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REVIEW ARTICLE

The potential emergence of mid-tier transit

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ABSTRACT

This paper reviews the emerging potential of mid-tier transit, articulating how a complex set of established and new factors could contribute both to better transit outcomes and the associated urban regeneration around station precincts. The analysis is based on two structured literature reviews, supported by insights from the authors' original research. The first provides an overview of the established and new rationale for mid-tier technologies such as the established Light Rail Transit (LRT) and Bus Rapid Transit (BRT) as well as the new Trackless Tram Systems (TTS). The established role for mid-tier transit is now being given extra reasons for it to be a major focus of urban infrastructure especially due to the need for net zero cities. The second review, is a detailed consideration of established and new factors that can potentially improve patronage on mid-tier transit. The established factors of urban precinct design like stop amenities and improved accessibility and density around stations, are combined with new smart technology systems like advanced intelligent transport systems and real-time transport information for travellers, as well as new transport technologies such as micro-mobility and Mobility on Demand. Also explored are new processes with funding and development models that properly leverage land value capture, public private partnerships, and other entrepreneurial development approaches that are still largely not mainstreamed. All were found to potentially work, especially if done together, to help cities move into greater mid-tier transit.

KEYWORDS

mid-tier transit; Trackless Tram; Mobility as a Service; Mobility on Demand; micro-mobility

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1. Introduction

The purpose of this paper is to help cities see how they could improve their transit services by investing in better mid-tier transit. It will use global literature and experience generated from the authors, as professionals and academics involved in changing cities, to create urban futures that are more sustainable and less car dependent (Newman and Kenworthy, 2015).

There is a growing recognition of the need for mid-tier transit for a range of reasons: first, there is a need to make a more complete transit system that enables it to be competitive with the automobile and this needs an integrated network that goes beyond local buses and corridor-based trains to a set of road-based rapid transit that connects the local to the long corridor (Glazebrook and Newman, 2018). Second, there is a need to stop urban sprawl by enabling the regeneration of suburbs in decline and this is now being seen as requiring new infrastructure that can increase land value and mid-tier has a track record in this area. Third, the new agenda of net zero cities requires both transit and the associated urbanism to be electric and renewably-powered with mid-tier offering this as well (Newman, 2023; Sharma and Newman, 2020, p. 20). The paper therefore seeks to provide for the world of urban practice, as well as academia, that there is a need to recognise established and new approaches that can help enable this emerging potential to be delivered in cities around the world.

The paper sets out in two parts the opportunities for mid-tier transit to reach this new potential. First, it will review the rationale for mid-tier transit particularly assessing how the new agendas of net zero and regenerative approaches can now be the basis of investment in mid-tier systems. Second, the paper reviews how to improve mid-tier transit patronage through established design and operational approaches as well as new operational technologies; it especially outlines how smart systems technology and integrated micro-mobility can add extra patronage to a mid-tier system. It also examines new operational and design practices that can improve patronage and enable station precinct regeneration through more entrepreneurial approaches.

2. The rationale for mid-tier transit

The term mid-tier transit refers to a collection of public transport systems that operate on direct and prioritised routes (Verschuer, 2020). This is achieved by a combination of dedicated lanes with right of way infrastructure. Mid-tier services operate on a smaller scale than heavy rail but provide a more consistent transit performance than a traditional bus system. As a result, they are considered the intermediary between high-capacity rail and legacy bus services and are commonly used as a cross-corridor linking system rather than a high speed corridor access service or a local collector (Newman, Hargroves, et al., 2021; Verschuer, 2020).

Technologies and systems associated with mid-tier transit include:

1) Light Rail Transit (LRT)

2) Bus Rapid Transit (BRT)

3) Trackless Tram System (TTS)

Other vehicle types are sometimes called mid-tier but usually don't have the same function of linking across corridors, though they may have the mid-level capacity in patronage. Tram buses are most often included within the category of BRT and are sometimes described as a stylised bus. Monorail, sky rail and maglev are mostly used to replace heavy rail, or even high-speed rail, when it is necessary to go above ground through a dense city; however, they can also be used as a mid-tier option. This paper will focus on the three systems of LRT, BRT and TTS and begins with the rationale for expanding their role.

There are established reasons for expanding mid-tier transit, usually based on the need for functional additions to the transit system. This means doing transit jobs that cannot be done by local buses or corridor-based heavy rail. They are most applicable in catchment areas un-serviced by heavy rail networks or are used to serve as a feeder system for high-capacity lines. Additionally, due to their reduced cost, mid-tier systems are best utilised in areas where it is economically inefficient to construct heavy rail, but transit demand still warrants dedicated infrastructure (Australasian Railway Association, 2021).

The second major rationale, which is also an established reason for focussing on it, is that mid-tier transit helps enable urban regeneration in parts of the city that need to be regenerated. This is particularly important because of the growing interest due to the problems of urban sprawl. With the advent of the automobile, cities over the past century have seen a radical shift in their urban fabrics towards a highly expansive and consumptive development approach (Thomson and Newman, 2018b). For a time, the automobile fabric provided untapped potential in time-efficient hyper-mobility where life areas no longer needed to be within proximity to one's home (Newman et al., 2016). However, cities are increasingly becoming suffocated by the automobile as congestion and rising operating costs have steadily eroded the benefits of motorised transport (Newman and Kenworthy, 2015). Policy shifts advocating for a return to corridor-based development centred around integrated walking and transit fabrics have increasingly been dominating urban politics (Huang and Wey, 2019; Newman and Kenworthy, 2021; Newton et al., 2022). Mid-tier transit is enabling the kind of urban regeneration in older areas that need redevelopment and at the same time building up living and working arrangements that are not car dependent.

Transit-Oriented Development (TOD) is the established urban process for this urban regeneration around transit systems. TOD attempts to utilise the beneficial land value generated from rapid transit to construct high-density precincts with walkability-based amenities (Cervero and Dai, 2014; Huang and Wey, 2019; Newman, Davies-Slate, et al., 2021).

Where cities have a majority of their land area devoted to automobile dependent suburbs, there is a need for a new approach to enable more walkable, transit-oriented centres to be created. There is growing evidence to suggest that cities need rapid transit networks in corridors where investment in high-capacity rail would be impractical (Australasian Railway Association, 2021; Verschuer, 2020). There is therefore growing interest in mid-tier rapid transit systems that provide something between a local bus and a regional heavy rail system. Mid-tier transit can fit into the main roads of cities and provide both a better transit service and the chance to unlock walkable urban development around it.

Such mid-tier transit systems are increasingly being understood as the missing component required to unlock underutilised urban areas as well as being inclusive, healthy and productive (Newton et al., 2022). Mid-tier transit has been found to enable this kind of urban regeneration around low value corridors as land value increases due to accessibility and amenity associated with this transport mode (Newman and Kenworthy, 2015).

The third rationale for mid-tier systems is a new rationale. It has come more recently from the literature due to the potential for mid-tier transit to be a catalyst in shifting urban development paradigms toward a new city fabric that is not just more sustainable but can help take on the new agendas of net zero and potentially help make a regenerative city (An et al., 2019; Childers et al., 2015; Newman, 2017). This rationale is given more attention in this paper as the world has rapidly shifted to wanting to see these outcomes as a major result of any future urban development. Thus, it does provide a major opportunity for increasing mid-tier transit investment.

The sustainable city is an established rationale but the net zero city is now a new concept that cities everywhere are signing up to achieve, though the guidelines are not clear yet (Newman, 2023). Net zero is really part of the emerging notion of a regenerative city. The regenerative city can be tied back to Reed (2007) who defines it as a city that not only minimises its ecological footprint but aims to regenerate it. At the crux of this new paradigm is a belief that human systems require integration and alignment within the planet's regenerative capacity (Gibbons, 2020). Accordingly, a regenerative city utilises renewable energy systems, generates new economic opportunities and restores the relationship between cities and the natural systems they depend on (Girardet, 2014; Thomson and Newman, 2018b). A regenerative urban system would see cities go beyond merely balancing their net inputs and outputs, but rather begin to use their significant potential to regenerate depleted resource stocks (Du Plessis and Brandon, 2015; Thomson and Newman, 2018b). Urban policies would foster outcomes such as decarbonised energy systems, recycling of water and waste, generation of local food and integration of nature positive biodiversity elements (Thomson and Newman, 2018a). Du Plessis and Brandon (2015, p. 1) suggest that this new paradigm would strengthen the adaptive capacity of socio-economic and ecological systems, thereby "creating the conditions for a thriving and abundant future".

Thomson and Newman (2018a) argue that urban fabrics (walking, transit, and automobile) and their associated infrastructure, exhibit different opportunities in generating sustainable development outcomes, with the automobile fabric being the least conducive. Mid-tier transit provides the opportunity of creating transit urban fabric and walking urban fabric through automobile fabric. Thus a mid-tier transit system and its accompanying operational features can have a significant impact on the ability of cities to provide regenerative outcomes (Arrington and Cervero, 2008) due to its construction around transit corridors accompanied by high-density regenerative development (Huang and Wey, 2019; Newman, 2017; Newton et al., 2022). These high-density developments are what Huang and Wey (2019) refer to as Green TOD, an expansion of the traditional TOD paradigm towards greater consideration of ecological and environmental dimensions (as illustrated in **Figure 1**).

Thus Green TOD's or Net Zero Corridors created by mid-tier transit, are argued to be a means to shift urban fabric towards more sustainable, climate resilient and potentially regenerative fabrics, as their high-density design can foster a number of positive urban outcomes if combined with a range of sustainable urban design principles (Cervero and Dai, 2014; Huang and Wey, 2019; Newman, Davies-Slate, et al., 2021).

These three rationales are likely to lead to many cities wanting to build new mid-tier transit systems. Despite the acknowledgement of mid-tier's growing importance, there is a sparse amount of dialogue regarding what elements would improve the performance of such systems, particularly considering new emerging trends such as smart systems and integrated micro-mobility networks. By reviewing factors that improve the operation of mid-tier transit, it may be possible to increase patronage and further unlock its potential as a catalyst for creating a net zero, regenerative city.

Source: Authors.

Figure 1. A Trackless Tram and a Green TOD that is net zero.

3. A review of the urban design and transport technology factors that enable the operation and adoption of mid-tier transit

There are established and new factors that were analysed from the literature. The first ones are part of precinct urban design—accessibility, high density and stop amenities —these are established but need to be renewed and improved by various means. The second group of factors are new as they are dependent on smart systems technology: intelligent transport systems, real-time transit information, micro-mobility and MAAS. The third group of factors are both established and new urban processes: funding and development models, leveraging land value capture, public private partnerships and other entrepreneurial approaches.

3.1. Precinct urban design

While urban design may be considered a self-evident factor in improving transport patronage, attractiveness and operational efficiency, its continued discussion in academic literature suggests current transport systems are producing inconsistent results when utilising urban design to improve transit operations (Knowles and Ferbrache, 2016; Su et al., 2022; Sulikova and Brand, 2021). Therefore, we will explore the impact of urban design features such as high-density development, urban accessibility and transit stop amenities, on transit operations.

3.1.1. High-density transit precincts

A shift toward high-density development that includes mixed land use and activity centres within close proximity to transit nodes has been cited as the principal means to improve the patronage of transit and the overall sustainability of urban environments (Guzman and Gomez Cardona, 2021; Newman, 2014; Newman and Kenworthy, 2015). Higher densities are argued to limit the consumption of sensitive environmental lands and reduce the necessity of motorised transport as transit systems are within distances that can be accessed by walking, cycling or micro-mobility

(Guzman and Gomez Cardona, 2021; Knowles and Ferbrache, 2019).

As a result of higher densities increasing the number of people in close proximity to public transport, several researchers have investigated the impact of distance as a determinant of patronage (Cervero, 2007; Ganning and Miller, 2020; Pan et al., 2017). A study by Cervero (2007) compared travel patterns of residents who were within 800 m of a station and those outside of 800 m. Results indicate that for those within 800 m of a station, public transport accounted for 27% of total trips, compared to 7% for those more than 800 m away. The study suggested that public transport use could be 42% higher if a person lived closer to a station, and concluded higher densities could be a major factor in increasing patronage of public transport (Ibraeva et al., 2020).

The introduction of micro-mobility modes such as e-scooters has been shown to extend the feasible distance patrons are willing to travel to access public transport or in some instances completely replace the necessity of utilising transit altogether. According to Cao et al. (2021), the desirable range for e-scooters peaks at around 3 km representing a significant extension of a transit network's radius which is usually capped at 1 km based on walking.

High density also reduces the need for parking. Research by Chatman (2013) suggests that high-density development impacts travel behaviour as a result of limiting parking supply. Commuting via automobile was found to be 60% lower in station precincts primarily because of limited parking. Consequently, daily trips in transit precincts were found to be completed via walking, cycling or public transport (Laham and Noland, 2017).

Ibraeva et al. (2020) in their review of transit-oriented development, suggest that the focus has recently shifted to the impact of commercial density as a critical component of improving passenger volumes. Cervero and Guerra (2011) argue that increases in commercial density within 400 m of stations result in improvements in ridership. Despite a retail core being a critical component of transit-oriented development, Ganning and Miller (2020) note that successful retail in station precincts is often elusive. These findings would suggest that retail and employment density could be as influential as residential density in increasing transport patronage (Guzman and Gomez Cardona, 2021), thus Newman and Kenworthy (2021) suggest that a minimum density for transit is 30 people and jobs per ha of urban land and is 100 per ha for walking.

3.1.2. Urban accessibility

A literature review completed by Saif et al. (2019) indicates that one of the most important factors in a transportation network is accessibility. Their review indicates that accessibility or perceived accessibility generated from high-quality infrastructure can drastically improve the attractiveness of public transport systems. Accessibility can be defined as "the network coverage of a PT system and access by active modes such as walking and cycling, to different land uses" (Chowdhury et al., 2016, p. 99). Ease of access is argued to be a strong factor in determining whether users continually utilise public transport for daily commutes (Chowdhury et al., 2016). Accessibility can be influenced by a multitude of factors such as pedestrian infrastructure, street connectivity, aesthetic quality and appeal of the local environment (Park et al., 2021; Saelens and Handy, 2008) but depends mostly on the time it takes to reach the station precinct (Newman, Hargroves, et al., 2021).

According to Boarnet et al. (2017), the ease and speed of first and last mile journeys play a strong role in user perceptions of transport accessibility. Many studies have claimed that to improve the experience of first and last mile journeys, adequate investment in urban walkability and micro-mobility infrastructure is critical (Abduljabbar et al., 2021; Jeffrey et al., 2019; Oeschger et al., 2020; Shaheen and Chan, 2016). Improving walkability can be achieved via several design choices and monetary investments. For example, the city of Barcelona has developed a pedestrian centric urban model known as "superblocks" (Mueller et al., 2020). The superblock model is based on the idea that primary accessibility should be afforded to active modes of transport first, with secondary support for residential traffic at speeds of 20 km/h. Within these superblocks would be dedicated infrastructure such as segregated cycling and pedestrian lanes, which are argued to increase the safety of first and last mile journeys within the precinct (Mueller et al., 2020).

Regarding safety, a study by Park et al. (2021) indicates that perceived accessibility of first and last mile journeys can be improved if user perception of safety on the route is high, features such as adequate lighting and well-placed cameras are suggested solutions. Research from Bogota by Rodriguez and Targa (2004) indicates there may be a causal relationship between walkability to BRT stations and the value of adjacent real estate. The study suggests that for every 5 minutes of additional walking time to a BRT station the rental price of properties decreases between 6.8 to 9.3%. Thus planners can still derive benefits from improving walkability as suggested by Nawrocki et al. (2014) where station area walkability had a measurable effect on LRT usage in the United States.

The importance of micro-mobility infrastructure in improving the operation and accessibility of transport systems is still a relatively new concept despite the fact the technologies utilised are somewhat dated (Oeschger et al., 2020). Micro-mobility includes several lightweight vehicles such as bicycles, scooters, skateboards and segways, that improve the speed of first and last mile journeys (Milakis et al., 2020). These modes can be either electric powered or human powered, providing a sustainable transport medium regardless of choice. Evidence from a number of studies indicates that micro-mobility services provide patrons with greater accessibility to public transport nodes, as well as additional economic opportunities (Abduljabbar et al., 2021; Du and Cheng, 2018). For example, a study by Jäppinen et al. (2013) revealed that a bicycle sharing system in Helsinki decreased public transport travel time by an average of 10% or 6 minutes from a single journey. For Oeschger et al. (2020), greater quantitative research on the impact of new micro-mobility services is warranted to better understand causalities, negative effects, and benefits for transit systems. How a micro-mobility system could further improve mid-tier transit operation will be discussed in later sections through its integration with stop amenities and ITS elements.

3.1.3. Stop amenities

As the previous section revealed, system design elements formulate an important aspect of transit operation. Stop amenities are a proven factor in increasing user satisfaction with public transport and, as a by-product, encourages new ridership and potential reuse (De Gruyter and Currie, 2018; Iseki and Taylor, 2010; Kim et al., 2020; Moran, 2022; Sun et al., 2020). A study in Salt Lake City, Utah, by Kim et al. (2020), produced a quantitative analysis of whether improvements in stop amenity resulted in changes in ridership. The improvements to stops included a covered shelter with an interior bench, a garbage bin, and pedestrian footpaths that allowed for safe access. While these amenities were basic, the results indicated that patronage increased at a rate of 141% compared to unimproved stops. Kim et al. (2020) do note that this improvement in ridership cannot be completely attributed to the new amenities, nor can it be entirely considered as new passengers.

They argue that the increase in patronage may be a result of pre-existing riders switching to a stop with higher amenities, supporting their general assumption that amenities influence derived satisfaction. It should be noted that the stops improved in the case study were often vacant grassland with a single transport sign before improvements were made. The findings of the Salt Lake City case study would support results from established literature on the importance of shelter in improving user satisfaction with public transport (De Gruyter and Currie, 2018; Iseki and Taylor, 2010).

The ability to sit and have some form of protection from inclement weather influences rider decision making, with users more likely to commute in harsh weather if stops provide adequate protective shelter (Miao et al., 2016; Moran, 2022). A study completed by Sun et al. (2020) revealed that rubbish bins, comfort while waiting, and security cameras were ranked as the most important variables influencing rider satisfaction. Shelters, lighting, benches, and real time information were also found to be important variables.

As technology has improved over the years, riders have steadily begun to place a premium on Real Time Information (RTI) in their transport systems (Gkiotsalitis et al., 2022). According to Dziekan and Vermeulen (2006), systems that display bus departure times or next train arrivals can greatly reduce anxiety. Providing riders with RTI is argued to reduce anxiety by limiting the emotional energy expended while commuting, as the uncertainty of transit is largely removed (Dziekan and Vermeulen, 2006).

In their current form, transit stop RTI systems primarily display departure times or time till the next arrival. Prandi et al. (2017) suggest the next step in transit stop RTI will be allowing riders to utilise an interactive display that allows for inter-trip rerouting. The ability to visualise and map journeys from stops as opposed to stations, is suggested to significantly improve user satisfaction with public transport (Sungur et al., 2015). Interactive RTI are also known as “smart stops” (Padrón Nápoles et al., 2020; Nápoles et al., 2020; Sungur et al., 2015). A smart stop can be defined as a transit stop that provides access to a digitised transport system via interactive displays, allowing for tailored route planning in real time (Nápoles et al., 2020). A relatively recent demonstration of a smart stop was revealed by Hungarian smart technology company AQUIS Innovo (See **Figure 2**). The smart stop includes a range of innovative features such as ticket vending, passenger counting, interactive transport information, Wi-Fi, USB recharging, weather forecasting, digital advertising, and taxi ordering capabilities. Additionally, the stop can integrate with local micro-mobility elements by providing an E-bike rental and recharging station. Accompanying each station is a surveillance camera to provide riders with improved perceptions of safety (Iseki and Taylor, 2010; Nápoles et al., 2020). AQUIS Innovo (2016) states that the stop is modular in design allowing for implementation to be relatively quick. This may suggest a potential opportunity to investigate smart stop integration with any mid-tier transit system such as those in modular trackless tram stations (Newman, Hargroves et al, 2021).

Perhaps the greatest impact transit stop amenity has on rider satisfaction is derived from its ability to decrease perceived wait times (Fan et al., 2016; Ji et al., 2019; Lagune-Reutler et al., 2016). Evidence suggests that riders who wait in stops with high amenities are more likely to underestimate perceived wait times compared to users who wait in low amenity stops. Research by Fan et al. (2016) concluded that users in low amenity stops report wait periods to be 1.3 times longer than they actually are. A cited example of this finding is the impact surveillance cameras can

Source: AQUIS Innovo, 2016.

Figure 2. AQUIS Innovo Smart bus stop concept art.

have on rider perceptions of security. Stops with some form of active surveillance were revealed to reduce perceptions of wait time significantly, particularly for women taking transit at night (Fan et al., 2016). Stop amenities are ultimately supportive elements in improving transit system patronage, as unless the broader transport system is frequent and reliable, then elevated investment in stop amenities is not very productive (Iseki and Taylor, 2010) though they are often an indicator of the quality of a transit system.

3.2. New smart technology and intelligent transport systems

3.2.1. Benefits of smart technology on user satisfaction, efficiency, and mobility

As noted in the previous section, technological innovation in the form of new smart technology and real-time transport information has significant potential to radically alter the user experience of public transport. They integrate with the need for precinct urban design, as do many other features displayed below. The implementation of smart stops is just a small component of a much greater attempt to redesign public transport systems with smart technology at its core (Kadam et al., 2018; Gohar and Nencioni, 2021; Cruz et al., 2018).

With the vast majority of transit vehicles having some form of a global positioning system (GPS), recent case studies such as Anytrip by Transport for NSW, have highlighted the potential of providing RTI to not only improve transit stops and stations, but to directly improve information by applying it to patron’s mobile devices as well (Sutar et al., 2016; Vakula and Raviteja, 2017; Transport for NSW, 2022). The adaptation of digital applications in the transport system has allowed for information such as real time location, time till arrival, and stops along the route to be provided to the user before their journey begins (Poon, 2021). Evidence indicates that providing users with interactive RTI in mobile formats improves their ability to make informed decisions before travel commences (Poon, 2021; Sutar et al., 2016). Adequate information prior to commencing a journey is argued to allow riders to determine their arrival time and consequently reduce unnecessary wait time (Brakewood and Watkins, 2019). The efficiency and flexibility of tailoring transport trips to individual circumstances is suggested to improve user satisfaction with public transport and encourage potential reuse (Brakewood and Watkins, 2019). For authors such as Sutar et al. (2016), the omnipresence of smartphones is the catalyst needed to develop a transit system that provides service based on user demand not on predetermined transit timetables.

Mobility on Demand (MoD) provides transit patrons with the ability to access multiple transit modes on demand, or in real time, primarily from the convenience of their smart phone. There have been a number of successful deployments of MoD systems such as Liftango's Bus on Demand trial in the Central Coast of NSW, Australia (McCallum, 2021). The trial provided users with the ability to request a bus to a number of pre-determined points that then proceed to the central rail station or vice versa. Evidence suggests the trial improved user access to the public transit network, in addition to increasing patron perceptions of network reliability.

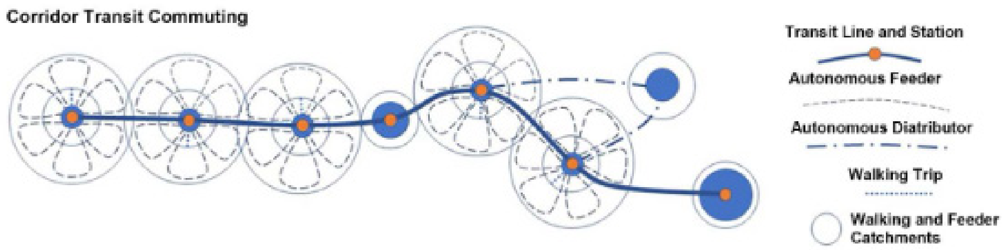
For the true value of MoD to be realised the use of autonomous vehicle fleets may be needed (Spieser et al., 2014). Autonomous technologies can be applied to mid-tier transit like trackless trams and enable guidance to be much improved and so help ride quality and they can also be applied to automobiles to be used as connecting systems to transit. Private automobiles, while a prominent feature of modern society are severely underutilised assets, being used for less than 10% of the time they are owned. Spieser et al. (2014) conducted an analysis of the potential of a shared MoD network serviced by autonomous vehicles in Singapore. Their results indicate that the mobility demands of the entire population could be met with a fleet roughly one-third of the total number of passenger vehicles in operation at the time. This would be achieved because of vehicles ferrying passengers for the entire day as opposed to remaining parked after one or two trips. A reduction of private automobile usage of this magnitude could provide significant environmental savings with regards to a reduction in emissions and reducing the footprint of urban environments as parking and garage space becomes increasingly redundant.

With the rapid acceleration of available transportt options and an increasing desire for systems designed for user demand, many governments and planning practitioners have been investigating a means to simplify usage of multi-modal MoD networks with what is known as Mobility as a Service (MaaS) (Giesecke et al., 2016; Utriainen and Pöllänen, 2018). According to Vij and Dühr (2022, p. 1):

> *"Mobility-as-a-service offers consumers access to multiple transport modes and services, owned and/or operated by different mobility service providers, through an integrated digital platform for planning, booking and payment".*

The core principle of MaaS is to provide a digital platform that integrates services such as taxi and ride hailing, car sharing, e-scooter and bike sharing, as well as other micro-mobility elements with public transport, in a bid to provide an attractive alternative to automobile usage (Alyavina et al., 2022; Smith et al., 2022). Studies completed in Ghent, Belgium and Sydney, indicate users participating in MaaS trials are less likely to commute via automobile, with the Ghent study revealing that 74% of participants did not use an automobile during the study (Smith et al., 2022).

The concept of an integrated transport application presents numerous opportunities and challenges for public transport authorities. A key benefit afforded by a MaaS application is that it reduces the complexity of completing multi-modal transport trips, as all modes and their respective



Source: Glazebrook and Newman, 2018.

Figure 3. A proposed mid-tier transit corridor with accompanying feeder networks.

payments are compiled into one singular intermodal journey planner (Alyavina et al., 2022; Smith et al., 2022). This will be particularly beneficial for mid-tier transit as new technologies such as the trackless tram are envisioned to be developed with a multi-modal feeder network such as autonomous shuttles, e-scooters, and legacy bus systems (Glazebrook and Newman, 2018)(See **Figure 3**) . By providing an application that allows users to plan, book and pay for all these services, the perceived inconvenience of transit journeys is suggested to shrink considerably (Smith et al., 2022). MaaS has the potential to improve the market visibility of feeder services such as e-scooters as they partner with transit authorities. Consequently, higher awareness of micro-mobility elements may elevate perceptions of accessibility to transit for a number of populations (Alyavina et al., 2022; Midgley, 2009; Oeschger et al., 2020). Moreover, there is significant economic potential in MaaS with Juniper Research (2021) estimating the total market value of MaaS platforms to be $52 billion by 2027. The increased revenue, as a result, could reduce the necessity for transit subsidies from governments.

There are some challenges in implementing a MaaS system, particularly concerning market considerations. For example, Alyavina et al. (2022) note that mobility service operators risk losing brand identity as they are incorporated under the banner of the MaaS operator. This issue was further discussed by Vij and Dühr (2022) who argue that market actors are unlikely to integrate to the extent that many planners and politicians expect as it could undermine their profitability. With the potential decline of individual product identity, there is a risk of MaaS operators becoming monopolistic, reducing the ability of potential competitors (Vij and Dühr, 2022). Monopoly could also be an issue for transit authorities as private operators may overlook important sustainability or equity considerations in service unless regulated to do so (Alyavina et al., 2022).

Pangbourne et al. (2020) highlight those excluded from utilising MaaS due to cost, dissent or digital access and competence. Mobility centres and common call numbers have helped minimise this divide by allowing patrons to have their travel itinerary planned by transit operators at call centres. Patrons still have the ability to pay for transit under one umbrella, but lack the ability for updates post departure (Huwer, 2004). Smarts stops may alleviate the lack of updates by providing access to the call centre or provide a visual update of the user’s journey. Despite this, further consideration of how MaaS can be utilised by disadvantaged groups needs to be undertaken.

3.2.2. Vehicle to vehicle communication and real-time synchronisation

With the influx of real time information from technologies such as on-board sensors, cameras, radio-frequency identifiers (RFID) and GPS, transit planners have begun to evaluate the potential of significantly upgraded Intelligent Transport Systems (ITS's) in mid-tier transit (Cruz et al., 2018; Gkiotsalitis et al., 2022; Sumalee and Ho, 2018). There has been a growth in research that details the application of vehicle-to-vehicle (V2V) or vehicle to everything (V2X) communication to generate synchronised networks (Kiela et al., 2020; Liu et al., 2014; Seredynski and Viti, 2016). A synchronised transport network would allow vehicles, infrastructure and pedestrians to exchange information so that simulation management and control measures can be implemented in near real-time (Gkiotsalitis et al., 2022; Sumalee and Ho, 2018). The primary objective of a synchronised transport network is to make transfers in multi-modal systems as seamless as possible by implementing scheduling and other control measures that maintain time efficiency (Nesheli and Ceder, 2015). Control measures typically utilised include vehicle holding, stop skipping, speed control, short turning and re-routing (Gkiotsalitis et al., 2022; Nesheli et al., 2015). Traditionally, control measures applied in the operation phase are reactionary in nature, trying to mitigate the externalities of unexpected interruptions. However, with advances in computational power, and the detail of data collected, it is argued that transit operators can manage systems in near real-time (Gkiotsalitis et al., 2022; Nesheli and Ceder, 2015; Nesheli et al., 2015). A case study by Nesheli and Ceder (2015) revealed a 58% improvement in system performance compared to operations with no real-time management.

Real-time network synchronisation could prove to be a critical component in the operation of mid-tier transit corridors where multiple feeder modes are in play. Synchronising feeder vehicles to ensure transfers are timely and efficient may improve user travel times and overall satisfaction and, when integrated into mid-tier transit technology, should provide more reliable and timely journeys.

3.3. New urban processes

3.3.1. Partnerships and funding mechanisms

Mid-tier transit developed 130 years ago and thus the urban processes like partnerships and funding mechanisms have gone through many different iterations. One approach having a comeback is the important role of private sector partnership and funding in the development of mid-tier transit systems.

Publicly funded transit systems often fail to recover initial investments strictly from operating revenues (Li et al., 2022). Land Value Capture (LVC) is a funding mechanism that has been utilised as a means for transit authorities to recover a portion of their initial investment (Chi-Man Hui et al., 2004; Sharma and Newman, 2020) and is increasingly being seen as a major new approach that builds on the historic processes that built tram systems worldwide (Davies-Slate and Newman, 2018).

According to Mathur (2019, p. 357), the theory is predicated on the assumption that:

"People are willing to pay for amenities such as transportation accessibility, good schools, and clean neighbourhoods, and as such, the value of these amenities should get capitalised into the value of the land that supports such activities. Applied to the transportation planning field, this theory suggests that the accessibility provided by a transit system should increase the value of station-adjacent properties".

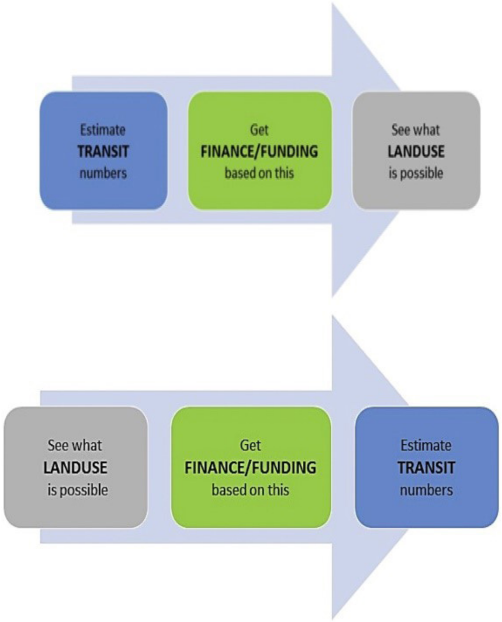
Therefore, the purpose of LVC is to calculate and capture a portion of the value generated as a result of transit developments (McIntosh et al., 2014). The exact premium that transit systems provide is dependent on variables such as transit technology, geospatial and socio-economic parameters, developer investment and adequate associated urban infrastructure (Li et al., 2022; Aveline-Dubach and Blandeau, 2019).

A case study of land value increases in East Asia indicates a 10% increase in distance from transit stations results in a 1% decrease in property values (Salon and Shewmake, 2011). Similar results were found in studies from Australia, Brazil, Hong Kong and Malaysia albeit with variations in estimated value uplift, consensus indicates that catchment areas surrounding precincts result in a net increase in property value (Bocarejo et al., 2013; Dziauddin, 2019; Li et al., 2022). McIntosh et al., (2014) showed a 20% increase in residential land value and 50% increase in commercial value along older rail lines in Perth and over 50% residential increases in residential value near stations on a new rail line, above any other socio-economic or spatial factors.

If estimations of land value increases are made without considering spatial and socio-economic factors then they may over-estimate LVC as a funding mechanism and thus be detrimental to project success (Li and Love, 2019; Li et al., 2022). This was displayed in the development of the Delhi Airport Express Rail Line, where LVC was expected to provide 70% of revenue, but could only capitalise on 6.4% of available retail space due to lower than expected ridership (Li and Love, 2019). On the other hand, Sharma and Newman (2020) showed that Hyderabad was able to fully utilise its private sector funding. The difference appeared to be the extent of the partnership between private and public perspectives.

There are two primary methods for extracting value from transit-oriented developments, a tax or fee-based method and a development-based option. The tax or fee method can employ a range of tools such as land taxes or betterment charges which extract surplus value from property owners and can be employed on an ongoing basis (Li et al., 2022; Mathur, 2019). Development-based value capture seeks to leverage the significant development potential of land surrounding transit precincts by either selling vacant land or fostering joint development partnerships where private developers will construct a number of station precincts (Li et al., 2022; Mathur, 2019). A highly successful example of Land Value Capture can be found in Hong Kong where 50% to 60% of the Mass Transit Railway Corporations (MTRC) revenue is extracted from Land Value Capture (Aveline-Dubach and Blandeau, 2019; Chi-Man Hui et al., 2004; Li and Love, 2022). The MTRC is a private for-profit entity that manages Hong Kong's rail network, but is majority owned by the government and therefore, has its risk significantly reduced (Li and Love, 2022; Sharma and Newman, 2020; Shen et al., 2006). Similar approaches were made in China's metro rail system.

The MTRC is a prominent example of the potential benefits of developing transport systems via a Public Private Partnership (PPP) in combination with LVC (Aveline-Dubach and Blandeau, 2019). Public Private Partnerships seek to harness the development and financial expertise of private developers to procure public services more efficiently (Ndlovu and Newman, 2021). For example, PPP could be utilised in MaaS development, where transit authorities are responsible for service provision and private developers take responsibility for the management of the MaaS platform (Polydoropoulou et al., 2020). Research by Currie and De Gruyter (2016) indicates that privately operated transit networks are significantly more efficient than those that are publicly operated as



Source: Newman, Davies-Slate, et al., 2018.

Figure 4. Welfare funding model compared to entrepreneurial land value creation model.

a result of their performance based contracts. Newman, Davies-Slate, et al. (2018) suggest a new practice for ensuring these partnerships are made with land development as a central focus, called the "Entrepreneur Rail Model" (ERM). It is seen to be a better means of procuring and delivering a rail or mid-tier transit system along with its integrated land development opportunities compared to a welfare model that only estimates land use possibilities after the transit has been completed, as in **Figure 4**.

The model of establishing funding and partnerships to drive mid-tier transit has begun to happen and is seen as an ideal way to make net zero corridors happen in cities in the developed and developing world (Ndlovu and Newman, 2021; Newman, Davies-Slate, et al., 2018).

The ERM effectively seeks to reduce public intervention in transit developments to a minimum, with the government utilising its place in the PPP to establish public good requirements such as quality design, integration of services, fares, and affordable housing, while reducing perceived risk for investors. Newman, Davies-Slate, et al. (2018) acknowledge that ERM would ultimately fail without adequate support from government in areas such as land acquisition, zoning regulations, urban design standards and network coherency. As such they recommend the creation of two government agencies that support and oversee the foundation of a market-oriented transit system. The first is a "Transit and Land Development Unit" which would oversee the bidding process for Entrepreneurial Rail Projects. Organisations such as this could be important in limiting the potential for "over-bidding" as displayed in the Delhi Airport Express Rail Line (2019). The second organisation would take a similar form to the MTRC as an organisation tasked with facilitating the planning, development, and delivery of ERM projects, especially mid-tier transit (Newman, Davies-Slate, and Jones, 2018).

A paper by Lawrie (2020) argues that ERM should be cautiously welcomed due to its potential to build more sustainable green fields at no cost to government. However, it raises a counterpoint that there may be a mismatch between what ERM deems as attractive real estate development and where transit services are most required, often where transit is poor in new suburbs without much value capture potential. Nonetheless, the literature suggests that mid-tier systems will increasingly rely on private expertise and Public Private Partnerships as funding and development mechanisms, especially where redevelopment is really needed, for example along main roads in middle suburbs Newton et al, 2022). Whether it be to the extent of the ERM or towards a Hong Kong style system should be determined on a case-by-case basis.

4. Conclusions

The review of the rationale for mid-tier transit systems indicates the potential for an extremely cost-effective mid-tier transit technology when the full benefits are considered, including its social, economic, and environmental benefits, and perhaps most critically the ability to help create regenerative cities including the new agenda of net zero cities.

The paper also reviewed how to improve the operation and support the adoption of mid-tier systems, finding several under-appreciated legacy features and funding frameworks in combination with new innovative technologies and urban processes.

An analysis of urban design features suggests that a new awareness of the value of high-density development in combination with improved access through dedicated pedestrian and micro-mobility infrastructure, elevates overall satisfaction with public transport services and hence patronage. The review expanded consideration of dedicated infrastructure to an analysis of the impact that stop amenities have on mid-tier operations, including that shelters, benches, adequate pavement, surveillance cameras and RTI are amenities that reduce wait time and safety perceptions, and are likely to significantly help with patronage.

Smart technologies, RTI and improved ITS, as well as mobile applications, smart stops, MaaS platforms and V2X communication that produces real-time synchronisation across transport modes, were also found to have the potential to positively impact the adoption and operation of mid-tier services.

The final factor reviewed in this paper was the potential of innovative urban processes that develop funding and development opportunities in ways that build on the legacy of mid-tier transit but are now creating new partnership approaches. This includes how land value capture is becoming a mechanism for funding mid-tier transit developments. Land development around stations is a critical part of this and literature is beginning to favour funding transit systems with partial or complete private funding to enable better integration of urban development. This is expanded by discussing how the growth in the Entrepreneurial Rail Model or a Public Private Partnership like Hong Kong's model is likely to provide more potential growth for mid-tier transit.

An approach to mid-tier transit that integrates all these established and new factors is likely to be much more successful than simply putting in a new set of vehicles or doing just a few of the innovations. Together they provide real potential for a successful addition to any city's transit system. However, there are always going to be trade-offs and compromises in any practical system so the need for a strategy that shows how short-term and long-term delivery of these established and new approaches to mid-tier transit, can eventually lead to a much more effective and sustainable city.

Finally, a reflection on how the politics of changing transport systems, especially public transport, is worthwhile. Transit systems are deeply conservative due to their large-scale infrastructure and intrinsically fixed operational systems. The Perth rail system was almost closed in the 1970's following the same decline pattern as the closure of trams in the 1950's and 60's across the world. This has been changed dramatically in Perth from a system in a death spiral to one with three times the length of rail and with ten times the patronage over a forty year period (Newman, 2021). The turn-around was described as coming from: "a combination of strong community-based political pressure, clear political leadership and a small group of technical rail specialists who have battled within the public sector to show that rail can perform in a world where constraints on automobile dependence must now be addressed" (Newman, 2021).

Our paper is motivated by the need for a similar transition to mid-tier transit, a reinvention of trams. Like many parts of the global economy, there is a need for a dramatic rate of change in terms of decarbonizing cities and this paper has shown that modern tram equivalents are needed as a major part of this transition. It will need to be much faster than the 40-year turn-around in Perth but will require the same combination of factors to drive it.

Conflict of interest

All authors declare no conflict of interest.

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