenda was drafted to formalise the paratransit services, refurbish the rail services, and develop new Bus Rapid Transit (BRT) services (Department of Transport (RSA), 2007).

During the initial stages of implementing the public transport reform agenda, it became clear that the original financial modelling, suggesting BRT services would not require operational subsidies, was unrealistic (Transport for Cape Town, 2015). Consequently, the financial viability of these planned access improvements was brought into question by academics and officials in both the cities where operations had commenced (Del Mistro & Bruun, 2012; Seftel & Peterson, 2014). Hunter Van Ryneveld (2014) illustrate that formal public transport systems in South African cities are among the least financially viable operations in the world; on par with, or less viable than, most major American cities despite the majority of South African residents being public transport dependent. In Cape Town, the transport authority embarked on successive 'moderation processes' for its new BRT services in order to reduce costs down to sustainable levels by optimising routes and vehicle frequencies, which has had limited success (Transport for Cape Town, 2015).

The source of this financial distress lies, primarily, in the land use environments created by Apartheid spatial planning, and income inequality. The fragmentation of the cities has led to highly inefficient demand patterns and trip flows across the public transport networks. It is within this paradigm that some have envisioned TOD as a mechanism to sustainably finance access improvements for South African residents. Simultaneously, a TOD planning approach has been proposed by both national and local government departments as a feasible method to increase the efficiency of the public transport demand patterns, leading to more financially viable and affordable public transport services (City of Johannesburg, 2013; City of Cape Town, 2016; Republic of South Africa, 2016; Venter, 2016).

5. TRANSIT-ORIENTED DEVELOPMENT

5.1. TOD and Travel behaviour

In the scholarly literature, Transit-Oriented Development (TOD) has been proposed as a mechanism to support the use and effectiveness of public transport services in varying contexts. TOD is enjoying increasing popularity across the world, with the view that it will bring about integration of public transport and the land use environment. The planning approach aims to provide greater choice in the housing sector, bolster public transport ridership and encourage development that conforms to the principles of sustainability. The potential effects of TOD on public transport finance and accessibility have been key considerations since the term was coined by Peter Calthorpe, 25 years ago.

The fundamental, cross-cutting relationship by which TOD influences both public transport finance and accessibility is the one that the built environment has with travel behaviour. Changing the built environment in order to change travel behaviour is at the core of the TOD planning approach. A common framework for conceptualising the primary facets of this relationship is through the five 'D' variables (*density*; *diversity*; *design*; *destination accessibility* and *distance to transit*), each of which describes a characteristic of the built environment that has a significant influence on travel behaviour (Ewing & Cervero, 2010). Ewing & Cervero (2010) performed a meta-analysis of the relevant literature, finding 62 studies that analysed at least one of the D characteristics. *Destination accessibility*, or access, is one of the five suggested built environment variables, and the one that was found to have the strongest influence over travel behaviour (Ewing & Cervero, 2010). The meta-analysis suggested its influence was nearly as strong as the first three D variables (density, diversity, and design) combined. Accessibility may have the strongest influence but it is also highly dependent on the other characteristics of the built environment. In order to shed light on the relationship that TOD can have with public transport finance and accessibility, the relationship that they have with the remaining four 'D' variables should be explored.

5.2. Density

High population density is synonymous with TOD, predominantly due to the trait being antithetical to the automobile-oriented urban sprawl of the American cities in which TOD, as a concept, was envisioned. Population and dwelling density has garnered much of the attention around the built environment's influence on travel behaviour (Guerra, 2013). A high population density translates to a high density of demand for goods, services and activities. Each service has an area of influence from which the minimum necessary number of users are most likely to be attracted. A higher density of demand means a smaller area of influence is needed, so the average distance between each user and the service decreases. Therefore, a resident of a high density neighbourhood is likely to have access to a greater number and range of services within a certain distance (Litman & Steele, 2017). Public transport operates in a similar fashion, with a similar area of influence around each stop or station.

Density has been at the forefront of the land use-public transport viability debate for decades, with an extensive literature base reviewed by Stead (2001); Ewing & Cervero (2010) and UN Habitat (2013). Further, as public transport is a networked service, the area of influence of the service is the cumulative area of all the stops and stations. A higher density in each of the areas of influence is expected to produce higher collective usage of the service and a higher level of financial viability due to the theory of 'economies of scale'. The theory is that, as density increases, ridership increases, and the marginal rate of user

financing increases faster than the marginal cost. This assumption that high population density is a prerequisite for viable public transport services has led to many authors developing density thresholds that are purported to assure service viability (Guerra & Cervero, 2011).

When high density correlates with lower average travel distances, Non-Motorised Transport (NMT) can supplement or replace motorised trips. Similarly, when demand density is high, more public transport options can be sustained by user financing within the same area. In general, a greater choice of mobility options improves accessibility (Litman, 2015). Each mobility option differs in its capabilities and limitations, meaning that each can be the most appropriate option for different users with varying demands.

In more recent years, the significance of density as a primary indicator of public transport use, or travel behaviour more broadly, has begun to be questioned (Eidlin, 2010). Other metropolitan-scale built environment characteristics have been found to have larger impacts on travel behaviour in a varied range of contexts (Brownstone & Golob, 2009; Ewing & Cervero, 2010; Boarnet, 2011; Guerra, 2013). In one of the few empirical studies on this relationship in the context of a Global South city, Zegras (2010) found that the effect of dwelling unit density in Santiago was not significant. In contrast, Guerra (2013) observed a significant and increasing effect of population density on car use in Mexico City. Overall, the results of studies using the context of a Global South city seem to be inconclusive, especially when analysing density as an indicator for public transport financial viability in South African cities (Cooke & Behrens, 2017).

Furthermore, TOD, and its high associated density, predominantly requires significant investment in the formal built environment. Building at a significantly higher density has higher associated costs. In countries like South Africa, with high levels of urban poverty and low rates of property market participation, it may not be realistic to expect to create a large, sustainable market for high density housing (Hogarth, 2015; Massyn et al., 2015). Similarly, pursuing high density social housing projects would place a significant financial burden on the government if an equivalent decrease in public financing for public transport did not materialise.

5.3. Distance to transit

Distance to transit describes the proximity of the average resident to public transport stops or stations. This characteristic often determines the access that a resident has to public transport services and considerably influences their overall level of access to opportunities. The value of proximity is at the heart of the TOD concept, especially proximity to trunk public transport stations. A useful metric for this built environment characteristic is that of ‘People Near Transit’ (PNT): the proportion of the population that is able to access the trunk public transport stations without the need of a feeder service. Trunk services are conventionally faster, more efficient, and given higher space priority than feeder or line-haul services. Therefore, access to trunk stations has a disproportionate effect on the overall level of accessibility (Institute for Transportation & Development Policy, 2016).

Similarly, ‘economies of scale’ suggests that trunk services are more cost-effective, per passenger served, than feeder or line-haul services. Increasing PNT is suggested to improve public transport financial viability by reducing the reliance on feeder services and by increasing ridership through higher levels of access (City of Cape Town, 2016; Cooke & Behrens, 2016; Institute for Transportation & Development Policy, 2016). The City of Cape Town has illustrated this in Figure 1, ranking the relative cost recovery ratio of trunk and

feeder services in the city (TDA, 2017a). The cost recovery ratio is the proportion of the direct operating costs of the service that are met through user financing. This metric is a common measure of financial viability, and Figure 1 mirrors the logic behind PNT's claimed financial benefits. Following on from the City of Cape Town's moderation processes, the future roll-out of formal public transport services is being rationalised to prioritise more cost-effective operations. Therefore, the planned provision of feeder services could be delayed or discontinued depending on the availability of funding. This affordability threshold could have a substantial effect on the accessibility of any residents outside of TOD zones.

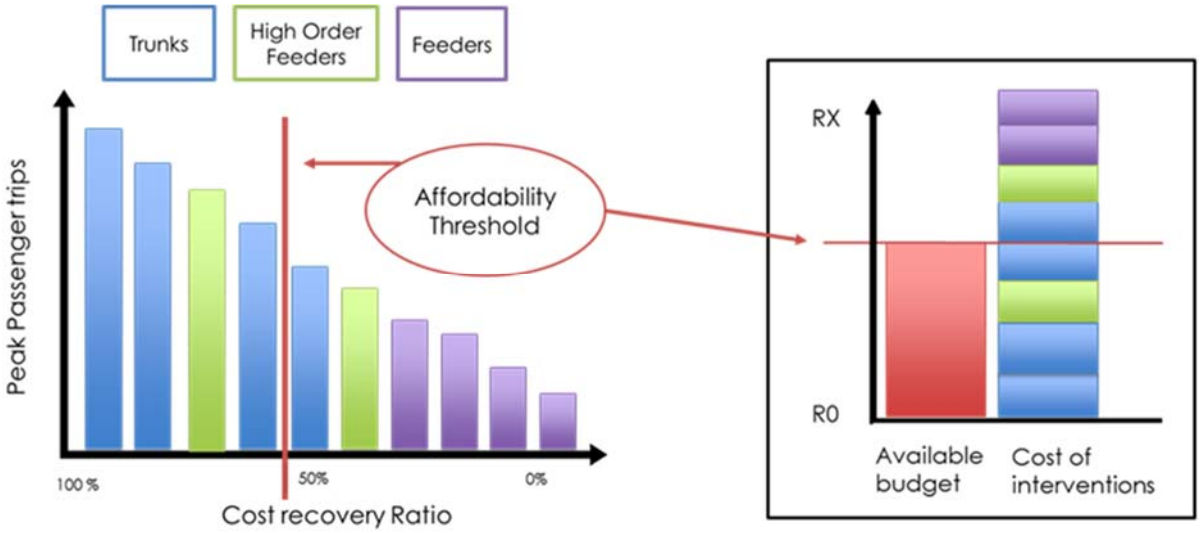

Figure 1: Conceptual affordability threshold based on relative cost recovery rates
Source: (TDA, 2017)

A key factor in distance to transit and PNT is the geographic profile of densification within a city. Global North cities are densifying in their central suburbs and around trunk public transport corridors, naturally increasing the level of PNT. Global South cities, especially those in Sub-Saharan Africa, tend to be densifying in the informal, low income settlements on the urban periphery, far from the trunk public transport services (Salazar Ferro & Behrens, 2015). This density profile undermines the efficacy of using metrics of TOD as a proxy for accessibility or financial viability as they, by their nature, only measure development that is proximal to major public transport lines; they do not measure the magnitude of less accessible, peripheral development that undermines the viability of public transport services in many Global South cities.

Furthermore, the ability of a city to create TOD is largely dependent on its ability to influence the real estate market and the proportion of the population that participates within that market. Due to the prevalent wealth inequality in South Africa, Hogarth (2015) estimates that over 70% of the population can only afford to buy houses in the affordable market, less than R500 000. As a result, only a minority of South Africans participate in the private-sector property market. In addition to the higher than average construction costs of high density TOD, land proximate to a trunk public transport station is highly valued. Therefore, it is unlikely that the property market will deliver the large magnitude of high density TOD that is necessary to compensate for the existing peripheral development. The majority of South Africans have neither sufficient income nor access to end-user finance to procure high density, formal housing from the property market (Hogarth, 2015).

5.4. Design

The urban design of the area surrounding public transport stations plays a significant role in promoting TOD, accessibility and financial viability. Design, in relation to travel behaviour, predominantly describes the street network characteristics of the area: intersection density; block size; and available NMT infrastructure; among others (Ewing & Cervero, 2010). Street design underpins much of the TOD concept, with half of the eight 'principles' in the Institute for Transportation & Development Policy's *TOD Standard* (2017) dedicated to its characteristics. According to Ewing & Cervero (2010), intersection density and street connectivity are among the built environment characteristics with the most influence over travel behaviour. Well-designed streets provide efficient, direct access to public transport stations, increasing first- and last-mile connectivity. A comfortable environment for pedestrians and cyclists also reduces the value-of-time associated with the trips to and from the public transport station by improving journey quality (Litman, 2015). These neighbourhood characteristics increase the perceived level of access for a public transport user, which is purported to increase ridership and financial viability.

A constrained fiscus, severely limited transport budgets, and a culture of vehicle dominance have all contributed to the underinvestment in NMT infrastructure in South African cities (Jennings, 2014). Strategic urban design that supports existing NMT use also has the potential to solve one of the key financial challenges identified earlier, the density profile of South African cities. As mentioned, the magnitude of existing peripheral development and low property market participation rates mean that conventional TOD typologies are unlikely to address the high reliance on feeder and line-haul services.

However, street design and NMT infrastructure can facilitate pedestrians and cyclists in accessing public transport trunk stations, directly, from much larger distances. If design can be used to expand TOD zones beyond the 'half-mile' convention, the proportion of the population within feeder or line-haul reliant areas would significantly decrease (Guerra, 2011). As the majority of South Africa's urban population is dependent upon public transport services, proximity to trunk public transport is less crucial in retaining ridership. If the PNT level of South African cities can be increased through street design and NMT infrastructure, public transport viability targets could be met without the construction of high density TOD. If cycling is embraced as a feeder service mode and the radius of a TOD zone can be extended to 3 km, the potential area wherein development could generate TOD benefits is eight times larger than that of pedestrian-based TOD and 35 times larger than the 'transit precinct' specified in Cape Town's TOD Strategic framework (City of Cape Town, 2016). Lee, Choi & Leem (2015) observed that using the local standard pedestrian access distance of 500m, the subway system of Seoul, South Korea has a coverage of 29.9% of the Metropolitan area. A bicycle access distance of just 1.96 km provides the subway system a coverage of 93.6%.

Although reducing feeder service reliance through NMT prioritisation could have desired financial effects similar to TOD, it's unclear if the accessibility improvement would be of a similar magnitude. South African cities could be a fertile context for exploring the concept of a lower density, NMT-facilitated TOD, but few studies have investigated whether the benefits are likely to be translated. Though, South Africa does have significant road safety and personal security issues, especially for NMT users, meaning that the magnitude of infrastructure required for NMT-facilitated TOD would still be significant (Jennings, 2014).

5.5. Diversity

Land-use mix, or diversity, refers to the spread of land uses and their level of interaction within a given area. At the metropolitan scale, land use mix describes the distribution of trip destinations and employment opportunities which influence trip patterns (Haque et al., 2013). Land-use diversity can be measured at different urban scales, each of which has a different effect on travel behaviour. The TOD planning approach has a strong focus on mixing land uses at the development or TOD precinct scale. A high diversity of opportunities and services within a TOD zone keeps trips short and walkable, thus reducing automobile dependence (Institute for Transportation & Development Policy, 2017). Short, walkable trips to a diverse range of opportunities and services has obvious implications for relative accessibility as well. Further, the variety of operating hours that a mixed use area provides improves temporal accessibility, which is an important facet of access (Litman, 2015). The differing periods of peak demand for different land use types also means that the passenger volumes on an adjacent public transport route will be more evenly spread throughout the day, and week, and 'peak-to-base' ratios will be reduced (Suzuki H., Cervero R., 2013).

Aside from the potential effects that land use diversity could have on public transport ridership, it also impacts financial viability when analysed at larger spatial scales. A common measure of land use mix at the metropolitan scale is the jobs-housing balance (Zhao & Li, 2016). The relative distribution of trip origins and destinations across a metropolitan area is a primary determinant of the efficiency of its public transport network. High metropolitan-scale land use diversity can create an even, bi-directional flow of trips along each public transport corridor, maximising vehicle productivity (Curtis, Renne & Bertolini, 2009). Similarly, a higher mix of land uses would increase the number of trip destinations along a corridor, leading to the same seat being utilised by many passengers throughout the vehicle trip, increasing the productivity of the vehicle (Cooke & Behrens, 2017). Finally, land-use diversity, at a metropolitan scale, can determine the length of a public transport corridor as they often terminate at the nearest major economic node. Hence, higher polycentricity can decrease the average distance to an economic node, decrease public transport corridor length and increase accessibility (Veneri, 2010). Corridor length can have significant effects on the financial viability of a public transport service when land use mix is low (Cooke & Behrens, 2017).

In Ewing & Cervero's (2010) review of built environment-travel behaviour studies, the jobs-housing balance was found to have a stronger effect than land use entropy, a common measure of land use mix at the precinct scale. Zegras (2010) also found relatively modest effects of land use mix on travel behaviour in Santiago compared to most Global North cities, but this may be due to the larger effects from income and distance to the central business district. A study by Haque et al. (2013) suggests that there is a significant land-use imbalance between urban zones in the city of Sylhet, Bangladesh, which has a significant effect on trip patterns. While Saghapour (2013) observed that increasing land-use diversity in Shiraz City, Iran, reduces trip lengths but does not significantly affect private vehicle usage. The significance of land use mix in the reviewed literature appears varied, but measures of land-use diversity at larger spatial scales do seem to have a stronger relationship with travel behaviour, especially in cities of the Global South. There was no study found that analysed the impact of land-use distribution on public transport viability in a city of the Global South.

Land-use diversity is a particularly problematic built environment characteristic for South African cities. Urban development control has been Euclidian in nature, in that land uses are purposefully segregated. The result is low levels of land use mix, and long trips from the

urban periphery to the major economic nodes, primarily during peak hours. The unidirectionality of the demand profile, the low levels of seat renewal, and the high peak-to-base ratios are due, in part, to low land use diversity; and has been posited as a fundamental reason why the creation of viable public transport in South African cities has been so difficult (Van Ryneveld, 2010). These operational characteristics are foremost on the list of changes that proponents hope TOD can resolve. However, these characteristics have been linked strongly to metropolitan-scale land use diversity rather than precinct-scale land use mix, the focus of TOD. Similar to density, the magnitude of TOD required to change land use diversity at the metropolitan scale is large.

6. PROBLEM FRAMING

South African cities, like Cape Town, are pursuing a TOD planning approach in order to improve accessibility and the financial viability of their formal public transport services. Apartheid spatial planning has left a legacy of access inequity and public transport network inefficiency. TOD has the potential to resolve these challenges by adopting built environment characteristics with a positive influence on travel behaviour.

However, the relationship between TOD, accessibility and public transport financial viability is complex, and not thoroughly understood, especially in the context of a Global South city. The aforementioned financial viability improvements resulting from TOD, due to ridership increases and mode shift, are unlikely to be realised in a context where the majority of urban residents are public transport-dependent. The high urban density associated with TOD has the ability to increase ridership and leverage the public transport supportiveness of a land use environment. But the majority of South Africans are already public transport-dependent and the inefficiency of the trip pattern means that higher density could just exacerbate the existing congestion on the network. In Cape Town, the formal housing market is delivering less than 10 000 units per year (which is down from 15 000 before 2008) and dwarfed by the 1 265 000 households already in existence (TDA, 2017b). Similarly, the total gross lettable area of retail activities in Cape Town is only expected to increase by 0.8% each year between 2015 and 2032. The ability of the property market to deliver a significant magnitude of high density, mixed use TOD is questionable. The density requirement for successful TOD could be overcome through good urban design and by innovatively reducing feeder service reliance, but there could be negative effects on accessibility.

For TOD to meaningfully affect the level of operating subsidisation in the South African context, the focus of the planning approach would still need to be adapted in order to address the crucial financial challenge that these cities face: an inefficient trip flow pattern at the metropolitan scale. The conventional TOD planning approach has been precinct-focused, in some cases leading to network-agnostic developments around public transport stations. Network-agnosticism is acceptable in contexts where increasing public transport ridership is the primary motivation of the TOD, but could exacerbate the trip flow pattern problems that South African cities are trying to solve. The TOD that Calthorpe envisioned for the American context may not adequately address these different challenges. The relationship that TOD-related land use change has with public transport operational finance in the South African context needs to be better understood.

Concurrently, the assumption that more financially viable public transport will inherently lead to higher levels of service, and, in turn, higher levels of access, has not been adequately explored. Although inextricably linked, the financial viability of South Africa's public transport services and the accessibility of opportunities for residents remain two distinct aims in the pursuit of successful TOD. How the TOD planning approach may solve both financial

viability and user accessibility challenges simultaneously needs investigation. Currently, in the absence of this information, decision-makers in South African transport authorities are left to use their intuition to evaluate the prioritisation of one objective or the other. A deeper understanding of this relationship could allow them to better manage these decisions and to sustainably finance accessibility improvements using TOD.

7. PROPOSED RESEARCH METHOD

The proposed study will endeavour to illuminate the complex relationship between TOD, accessibility and public transport finance in a South African context: Cape Town. In 2016, the City of Cape Town released the first African TOD Strategic Framework, and Cape Town's Transport and Urban Development Authority (TDA) has been investigating the potential for TOD in its context. To guide transport planning in the city, TDA has produced an Integrated Public Transport Network (IPTN) Plan for 2032. In turn, future land-use scenarios were then developed for the year 2032 in order to guide the development of TOD around the existing and future IPTN stations. TOD Comprehensive (TODC) is an ambitious urban growth land use scenario that was created to test the full impact of embracing the TOD planning approach—as it was understood at the time—on the operational and financial performance of the 2032 IPTN. The TODC land use scenario was derived by optimising the land use distribution to correct Cape Town's inefficient trip flow pattern by reducing travel distances, increasing seat renewal and balancing bi-directional flows. It was believed that achieving these three objectives would significantly improve the financial viability of the 2032 IPTN, as well as the level of accessibility for the average resident. The reason that the objectives were used as proxies for financial viability was due to the lack of a fully integrated land use-transport interaction (LUTI) model. Consequently, the individual relationships between the facets of TOD and public transport financial viability could not be effectively understood, and the IPTN plan for 2032 had to be assumed as a static end state. Similarly, the City of Cape Town lacks a comprehensive accessibility model, meaning that the anticipated improvements in access from TODC have not been measured. No model can capture the complexity of the built environment; a certain level of intuition and judgement is required when making decisions regarding transport and development planning. This study will attempt to improve the intuition and judgement of decision-makers, by deepening their understanding of how to manage the decisions around accessibility and public transport finance.

In order to manage these decisions, the underlying relationships between each component requires investigation. This study will build upon the work that has already been done at TDA on the TODC scenario and return the analysis to the fundamentals of the relationship between land use and public transport operations. A model will be created that combines a land use model, a transport model, an accessibility model and full costing functionality. In order to simplify the complex relationships, the model will not be fully dynamic, but will test a range of land use and transport scenarios to determine their effect on the distribution of access across the city and the financial viability of the network. The scenarios will be sourced by interviewing decision-makers in TDA to ascertain their intuition around TOD, access and public transport finance. Trends and commonalities will be identified among the responses to form a picture of the characteristics of the TOD being pursued. By testing this scenario, or multiple scenarios depending on the disparity in vision for the TOD concept, the model will be able to reveal whether the intuition of the decision-makers aligns with the best estimates. Other scenarios will then be tested, based on prevailing or innovative propositions in the research field, to determine if better solutions can be found and how they differ from those of the decision-makers. However, the aim of this research is not to propose

optimal solutions, but a spatial decision support system that guides the myriad of choices that need to be made in order to develop more accessible and financially viable cities.

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