Entrepreneurial Transit and Urban Regeneration

The Entrepreneurial Rail Revival, Transit Activated Corridors and Trackless Trams

by

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A thesis submitted to Curtin University to fulfil the requirements for the degree of Doctor of Philosophy

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Author’s Declaration

I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution.

Sebastian Davies-Slate

31 December 2020

Statement of Contributors

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material, which has been accepted for the award of any other degree or diploma in any university.

This exegesis was solely written by myself, with the contained publications written with co-authors. Signed statements from each co-author relating to each publication are provided as appendices at the back of this thesis.

Abstract

This research investigates entrepreneurial approaches to transit development and emerging transit technologies, and their potential to regenerate cities, foster economic development, relieve pressure on public budgets and reduce our environmental impact.

A number of practical problems currently facing cities are addressed. These include: the imperative to regenerate cities and improve the urban fabric and quality of the urban environment; addressing traffic congestion; promoting economic development; improving human health through the built environment; and managing the environmental effects of motorised transportation.

The thesis by publication contains five papers with an Exegesis. The key research question it addresses is: "Under what circumstances can the Entrepreneurial Rail Model solve the problem of how cities can be regenerated and can this be re-invented with twenty-first century transit technology?"

Publication 1 explores the limitations of the conventional public transit delivery model, and proposes an alternative method of railway procurement titled the Entrepreneur Rail Model. Different models of private involvement in railway development are discussed and assessed, based on case studies from cities in a number of countries. These different case studies are categorised, according to the level of private participation. The concept of "value creation", as opposed to "value capture" is explored.

Publication 2 reviews the global private rail history, as well as some emerging models of entrepreneurial rail delivery, notably from Japan and Hong Kong and the nascent revival of private passenger rail in the United States. The paper develops a history of the structure of private rail delivery in Perth, Western Australia. In contemplating the revival of such delivery models, the paper discusses City Deals as a potential mechanism for mimicking historical governance and regulatory structures, taking account of the current reality of heavy government involvement in transit provision.

Publication 3 examines the emerging technology of Trackless Trams, including an overview of the potential of the technology itself, and an assessment of how it could operate in cities in both the developed and developing world. Trackless Trams are defined as a bundle of 21st century technologies for an on-road vehicle, which it is proposed can deliver the benefits of light rail transit in a way that bus-based transit systems cannot. Two case studies are assessed: Perth, Western Australia, as a developed world case study, and Thimphu, Bhutan, as a developing world case study. The paper also provides an overview comparison of the capabilities of Trackless Trams, Light Rail and Bus Rapid Transit systems.

Publication 4 extends the concept of transit-oriented development, exploring the potential of transit activated corridors with the Entrepreneur Rail Model, and expanding on the principles of entrepreneurship. Transit Activated Corridors (TACs) are a linear series of walkable TODs, joined up with quality corridor transit. The paper assesses the capacity of a Trackless Tram System to deliver TACs, with this new technology arguably having advantages over light rail, as the lower cost and risk brings it within the scope of smaller and more local parties, and there is less intrusion from infrastructure into the urban fabric. The paper extends the three principles of entrepreneurship with two new urban planning principles, to make five design principles for delivering a TAC.

In Publication 5 the potential for Trackless Trams to shape urban form of Australian cities is examined. The paper documents the history of the development of Trackless Trams, and its potential to generate Transit Activated Corridors and reduce car dependence. Informed by the Theory of Urban Fabrics and case study projects in four Australian cities, the paper explores how this new technology can assist urban regeneration in automobile, transit and walking urban fabric. The paper also develops emergent principles for urban regeneration in the precincts that are to be created around Trackless Tram stations.

The thesis is drawn together in the Exegesis to show how the primary question has been answered and what further work is needed.

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Finally, I acknowledge my parents and my wife Jenny, who have provided unfailing patience and support throughout this long process.

Dedication

I dedicate this thesis to my parents, Stuart and Margaret Davies-Slate. who enthusiastically supported my decision to undertake this study right from the start.

Publications submitted as part of this thesis

Publication 1

Newman, P., Davies-Slate, S., and Jones, E. (2017a) The Entrepreneur Rail Model: Funding urban rail through majority private investment in urban regeneration. Research in Transportation Economics. Volume 67, May 2018, Pages 19-28. DOI: http://dx.doi.org/10.1016/j.retrec.2017.04.005

Publication 2

Davies-Slate, S. and Newman, P. (2018) Partnerships for Private Transit Investment – The History and Practice of Private Transit Infrastructure with a Case Study in Perth, Australia. Urban Science, 2(3), 84-104, https://doi.org/10.3390/urbansci2030084

Publication 3

Newman, P. , Hargroves, K. , Davies-Slate, S. , Conley, D. , Verschuer, M. , Mouritz, M. and Yangka, D. (2019) The Trackless Tram: Is It the Transit and City Shaping Catalyst We Have Been Waiting for? Journal of Transportation Technologies, 9, 31-55. http://doi.org/10.4236/jtts.2019.91003

Publication 4

Newman, P.; Davies-Slate, S., Conley, D., Hargroves, K. and Mourtiz, M. (2021) From TOD to TAC: The Transport Policy Shift to Transit Activated Corridors along Main Roads with New Technology Transit Systems. Urban Science, 5, 52. https://doi.org/10.3390/urbansci5030052

Publication 5

Newman, P., Mouritz, M., Verschuer, M., Davies-Slate, S., Caldera, S., Desha, C. and Reid, S. (2019) Trackless Trams and Australian Urban Fabric. State of Australian Cities Conference, 3-5 December 2019, Perth, Australia.

Other relevant publications (not submitted as part of this thesis)

Publication 6

Newman, P., Davies-Slate, S., Green, J., and Jones, E. (2016) The Entrepreneur Rail Model [Discussion Paper]. Perth: Curtin University Sustainability Policy (CUSP) Institute. Available at: http://www.curtin.edu.au/research/cusp/local/docs/Rail_Model-_Report.pdf

Publication 7

Newman, P., Mouritz, M., Davies-Slate, S., Jones, E., Hargroves, K., Sharma, R. and Adams, D. (2018) Delivering Integrated Transit, Land Development and Finance – a Guide and Manual: with Application to Trackless Trams. Sustainable Built Environment National Research Centre (SBEnrc), Australia.

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Chapter 1 Introduction

This research investigates entrepreneurial approaches to transit development and emerging transit technologies, and their potential to regenerate cities, foster economic development, relieve pressure on public budgets and reduce our environmental impact. This is in contrast to the conventional approach in much of the world, in which government agencies centrally plan land development and large-scale transport networks, with transit often delivered in part as a form of welfare whilst freely providing new urban housing and urban services which are completely car dependent.

This approach can be particularly powerful when combined with appropriate use of emerging transport technologies, such as electric traction, vehicle autonomy and micro-mobility.

Such matters are the subject of this thesis by publication. The Introduction will set out the research context, the five aims that structure the thesis and the significance of the work. This will be followed by chapters that cover the Methods, an Overview of Publications (the actual publications are in an Appendix), a Discussion of three key ideas, and a Conclusion and Recommended Further Work.

1.1 Research context

There has been renewed interest in railways in recent years worldwide (Altshuler and Luberoff, 2004). Cities in the developed world have begun investing in railways again, and taking a renewed interest in improving their transit systems, often after decades of neglect and decline. In the developed and developing world, many cities and national governments are pursuing their ambitions to develop railways, and with that, develop their economies (Murakami and Cervero, 2017; Newman and Kenworthy, 2015). This railway renaissance has been dubbed the “Second Rail Revolution” (Newman, Glazebrook and Kenworthy, 2013). There are several plausible contributing factors to this return to rail.

First, traffic speeds are slowing, while railways are improving, with greater speed and increased coverage. The average speed of travel by rail has been steadily increasing compared with the general traffic speed in cities around the world. In much of the world, rail is already notably faster than travel by road (see Table 1).

	1960	**1970**	**1980**	**1990**	**1995**	**2005**
Ratio of overall public transit system speed to road speed						
American cities	0.46	0.48	0.55	0.50	0.55	0.54
Canadian cities	0.54	0.54	0.52	0.58	0.56	0.55
Australian cities	0.56	0.56	0.63	0.64	0.75	0.75
European cities	0.72	0.70	0.82	0.91	0.81	0.90

	1960	1970	1980	1990	1995	2005
Asian cities	–	0.77	0.84	0.79	0.86	0.86
Global average for all cities	*0.55*	*0.58*	*0.66*	*0.66*	*0.71*	*0.70*
Ratio of overall metro/suburban rail speed to road speed						
American cities	–	0.93	0.99	0.89	0.96	0.95
Canadian cities	–	–	0.73	0.92	0.85	0.89
Australian cities	0.72	0.68	0.89	0.81	1.06	1.08
European cities	1.07	0.80	1.22	1.25	1.15	1.28
Asian cities	–	1.40	1.53	1.60	1.54	1.52
Global average for all cities	*0.88*	*1.05*	*1.07*	*1.11*	*1.12*	*1.13*

Table 1: Comparative travel speeds in global cities by mode.
Source: Newman and Kenworthy, 2015. The ratio of overall public transit speeds and metro/suburban rail speeds to road speeds are calculated individually for each city, and then averaged for each country. The road speeds of cities that do not have these transit systems are therefore not included.

Second, mass transit can promote economic development, by enabling dense, concentrated land uses, which have been shown to raise productivity and land values (Bannister and Berechman, 2001; Weisbrod, 2008; Chatman and Noland, 2011). This phenomenon is known as agglomeration economies, and has been observed in cities around the world, including in the car-dependent cities of Australia (Trubka, 2011; SGS Economics and Planning, 2012; Center for Transit-Oriented Development, 2009) and the United States (Glaeser, 2011), as well as Asia (Suzuki et al, 2015; Li and Gibson, 2015; Lopez-Acevedo, et al. 2017) and Europe (Combes et al. 2008; Melo and Graham 2009). The productivity benefits associated with larger and denser cities is particularly marked in knowledge-intensive industries (Trubka, 2011), and has been noted in the economic literature as far back as Marshall (1890). Car-based planning, including its restrictions on development density, reduces productivity by limiting the development of dense agglomerations, as well as consuming excess resources and distorting urban transport markets (Litman, 2014b). The high speed and capacity of rail, enables large numbers of workers to concentrate together, increasing the competitiveness of knowledge industries through agglomeration economies (Murukami and Cervero, 2017).

These dense agglomerations, developed as transit-oriented developments, can greatly increase accessibility within a city (Bannister and Berechman, 2001), including for disadvantaged citizens. The focus of transportation planning is has begun to shift, from a focus on automobile travel time and reliability, to a broader consideration of accessibility (Litman, 2013). Conventional planning practice equating accessibility to savings in the time or cost of travel will not fully capture the accessibility benefits of a particular intervention (Yan, 2021).

A body of knowledge has been developed around best practice transit-oriented development design, such as the World Bank's 3 Value Framework, which considers a TOD's the transport node, place and land value potential, as in (Salat and Ollivier, 2017), and its five-step TOD Framework (World Bank, 2018). Further to this, transport project appraisal models provide insight into the economic benefits of transit infrastructure (for example models developed for the New Zealand context in Allison et al. 2013 and Wallis et al. 2013).

Third, the link between transport patterns and greenhouse gas emissions is increasingly clear, and air pollution more generally. Greenhouse gas emissions per kilometre travelled are lower on mass transit modes than in private cars (Newman and Kenworthy, 2015b).

While many city and national governments aspire to deliver more railways as a tool of urban regeneration and economic development, it is difficult to fund and deliver this expensive infrastructure. Railways were developed in the United Kingdom by the private sector in the Nineteenth Century (Levinson, 2008), but after a period of explosive growth, were progressively regulated and eventually nationalised in most parts of the world. Central planning and taxpayer funding has become the dominant mode of delivering railways around the world since that time. However, many of the cities where transit has been most successful and prolifically delivered retained the old model of commercial and entrepreneurial railways, particularly in Japan (Cervero, 1994; Mathur and Smith 2013). These cities have greater private involvement in transit planning and delivery, or else publicly-owned companies that delivered railways on commercial principles and as part of larger development projects. The entrepreneurial approach to railways is at the core of this research.

Transit, economic development and urban regeneration are objectives of national governments, as well as city leaders, and there are various means by which national governments can encourage and support what is generally a local endeavour. The private sector role can be seen as stimulating property development and investment (Adair et al. 2000).

National governments have experimented with various means to support private involvement in transit planning, including for the London Crossrail project in the United Kingdom, the Government of India's (2017) Metro Rail Policy, and City Deals in Australia. All of these policies attempt to align the actions of multiple levels of government, private industry and the broader community.

In addition to the high capital cost of rail, another barrier is the high risk in planning and delivering the infrastructure. Flyvberg (2007) estimates an average cost escalation of approximately 45% from a sample of 44 urban rail projects. To make matters worse, ridership was on average 37.5% lower than forecast from 24 of these projects, and if two projects in Germany are excluded from this smaller sample, the shortfall jumps to 50.8%, In Australia, the troubled George Street Light Rail project in Sydney casts a long shadow. This light rail project has experienced significant delays and substantial cost overruns, at least partly due to the discovery of inadequately mapped underground water and electrical services beneath the alignment. The light rail ended up costing A$185 million per kilometre. Such problems would most likely fail a fully commercial project, and a reluctance to commit by private operators and financiers would be understandable.

Buses are often seen as a lower-cost alternative to railways, and viewed as able to perform the task of a railway, only cheaper. For example, the Australian Bus Industry Confederation (2014) claims that:

> "BRT offers cost effective, environmentally beneficial and high performance mass transit where population density often does not justify the construction of costly fixed rail systems and the need for greater flexibility in route mapping is better served by wheel-to-road transport systems."

Looking at the transport task alone, it is true that bus-based transit systems can be made to move large numbers of passengers along their alignments. Particular standouts are the Bus Rapid Transit (BRT) pioneered in Curitiba, Brazil, the busways in Brisbane, Australia, and the Transmillenio system in Bogota, Colombia. A number of high-capacity systems have also been developed in Brazil (BRT Centre of Excellence, 2020).

However, this view of bus-based systems views the transport task in isolation of the wider urban context, and the effects of the system on urban regeneration, economic development, the local environment and air pollution. Bus-based systems are lower in capacity than rail, require more space if built to a high specification (Brisbane's busways resemble small freeways), provide a less comfortable ride, due to vibrations and lurching, generally have a poorer image among the travelling public, and are usually powered by internal combustion engines, which emit greenhouse gases, toxic exhaust and engine noise. By contrast, rail transit uses electrically-powered, physically supported vehicles, which can be easily coupled for a high passenger capacity per vehicle (Vuchic, 2005). This is reflected in the effects of these transit systems on surrounding land values. Railways, both light and heavy rail, have been observed to substantially increase land values near their stations. This phenomenon has been observed in numerous studies in cities around the world, including in car-dependent cities in the United States and Australia. The evidence on bus-based systems shows that there is some value effect, but of a lesser magnitude than the value creation associated with rail (see Zhang and Yen, 2020, for a recent meta-analysis of this substantial body of research) . Urban regeneration, with increased land values and development opportunities are at the core of commercial railway development. Development returns around stations can be very high over the long term, and there social equity benefits to developing services and affordable housing in such accessible locations (Litman, 2014a)

The emerging technology of Trackless Trams is seen as a potential third way for transit provision. These vehicles mimic many of the qualities of light rail, with ride quality improved by a combination of rail-inspired bogeys, electric motors, vehicle autonomy (driver assist) and exclusive rights of way providing a similar ride quality to a light rail, but without the cost, risk and disruption of physically installing rails into the road bed. These a Twenty-First Century characteristics should not be feared as they may offer a new way of creating solutions to how transit can be provided in a Twenty-First Century cities (Cohen and Jones, 2020).

The big issue is how to get more rail (or rail-like vehicles) into cities without the historically huge cost and disruption, making the most of 21st century smart technologies, and with partnerships that facilitate the agglomerations and value outcomes associated with such infrastructure. Perhaps a Twenty-First Century version of the entrepreneurial rail approach could provide the solution.

1.1 Research aims

This key question this research addresses is:

"Under what circumstances can the Entrepreneurial Rail Model solve the problem of how cities can be regenerated, and can this be re-invented with Twenty-First Century transit technology?"

This question is answered by drawing on a wide range of global case study projects, including historical examples of railway and streetcar development, government policies, contemporary funding models and emerging technology. It draws on principles of urban planning, land economics and transport planning. The key theoretical basis for this research is the Theory of Urban Fabrics and Entrepreneurship Theory. The question is therefore broken down into a series of sub-questions with each having a publication providing the major answers.

Sub-question 1: What roles can the private sector play in alternative funding models for transit infrastructure and urban regeneration?

This initial part of the research examines the problems of transport infrastructure being publicly planned, funded and delivered, including a funding gap and unmet demand, high costs and reduced transport-land use integration. There is a need to re-assess the concept of value capture, which has generated a lot of academic and policy discussion, but has had limited examples of successful implementation.

This sub-question is addressed in Publication 1: "*The Entrepreneur Rail Model: Funding urban rail through majority private investment in urban regeneration*" in the journal *Research in Transportation Economics.*

Sub-question 2: How was the private sector involved in rail funding historically? A survey of the global history, and the private rail history in Western Australia as a case study.

Railways had historically been delivered wholly or substantially by the private sector, and in that sense the Entrepreneur Rail Model proposed as part of the first sub-question is not new. The second sub-question sought to develop a global overview of private involvement in railways and some of the different institutional arrangements.

This part of the research examined the existing literature and historical record of private rail projects throughout history, those contemporary commercial passenger rail projects that have survived into the current day, and new models which are emerging in various parts of the world.

This sub-question is addressed in Publication 2: "*Partnerships for Private Transit Investment—The History and Practice of Private Transit Infrastructure with a Case Study in Perth, Australia*" in the journal *Urban Science.*

Sub-question 3: What is the future of Trackless Trams, how does it compare with light rail, and how can it be deployed in cities?

While there is clear potential value creation from the Entrepreneur Rail Model, there is still a sense of risk aversion among potential private proponents of a transit and real estate development project. In particular, the substantial cost of retrofitting either a light rail or heavy rail into a heavily regulated, developed-world city is a major barrier, and presents substantial risk to a commercial proponent. There is a need for a lower cost solution to entrepreneurial transit provision. For this sub-question, the emerging technology of Trackless Trams is investigated. The technical aspects of a Trackless Tram System are analysed along with its a Twenty-First Century smart technologies, and its potential to enable urban regeneration along corridors.

This sub-question is examined in Publication 3: "*The Trackless Tram: Is It the Transit and City Shaping Catalyst We Have Been Waiting for?*" in the *Journal of Transportation Technologies*.

Sub-question 4: How can cities be regenerated using Transit Activated Corridors; can private financing and entrepreneurship be enabled to deliver Transit Activated Corridors?

The concept of transit-oriented development (TOD) has become mainstream in planning theory and policy contexts, but similar to value capture, has had a patchy record of implementation. This sub-question expands the concept of TOD, learning from the entrepreneurial rail history and assessing Entrepreneurship Theory to explore how cities can be regenerated along corridors of TODs, linked by high-capacity transit.

This part of the research is addressed in Publication 4: "*From TOD to TAC: The Transport Policy Shift to Transit Activated Corridors along Main Roads with New Technology Transit Systems.*" in *Urban Science*.

Sub-question 5: How can Trackless Trams be used to regenerate Australian cities?

Trackless Trams have gained growing attention from around the world and have been readily accepted as the solution to many cities' transport and urban development requirements. The value of transit and walking urban fabrics is increasingly being recognised, for their potential for economic development, a lighter environmental footprint and a healthier environment for people. This research examines the development of Trackless Tram technology, drawing from field trips, prior studies and trials that are currently being developed, and the ways this technology could be applied to Australian cities, assessed through the Theory of Urban Fabrics.

This work is presented in a refereed Conference Paper 1: "*Trackless Trams and Australian Urban Fabric*", presented at the State of Australian Cities Conference 2019, in Perth, Western Australia.

1.2 Structure of the thesis

The thesis is structured as five academic publications, with this exegesis providing a summary and context for the research.

The exegesis is structured as follows:

- Chapter 1is the introduction, providing research context.
- Chapter 2 is an explanation of the research design and methods
- Chapter 3 is a summary overview of the academic publications

- Chapter 4 is a summary discussion of the results from the publications.
- Finally, Chapter 5 provides concluding remarks and recommendations for further research.

The five publications are appended to the end of the thesis, following the consolidated reference list. They are summarised here briefly to provide a sense of how the thesis hangs together and will be explained in more detail in Chapter 3 after setting out the methodology of the research.

Publication 1 explores the limitations of the conventional public transit delivery model and proposes an alternative method of railway procurement, titled the Entrepreneur Rail Model. Different models of private involvement in railway development are discussed and assessed, based on case studies from cities in a number of countries. These different case studies are categorised, according to the level of private participation and urban regeneration potential. The concept of "value creation", as opposed to "value capture" is explored.

Publication 2 reviews the global entrepreneurial rail history, as well as some current models, notably from Japan and Hong Kong and the nascent revival of private passenger rail in the United States. The paper develops a history of private rail delivery in Perth, Western Australia. Publication 2 draws from a number of historical documents, including contemporary government correspondence, advertising material and parliamentary debates. This history includes a case study of the private rail history in Western Australia, examining two land grant railways and a private tramway network. Also explored are some mechanisms for reviving such models, including the recent governance innovation of City Deals.

In contemplating the revival of such delivery models, the paper discusses City Deals as a potential mechanism for mimicking historical governance and regulatory structures, taking account of the current reality of heavy government involvement in transit provision.

While the benefits of rail to cities are well established, the high cost of building quality urban rail still presents a barrier, particularly when retrofitting rail into constrained urban areas. In Publication 3, the emerging technology of Trackless Trams is examined, including an overview of the potential of the technology itself, and an assessment of how it could operate in cities in both the developed and developing world. Trackless Trams are defined as a bundle of Twenty-First Century technologies for an on-road vehicle, which it is proposed can deliver the benefits of Light Rail Transit in a way that bus-based transit systems cannot. Two case studies are assessed: Perth, Western Australia, as a developed world case study, and Thimphu, Bhutan, as a developing world case study. The paper also provides an overview comparison of the capabilities of Trackless Trams, Light Rail and Bus Rapid Transit systems.

Publication 4 extends the concept of transit-oriented development, exploring the potential of Transit Activated Corridors. Transit Activated Corridors (TACs) are a linear series of walkable TODs, joined up with quality corridor transit. The paper assesses the capacity of a Trackless Tram System to deliver TACs, with this new technology arguably having advantages over light rail, as the lower cost and risk brings it within the scope of smaller and more local parties, and there is less intrusion from infrastructure into the urban fabric. The paper extends the three principles of entrepreneurship (Sarasvathy, 2009) with two new urban planning principles, to make five design principles for delivering a TAC.

In Publication 5 the potential for Trackless Trams to shape urban form of Australian cities is examined. The paper documents the history of the development of Trackless Trams, and its potential to generate Transit Activated Corridors and reduce car dependence. Informed by the Theory of Urban Fabrics and case study projects in four Australian cities, the paper explores how this new technology can assist urban regeneration in automobile, transit and walking urban fabric. The paper also develops emergent principles for urban regeneration in the precincts that are to be created around Trackless Tram stations.

1.3 Significance of the research

Practical and Professional significance

This research addresses a number of problems or objectives facing cities:

Firstly, the imperative to regenerate cities, and improve the urban fabric and quality of the urban environment. This is taking place in the context of the “return to the city”, the revival in the inner areas of cities taking place around the world (Glaeser, 2011). The increasing importance of the knowledge economy, with its requirement for face-to-face interaction, drives demand for large, compact and walkable cities. This type of development increases productivity, a phenomenon known as agglomeration economies.

The second consideration is economic development. Railways are a path to economic development, as they lower the cost of travel and can support large agglomerations of activity. Railways can move large volumes of people in a constrained space, frequently delivering the capacity to transport the equivalent of 10, 20 or 30 lanes of freeway traffic (derived from Newman and Kenworthy, 2015).

Third, as economic development progresses, increasing priority is placed on the health effects of living in cities, and safety. The transport and urban fabric can affect human health in a number of ways, including through air pollution, imposed physical inactivity (and social isolation. As well as the human cost, this unnecessary damage to the population's health has financial and economic implications. Calthorpe and Walters (2016) found that between 1.5% and 3% of the cost of health care was due to sedentary lifestyles in developed world cities. Not only does inactivity raise the spending required for health care; there is also a productivity benefit accruing to cities where active transport is common. Similarly, Lyle (1996) found that higher rates of walking boosts GDP. Effective, electrically-powered transit reduces air pollution, increases regular walking and increases opportunities for unplanned social interaction, as well as reducing the rate of traffic accidents.

Finally, environmental effects. Exhaust fumes from vehicles powered by the internal combustion engine create local air and noise pollution, as well as emitting greenhouse gases, perhaps the biggest challenge facing cities into the future and which needs solutions to be started now (Newman, 2020a; 2020b). Further, traffic congestion – a perennial problem for cities – has grown to the point that general traffic is often out-paced by rail, as shown in Table 1. Addressing this will require continued investment in alternative modes of travel, the increased relative speed of transit relative to general traffic favours such modes.

Increased investment in quality transit and the regeneration of the urban fabric addresses these matters. This has traditionally meant investment in rail, which delivers the benefits outlined above, but is complex and expensive to deliver. The infrastructure is usually planned and delivered by the government in most parts of the world, although this was not always the case historically. Public railways generally fail to recover their full operating costs, much less the upfront costs of construction. When combined with the scarcity of public capital, it is difficult to provide the necessary rail infrastructure, creating a bottleneck in rail provision.

This research responds to the difficulty in funding urban rail and mitigating car dependence, addressing the problem both from the funding and cost perspectives. The proposed Entrepreneur Rail Model is a new source of funding, while also bringing the creativity of entrepreneurship and partnerships to rail provision and transit-oriented development. Trackless Trams promise to deliver the qualities of light rail (and perhaps even heavy rail if cities have no rail at all such as in the developing world) in ways that traditional bus transit systems cannot, but at a much lower cost than light rail, and with reduced construction risk and disruption. Also addressed are new planning paradigms for integrating these innovations into existing cities, through Transit Activated Corridors. These are all practical insights that are likely to be needed by professionals in cities as they prepare for the future.

Academic significance

As noted above, there have been studies on the potential economic benefits of rail, and the conditions under which economic development might be generated (Bannister and Berechman, 2001; Weisbrod, 2008; Chatman and Noland, 2011; Salat and Ollivier, 2017). The term "wider economic benefits" is in common use both in government project appraisal and in the academic literature (see, for example, Chen 2014; Wang et al. 2019).

This research should also be viewed in the context of increasing numbers of mega projects, and the complexity inherent in large-scale urban rail and development. Private involvement in large scale projects can bring benefits to both public and private sectors, although these projects are inherently risky, and the profit motivation may not align with the government's priorities for urban development (Fainstein, 2008). There has been a growing convergence in the practice of large-scale urban development projects in Europe and North America, in terms of the physical form of development and financing practices (Orueta and Fainstein, 2008).

There has to date been minimal research done on the role of the private sector, commercial enterprise and entrepreneurship in developing cities with transit and walking urban fabric in an integrated and creative way. There has been substantial research undertaken on the benefits to cities of transit, compact development and a reduction in car dependence (see for example, Newman and Kenworthy, 2015; Creutzig et al. 2012; Renne and Fields, 2013; Park et al. 2019). Also well researched are transit-oriented developments, including a considerable body of research on the characteristics of successful TODs and their benefits in terms of higher transit mode share, increased convenience, reduced car dependence and lower cost of living (Calthorpe, 1993; Renne et al. 2016, Curtis et al, 2017). There has been some research on various private transit systems, public-private partnerships (generally taken to mean alternative methods for governments to procure infrastructure from the private sector) and the effects of privatisation. This thesis explicitly considers the potential role of the private sector in delivering transit and urban regeneration.

But it also does it in a new way by considering Entrepreneurship Theory and Urban Fabric Theory. And it examines new Twenty-First Century transit technology that makes an entrepreneurial approach feasible and indeed effective and attractive as it demonstrates the public value of smart technologies (Cohen and Jones, 2020). It is this combination which makes the thesis to have academic significance. It combines understandings of how new technology can transform old transit systems, with understandings of planning based on reassessment of an old approach that integrates land development into rail funding, with new planning and entrepreneurship theories of how to make it happen in a world that is looking for such change.

Chapter 2 Methods

This research has drawn from case studies from several different countries, but with a particular focus on Australia, with a focus on Australian policy in Publications 2, 3 and 5.

Focussing on a particular jurisdiction has allowed for detailed examination of government policy and historical events. This research has also referenced conceptual models developed in recent research and proposed new conceptual models for the integration of land use and transport, and transit infrastructure procurement. The approach can be characterised as mixed methods. Specifically, these methods are: conceptual analysis and theoretical development; analysis of multiple case studies; industry investigation through field trip and desktop research; and numerical estimates of various proposed urban development benefits. The methods used are set out in more detail in Table 2 below.

The heavy reliance on case studies was appropriate for this research, for two reasons: firstly, there is a relatively small number of relevant projects, even on a global scale, limiting the potential for statistical or quantitative techniques; and secondly, limited surviving information on the historical case studies. For example, no financial records of the historical rail projects presented in this research were found to still be in existence.

Data was gathered for the case studies through the following techniques:

- Analysis of historical documents, including sales material, official communications and other government records;
- Policy analysis – a critical review of existing government policies, from national and sub-national governments;
- Desktop search for relevant projects globally; and
- Interviews with contemporary industry participants and others with detailed knowledge of the case studies. This included a field trip to China, to visit CRRC, the manufacturers of the first true Trackless Tram vehicles.

The case studies developed through primary research were also discussed in comparison with case studies from the existing literature, with a view to gaining new insights on the broader trends in rail development globally, developed as a coherent narrative. In addition to this, each publication referenced the findings from a substantial body of literature.

The methods used in this research are summarised in Table 2 and are further explained below for each publication.

Paper title	Research sub-question	Methods used
The Entrepreneur Rail Model: Funding urban rail through majority private investment in urban regeneration.	What roles can the private sector play in alternative funding models for transit infrastructure?	Development of conceptual model, to frame the remainder of the research.
Partnerships for Private Transit Investment – The History and Practice of Private Transit Infrastructure with a Case Study in Perth, Australia.	How was the private sector involved in rail funding historically? The private rail history in Western Australia as a case study.	Multiple case studies, with review of relevant contemporary policy.
The Trackless Tram: Is It the Transit and City Shaping Catalyst We Have Been Waiting for?	What is the future of the emerging technology of Trackless Trams, how does it compare with light rail, and how can it be deployed in cities?	Mixed methods: industry investigation through field trip and desktop research; case study cities; estimates of urban development benefits.
From TOD to TAC: The Transport Policy Shift to Transit Activated Corridors along Main Roads with New Technology Transit Systems	How can cities be regenerated using Transit Activated Corridors. How can private financing and entrepreneurship be enabled to deliver Transit Activated Corridors?	Mixed methods: combined theory (Theory of Urban Fabrics and Entrepreneurship Theory); Transit Activated Corridors concept proposed and principles developed.
Trackless Trams and Australian Urban Fabric.	How can Trackless Trams be used to regenerate Australian cities?	Mixed methods: urban regeneration principles, based on Theory of Urban Fabrics and case study projects.

Table 2: Summary of research methods

2.1 Conceptual Model – Publication 1

Publication 1 proposes a conceptual new model for planning and delivering transit, namely the Entrepreneur Rail Model. The paper proposes an alternative to the conventional process used by government planners, and urban rail delivered instead on commercial principles, and involving private sector land development and other complementary businesses.

This new approach is placed in the context of contemporary trends in transit usage and on the expansive scholarship on the effects of urban rail on land values in recent years.

Publication 1 provided a conceptual framework for the remainder of this research. It was based on literature reviews and some case studies but essentially built on the automobile dependence literature and data bases of Newman and Kenworthy (1989, 1999, 2015).

2.2 Multiple Case Studies – Publication 2

Publication 2 developed multiple case studies from the private rail history in Western Australia, being the early tramway network in Perth, Western Australia, and two private land grant railways, the Great Southern Railway and Mid-West Railway. The paper also reviews similar case studies internationally, drawn from a range of publicly available information found online, supplemented with prior literature.

Publication 2 makes use of a variety of historical documents in developing the case studies from late-Nineteenth and early-Twentieth Century Western Australia. Some of these records have been digitised, and desktop access was used whenever possible. Original documents were also accessed and scanned or copied, mostly from the J.S. Battye Library of West Australian History and the Western Australian State Records Office. Also referenced were the Acts of Parliament that authorised the construction of the tram and rail lines in question, and the Tramways Act (Western Australia) 1885, which provided the basis of the regulatory framework which governed the development of the tramways. The pieces of legislation relating to individual projects were valuable sources of information on the alignment of the lines, among other information.

The record of parliamentary debates (Hansard) archive on the Western Australian Parliament website was another major source of information. Hansard was the most complete source of information from the period in question, being a detailed record of parliamentary debates.

A number of other documents have been preserved by the Battye Library and the State Records Office. Documents found in these collections included government correspondence, including between state and local government, and advertising material from a residential development centred on a tramway, including sales posters and a brochure.

These local case studies were discussed in the context of the global entrepreneurial rail history. The publication drew some key lessons from the Western Australian case studies and examined the potential for the recent policy innovation of City Deals to mimic the historical governance and regulatory model that was successful during that period.

In addition to the case studies, Publication 2 reviewed contemporary policy developments in Australia, in particular the development of City Deals, as a means to co-ordinate the different tiers of government and the private sector.

2.3 Mixed Methods – Publications 3, 4 and 5

Publication 3 discusses the emerging technology of Trackless Trams and explores its potential use in two cities: Thimphu, Bhutan, and Perth, Western Australia.

Technical information on the Trackless Trams was gathered through correspondence, and in personal conversations during a visit by three members of the research team to the CRRC company in China and other Trackless Tram manufacturers in Europe, as part of this project. There was a large amount of data gathering of company information from a range of transit vehicle manufacturers. Most notably CRRC, whose Autonomous Rail Rapid Transit (ART) vehicle is considered the first complete example of Trackless Tram technology, were able to provide a lot of data when asked specific questions. Publication 3 was primarily based on this vehicle. Several of the co-authors for this publication visited CRRC's test track and other facilities in China in August 2018 and spoke with a number of company officers.

Aspects of this emerging transit technology that are addressed include the following:

- The operational systems, including guidance, electrical storage and charging
- Capacity
- Speed
- Cost-efficiency

In further developing the Trackless Tram case study, the paper draws conclusions on this technology's transport niche, comparing its capacity with other transport modes – cars travelling on regular streets, cars in a freeway lane, buses in traffic, Bus Rapid Transit, light rail and heavy rail.

Further investigation is warranted relating to some other aspects of Trackless Trams. The absence of physical fixed routes creates the potential for greater route flexibility and resilience in case of disruptions to the corridor, which would improve reliability. The requirement for exclusive use of a carriageway on a public road by this service also requires consideration.

Two case study cities were examined in this publication, as mentioned above, assessing the effects of building Trackless Trams. The Thimphu and Perth case studies considered the effects of Trackless Trams and associated urban corridors for a target increase in population. Both cities have grown rapidly in recent years, and the population targets used reflect contemporary planning horizons. Data on Perth was easily gathered as it has been well studied by the CUSP research group over many years. Thimphu in Bhutan was open to study (a rare opportunity in a relatively closed country) because one of the CUSP research team was asked to do a study there for the United Nations, and his report contained much of the findings from there (Hargroves and Gaudremeau, 2017). As well, Dorji Yanka from Bhutan was doing his PhD at CUSP and was able to provide any missing data.

The analysis centred on several aspects of the urban regeneration benefits that would accrue with the implementation of Trackless Trams. Like all forms of high-quality public transit implementing a Trackless Tram, with integrated development surrounding it, can bring many benefits to cities. These include:

- land savings, due to higher density development within the transit corridors, and from reduced parking requirements, due to increased capacity along the corridor as compared with general traffic;
- reduced traffic congestion;
- employment creation, due to the increased urban density;
- environmental benefits, including reduced energy consumption and air pollution, due to higher density and less car use;
- consumer savings;
- traffic safety benefits, due to a reduced per capita motor vehicle accident rate;
- improvements to public fitness and health;
- greater independence for non-drivers;
- increased economic opportunity and mobility for physically and economically disadvantaged people;
- improved neighbourhood liveability;
- and reduced sprawl-related costs.

The publication draws conclusions on the city-shaping potential of Trackless Trams, based on these findings. It is significant as it is one of the few papers taking Twenty-First Century transit technologies and suggesting that an emerging world city could leap-frog into using it.

Publication 4 develops the concept of Transit Activated Corridors (TACs), with on-road transit connecting a corridor of transit urban fabric and develops a set of five principles for delivering them.

These five principles are informed by two bodies of theory:

1. Urban Fabric Theory, as developed by Newman, Kosonen and Kenworthy (2015); and
2. The Theory of Entrepreneurship, particularly the principles of ‘effectuation’ pioneered by Sarasvathy (2009).

Another relevant theoretical concept would be Cervero’s (1998) four typologies of strong transit cities:

- Adaptive cities (Stockholm, Copenhagen, Tokyo and Singapore are given as case studies);
- Adaptive transit (Karlsruhe, Adelaide, Mexico City);
- Strong-core cities (Zurich and Melbourne); and
- Hybrids: cities with characteristics of both the adaptive city and adaptive transit model (Munich, Ottawa and Curitiba) are given as examples of hybrid cities.

The adaptive transit model involves an acceptance of sprawl and a decentralised city, with transit attempting to deliver a similar performance to the private car. This aligns well with the concept of transitioning major arterial roads into TACs.

Publication 4 also discusses Trackless Trams as an emerging technology that could catalyse Transit Activated Corridor development. The potential of Trackless Trams is compared with that of Bus Rapid Transit and Light Rail Transit, assessing each transit technology against the five TAC design principles.

The role of other emerging transport technologies is discussed in terms of the capacity to serve the Transit Activated Corridor form of development.

Publication 5 combines the Theory of Urban Fabrics as a conceptual framework, technical information on Trackless Tram technology and a number of case study projects in four Australian cities to develop principles for urban regeneration for different types of urban fabric.

Drawing on the same information from Publications 3 4, Publication 5 develops an indicative comparison of three medium-capacity transit technologies: Bus Rapid Transit, Light Rail Transit and Trackless Trams, and traces the technological development of Trackless Trams.

Urban Fabric Theory provides the conceptual model for analysing the effects of Trackless Trams on different types of city, and in particular, how the three types of urban fabric – walking, transit and automobile – can be regenerated in different ways but each requiring something like a Trackless Tram as catalyst. The paper proposes seven emergent principles for urban regeneration derived from a detailed literature review (Caldera et al, 2020), and applies these principles to the different types of urban fabric.

Publication 5 distinguishes between four types of urban fabric which came from detailed work undertaken with the Sustainable Built Environment National Research Centre, on case studies in four Australian cities: Townsville, Sydney, Melbourne and Perth. These four fabrics were: central city walking fabric; inner city transit fabric (historical tram/streetcar areas); infill transit fabric in middle suburban areas; and outer area automobile fabric. This Publication draws conclusions regarding specific issues that will need to be addressed in implementing Trackless Trams, with reference to the seven urban regeneration principles and the case study projects in the four cities. It was presented at a major Australian planner's conference and thus has a strong emphasis on the practice and professional approaches of planners.

2.4 Semi-structured interviews

In addition to the methods detailed above for the publications that make up this thesis, the overall direction of this research was informed by a number of informal discussions and semi-structured interviews. This included interviews and conversations with some figures from relevant industries such as real estate development or private bus operators, and current and former public sector officers.

The only of these interviews that was used as a reference in any of the publications was a personal communication with Cleary (2018) in Publication 2, who is leading the proposed CLARA project, one of the case study projects used in that paper.

Chapter 3 Overview of Publications

This chapter is an overview of the five publications included in this thesis, with the full papers provided in an appendix.

Paper title	Publication and status	Sub-question addressed
The Entrepreneur Rail Model: Funding urban rail through majority private investment in urban regeneration.	Research in Transportation Economics, Volume 67, May 2018, 19-28. doi.org/10.1016/j.retrec.2017.04.005. Published.	What roles can the private sector play in alternative funding models for transit infrastructure?
Partnerships for Private Transit Investment – The History and Practice of Private Transit Infrastructure with a Case Study in Perth, Australia.	Urban Science, 2(3), 84-104, doi.org/10.3390/urbansci2030084. Published.	How was the private sector involved in rail funding historically? The private rail history in Western Australia as a case study.
The Trackless Tram: Is It the Transit and City Shaping Catalyst We Have Been Waiting for?	Journal of Transportation Technologies, 9, 31-55. doi.org/10.4236/jtts.2019.91003. Published.	What is the future of the emerging technology of Trackless Trams, how does it compare with light rail, and how can it be deployed in cities?
From TOD to TAC: The Transport Policy Shift to Transit Activated Corridors along Main Roads with New Technology Transit Systems	Urban Science, 5, 52. https://doi.org/10.3390/urbansci5030052	How can cities be regenerated using Transit Activated Corridors. How can private financing and entrepreneurship be enabled to deliver Transit Activated Corridors?
Trackless Trams and Australian Urban Fabric.	State of Australian Cities Conference, 3-5 December 2019, Perth, Australia. Published	How can Trackless Trams be used to regenerate Australian cities?

Table 3: List of publications

3.1 Publication 1

Newman, P., Davies-Slate, S., and Jones, E. (2017b). The Entrepreneur Rail Model: Funding urban rail through majority private investment in urban regeneration. Research in Transportation Economics, 67, 19-28.

Publication 1 opens this body of research by proposing a change in the conventional model for planning, funding and delivering railways – the Entrepreneur Rail Model (ERM). The ERM is predicated on integrated land development as a source of funding, and the project being delivered by a private consortium with capacity in construction, railway operation, land development and finance. This contrasts with the conventional model in which railway projects are publicly funded and planned by a government department and funded through taxes.

The ERM reverses the conventional rail model, in which transit ridership numbers are estimated, funding is sought from public finances to deliver the project, and then land use is considered as an afterthought, if at all (see, for example, ATAP, 2017). Under the ERM, potential land use is considered first, and finance sought based on the potential redevelopment profits. Transit numbers are then estimated and an engineering solution to unlock this potential redevelopment. This distinction is illustrated in Figure 1 and Figure 2, below.

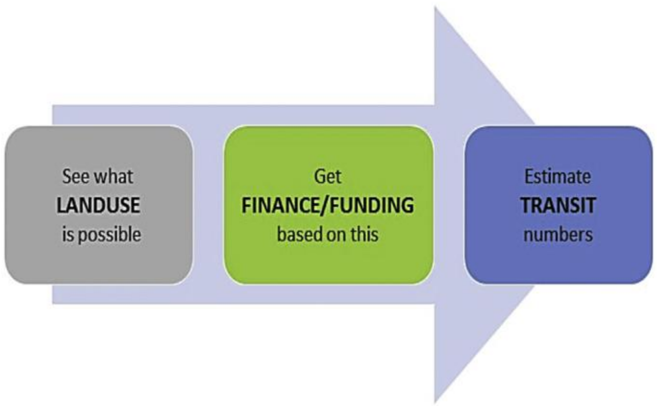

Figure 1: Graphical representation of the Entrepreneur Rail Model.
Source: Newman et al. 2015

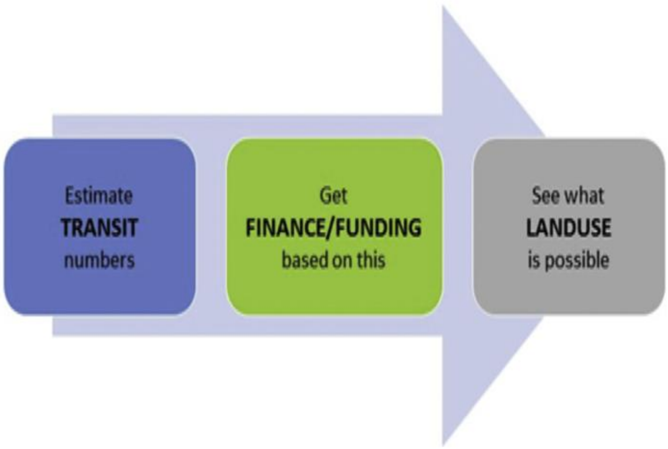

Figure 2: Graphical representation of the conventional rail model.
Source: Newman et al. 2015

Also in Publication 1, a range of contemporary case study rail projects are examined, which employ varying levels of private involvement. From these case studies, four potential options for funding and delivering the infrastructure are proposed:

- Full public sector capital;
- Some private and substantial public capital;
- Substantial private and some public capital; and
- Totally private capital.

It is proposed that the greater the level of private involvement, the greater the value created by the project, and this has been borne out by recent evidence from metro rail projects in India (Sharma and Newman, 2018a) and is expanded further in how this greater value is created (Sharma and Newman, 2020) building on a non-refereed book (referred to here as Publication 7).

Publication 1 concludes by identifying reforms needed to the current transport planning system, including new roles for town planners and transport planners, and proposes a potential delivery framework for an Entrepreneur Rail Model project. This sets the scene for the whole thesis.

3.2 Publication 2

Davies-Slate, S. and Newman, P. (2018) Partnerships for Private Transit Investment – The History and Practice of Private Transit Infrastructure with a Case Study in Perth, Australia. Urban Science, 2(3), 84-104, doi:10.3390/urbansci2030084.

Continuing from the first publication, Publication 2 investigates the history of the entrepreneurial approach to railway building proposed in Publication 1. Publication 2 surveys the historical record globally, and presents a detailed new case study: the Nineteenth Century entrepreneurial rail history in Perth, Western Australia. The Perth history includes a tramway (street car) company, engaged in suburban expansion, and two land grant railways, which were used as an instrument of the colonial government's policy of expanding agricultural production in Western Australia, as a form of economic development.

Interestingly, the operations of the tramway company were reminiscent of the "land readjustment" model practiced by the Japanese suburban private rail companies in recent decades (Suzuki et al. 2015). Residents of the then semi-rural Victoria Park locality were made an offer for the company to build and operate a tramway in return for a land concession equal to one-tenth of the area of the large land estates in the district. This offer was refused and a modified project was later allowed. The project demonstrates that sophisticated land and transit deals were being considered even in remote colonial areas like late Nineteenth Century Western Australia. The entrepreneurial rail model was alive and well across the world in this period.

Publication 2 includes a description of the regulatory framework under which this development took place, and this could guide the governance of a revived entrepreneurial rail model in the Twenty-First Century. In this case, an Act of Parliament provided a standard process for a private or municipally-led tramway project to be developed. Under this system, the proponent applied to the Commissioner of Railways (a political position, rather than bureaucratic; what would now be called a Minister of Railways, or similar). The Commissioner, once satisfied that all particulars were in order, would grant an approval known as a Provisional Order. This Provisional Order would then require ratification by Parliament to come into force and finally authorise the tramway.

Of the private tramway projects, the most interesting case study was the Nedlands Park Tramway Estate. This development resulted from a partnership between a large landowner on the outskirts of the city and the tramway company. The 240-hectare site was divided into 800 residential lots, and a hotel, tea rooms and public baths built at the far end of the line, to attract both fare-paying visitors and prospective homebuyers. This closely resembles the process followed on a much larger scale by the Japanese railway conglomerates, as recounted by Cervero (1994), and the Boston street cars (Warner, 1963), among many others. A sales poster from Nedlands Park is reproduced in Figure 3.

Of particular interest, the project began with an agreement between the tramway company and the relevant local governments (the project ran along the boundary of two local authorities). This was the case with all the private tramways in Western Australia, a contrast with contemporary Australia, where transit is almost exclusively the business of state and federal governments.

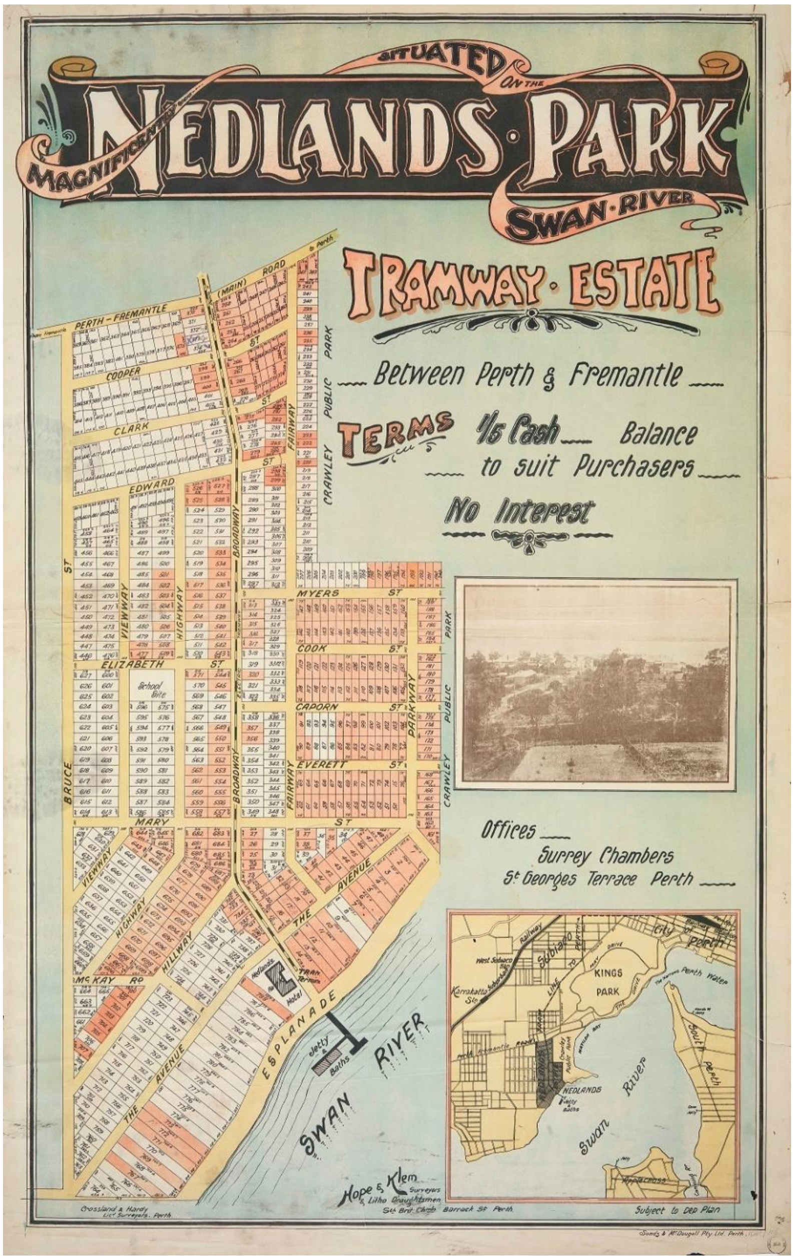

Figure 3: Sales poster for the Nedlands Park Tramway Estate, Western Australia
Source: J.S. Battye Library.

Publication 2 finishes by discussing the potential for the emerging governance tool of City Deals to mimic the historical governance models that regulated the old tramways.

3.3 Publication 3

Newman, P., Hargroves, K., Davies-Slate, S., Conley, D., Verschuer, M., Mouritz, M. and Yangka, D. (2018). The Trackless Tram: Is It the Transit and City Shaping Catalyst We Have Been Waiting for? Journal of Transportation Technologies, 9(1), 31-55.

Informal discussions with industry on the Entrepreneur Rail Model led to the conclusion that infrastructure cost, risk and disruption were barriers to the proposed model being realised in practice. Publication 3 documents the emerging technology of Trackless Trams, and considers its potential impact on two cities, one from the developed world and one from the developing world.

Figure 4: The Trackless Tram System developed by CRRC and demonstrated in Zhuzhou, China.
Source: CRRC Corporation.

This technological progression has been made most clear by developments at the Chinese railway-building state owned enterprise, CRRC. CRRC have developed a vehicle which draws a number of innovations from the high-speed rail program into a rubber-tyred vehicle, which has been titled the Autonomous Rail Rapid Transit System, or ART. There are four key innovations brought together in this vehicle, which sets it apart from a conventional bus-based system such as bus rapid transit, and also from light rail:

- It uses electric power, with on-board batteries that use rapid recharging technology at the stations. This reduces vibrations, eliminates the need for overhead catenaries, reduces vehicle noise and does not produce local emissions.
- It runs on rubber tyres, instead of steel wheels on steel rails, eliminating the need for on-road tracks to be laid, and thereby reducing capital cost.
- Train-style bogeys, low-set axles and hydraulic systems provide stabilisation, preventing the vehicle swaying and bouncing through a sophisticated sensor system that 'reads the road ahead'.
- Finally, the vehicle autonomously drives, under supervision, using optical guidance and GPS. This also contributes to a smoother ride, and allows for precision entry into stations, speeding their entry and facilitating boarding and alighting. This system can be over-ridden by the operator when required.

The new technologies provide better ride quality, quieter vehicles and comparable capacity to light rail, due to longer vehicles and the potential to couple multiple vehicles using their autonomous driving technology. Estimates of patronage capacity are shown in Table 4, below. It follows a fixed route, providing the certainty required by property developers. In addition, Trackless Trams have the advantage of lower infrastructure costs and less disruption, with modular stations able to be manufactured off-site, and installed very quickly. Because of these advantages, it is arguably a superior technology to light rail.

Transport mode	**Average Passengers per hour per lane per km**	**Multiples of car capacity in a suburban street**
Car in suburban street	1,000	1
Car in freeway lane	2,500	2.5
Bus in traffic	5,000	5
Bus in freeway lane (BRT)	10,000	10
Trackless Tram (or Light Rail)	20,000	20
Heavy Rail	50,000	50

Table 4: Estimations of average patronage capacity for various transport modes. Source: Compiled from Newman and Kenworthy.

Source: Newman and Kenworthy (1989; 2015). Compiled in Publication 3.

The paper explores the transport niche and city-shaping role for Trackless Trams, concluding that it can perform a comparable role to light rail. It considers two case study cities: Perth, Western Australia and Thimphu, Bhutan.

Publication 3 also compares Trackless Trams with Bus Rapid Transit and Light Rail Transit technologies, with a summary of these findings shown in Table 5.

Characteristic	**Bus Rapid Transit (BRT)**	**Light Rail Transit (LRT)**	**Trackless Tram System (TTS)**
Speed and capacity	✓	✓✓	✓✓✓
Ride quality	×	✓✓	✓✓
Land development potential	×	✓✓	✓✓
Cost	✓	×	✓
Disruption during construction	✓	×	✓✓
Implementation time	✓	✓✓	✓
Total	✓	✓✓	✓✓✓

Table 5: Indicative comparison of characteristics of corridor based urban rapid transit systems.

Source: Reproduced from Publication 3.

One limitation to the widespread adoption of Trackless Trams is that the vehicle has only been developed to fully meet the concept outlined in Publication 3 by one supplier worldwide. This creates the risk of dependence on a single supplier, which is likely to reduce the attractiveness of this technology to governments or other organisations seeking to operate transit. Further, as this supplier, CRRC is a state-owned firm from China, there are further risks relating to foreign investment and technological reliance. Publication 3 discussed Perth, Australia as one case study. Introducing the CRRC vehicles to any Australian city would now face the risk of approval not being granted by the Australian Government, particularly in light of its recent decision to ban the Chinese-owned Huawei from Australia’s 5G telecommunications network.

A further potential limitation on the deployment of Trackless Trams, compared with alternative modes, is the inherent limitations of on-road transit. Vuchic (2005) defines three classes of transit right-of-way:

- C – street with mixed traffic;
- B – partially separated; and
- A – fully separated.

Trackless Trams would fit into category B, similar to an on-road LRT system.

Right-of -way category B services have considerable advantages over category A, including greater speed and reliability, and the ability to operate multiples carriages on a single transit vehicle. However, their performance is still inferior compared with right-of-way A services (fully grade-separated, exclusive right-of-way). The advantage over a full grade separation is lower cost and less intrusive structures in the urban environment. (Ibid.) The most appropriate transit mode will require a trade-off between the available cost, the required level of service (speed, reliability and passenger volumes) and the particular constraints of the urban environment.

3.4 Publication 4

Newman, P.; Davies-Slate, S., Conley, D., Hargroves, K. and Mourtiz, M. (2021) From TOD to TAC: The Transport Policy Shift to Transit Activated Corridors along Main Roads with New Technology Transit Systems. Urban Science, 5, 52. https://doi.org/10.3390/urbansci5030052

Publication 4 expanded on the Entrepreneur Rail Model developed in Publication 1, incorporating transit-oriented development with the principles of entrepreneurship and the Theory of Urban Fabrics. The paper introduces the concept of Transit Activated Corridors, a series of walking city fabric centres, linked by high quality corridor transit. It explores how Transit Activated Corridors can be mainstreamed in the planning process.

Transit-oriented development is a concept that has gained widespread acceptance in urban planning theory since the concept was proposed by Calthorpe (1993). However, the revival of rail transit construction in the early part of the Twenty-First Century did not always result in TODs being effectively developed, as the institutional mindset that had developed around transport delivery was not conducive to this style of development. Transit-oriented development was often viewed as an optional extra, and de-prioritised in favour of station area car parking. Publication 4 argues that "transit-adjacent development", as opposed to successful transit-*oriented* development, is inevitable if funded entirely by government, and suggests a re-invention of the historic approach to building transit as a partnership with the private sector through land development.

The paper develops five principles for developing Transit Activated Corridors: three derived from the principles of entrepreneurship, or effectuation, as developed by Sarasvathy (2009), and two drawn from urban planning:

- Principle 1: Create partnerships from the start
  Bringing together a group of stakeholders at the beginning reduces risk and uncertainty by creating a co-developed vision for the undertaking. Strong partnerships also tend to increase commitment to the project by affected stakeholders. In the context of an Entrepreneur Rail Model or Transit Activated Corridors project, this would involve a partnership of local community, landowners, the local authority and financiers.
  As a tool for creating such partnerships, City Deals require agreement between multiple tiers of government, greater community involvement in a project and involvement by the private sector (Glazebrook and Newman, 2018).
  The form such partnerships will take will be dependent on local context: local institutional structures and networks of stakeholder relationships.
- Principle 2: Value creation rather than prediction
  According to Sarasvathy (2009), entrepreneurs tend to focus on those factors that can be controlled, rather than acting according to predictions about the future.
  This is the opposite of the conventional approach to transport planning, as discussed in Journal Paper 1, which are planned and justified according to predict-and-provide models. This naturally follows on from their public funding, as a justification needs to be provided for allocating scarce public funds to provide a service to the community. Similarly, government-led value capture approaches are based on new taxes on property owners, justified in terms of predicted increases in private property values. Transport planners struggle with predicting travel patterns accurately, in the face of unpredictable changes of behaviour by commuters in response to new road capacity, which tends to fill quickly due to induced demand (Levinson, Marshall and Axhausen, 2017).
- Principle 3: Begin with available means, rather than pre-determined ends
  Expert entrepreneurs will often begin an enterprise by working with available resources and favouring decisions that make use of these resources, rather than developing a detailed plan for a “final product” and then assembling the necessary resources to develop it. In addition, entrepreneurs tend to try to minimise risk by controlling potential downside scenarios.
  In the context of transit and land use, this suggests that developable land should be considered as key resource from the outset, which can be made viable with good transit access. As transit stations and their surrounds begin to generate value, additional investment can be made into the transit service and their surrounding developments. This organic style of development can be seen in development along a number of rail line corridors in the United States, including the Pearl District Streetcar in Portland, Oregon; the South Lake Union Streetcar in Seattle, Washington; and the Brightline in Florida.

- Principle 4: Define Transit Activated Corridors

  A Transit Activated Corridor can be facilitated by declaring or zoning it as primarily for transit and dense urbanism. Plans for such corridors are being developed in a number of cities around the world, modelling on London's Street Families (Transport for London 2013), which was modelled on the Link and Place concept developed by Jones, Boujenko and Marshall (2007a). In Australia, a number of jurisdictions have developed a similar framework, named "Movement and Place", as an adjunct to the conventional road hierarchy.

  Establishing such a corridor, and planning for how transit could travel along it unimpeded, sends the signal that dense urban development would be favoured in these places. The responsibility for enabling TACs in this way would be given to an agency or group of agencies with responsibility for delivering both transit and urban regeneration.
- Principle 5: Walkable and sustainable station precinct design

  Statutory town planning instruments must allow for dense and mixed use development around the station areas, which is often not permitted in car-dependent cities. Beyond this, there are a range of design considerations, which would include walkable urban design, solar design, water sensitive design, biophilic design, affordable housing design and most of all integrated design (Newman et al. 2019b). Detailed manuals have already been developed for designing centres in this way.

Trackless Trams can facilitate this mode of development, due to lower barriers to entry through cost and disruption, and less intrusive infrastructure at street level (Newman et al. 2018a; 2018b). This emerging technology may even be more suitable for developing Transit Activated Corridors than light rail, as explained in Table 6, which compares the suitability of three transit modes – Bus Rapid Transit, Light Rail Transit and Trackless Trams – against the five principles of Transit Activated Corridors.

There are likely to be unexpected issues emerge from a technology that is rail-like and is much cheaper, for example some types of PPP may not unlock finance when there is uncertainty about how fixed is the transit route.

Characteristic 1: Ability to facilitate partnership-driven planning		
BRT	BRT is able to achieve partnership driven planning, however partnerships are generally transport-centric given the lesser urban regeneration ability achieved by traditional bus-based schemes.	✓
LRT	LRT is able to bring transit, land development and community interests to the table and this has been demonstrated around the world, including in the case studies above.	✓✓
TTS	TTS are able to bring the same interests together as LRT to plan a transit project financed by urban regeneration, however TTS can enable the inclusion of far more parties than under the recent welfare finance model of most light rail. Projects do not need to be 'Tokyo' in scale to get started, and have less risk. An inclusive, bottom-up, community-engaged planning approach can be achieved with the less expensive trackless trams, rather	✓✓✓

	than only being considered by the top-down stakeholders.	
Characteristic 2: Ability for value creation through urban regeneration		
BRT	Bus-based systems have had less urban regeneration success in most cases.	✗
LRT	Light rail has been successful in attracting investment and urban regeneration around its lines, especially given its fixed nature, however urban regeneration is best achieved if land development is used as the cornerstone of transit finance such as proposed here.	✓✓
TTS	Ability to be used like light rail, particularly through an entrepreneurial financing process to ensure urban regeneration is undertaken, but at lower cost to the entrepreneurs and thus is more likely.	✓✓
Characteristic 3: Ability for organic resourcing through staged financing		
BRT	The lack of strong urban regeneration attraction created by BRT systems creates a lack of investor incentive for the finance of new lines.	✗
LRT	Has been achieved in a number of cities, highlighted in case studies above.	✓✓
TTS	Organic resourcing through staged financing would be similar to the LRT as in the case studies outlined above. At each stage of financing the two parts of the TAC, the Trackless Tram and the chain of TOD's could be financed with steps assessed for land value uplift, patronage and other benefits and costs, before proceeding to the next stages.	✓✓
Characteristic 4: Ability to service strategic plans (TAC route)		
BRT	If strategic plans are developed mode agnostically, BRT is competitive on infrastructure cost and speed if given priority. However, it will not achieve urban regeneration outcomes.	✓
LRT	If strategic plans are developed mode agnostically, LRT is competitive on capacity per vehicle, speed and ability to attract regenerative investment.	✓
TTS	If strategic plans are developed mode agnostically, TTS can enable the capacity and speed of LRT but cost much less. This is likely to open up the potential for many more strategic routes and help create an overall network with far greater overall benefits.	✓✓
Characteristic 5: Ability for integrated application of TOD design tools		
BRT	The same TOD principles can be applied but without private investment they rarely happen.	✗
LRT	Able to utilise best-practice integrated TOD design from light rail projects to achieve walkable, people-centric transit precincts.	✓
TTS	Design tools for TODs would be just as effective in station precincts around Trackless Trams as around LRT except the cost of the infrastructure is much less (no overhead catenary and no steel tracks).	✓✓

Table 6: Comparison of TAC characteristics for corridor based urban rapid transit systems of BRT, LRT and TTS.
Source: Reproduced from Publication 4.

3.5 Publication 5

Newman, P., Mouritz, M., Verschuer, M., Davies-Slate, S., Caldera, S., Desha, S. and Reid, S. (2019) Trackless Trams and Australian Urban Fabric. State of Australian Cities Conference (submitted).

Publication 5 explores the potential of Trackless Trams to facilitate urban regeneration in an Australian context. This includes examining the challenges and opportunities inherent in integrating these new vehicles into existing cities. The paper documents the technological development of Trackless Trams, considering various predecessor vehicles and informed by field trips to a test line in China. This technological progression is summarised in Table 7, overleaf.

Additionally, Publication 5 considers this new technology in the context of the Theory of Urban Fabrics, and the potential of Trackless Trams to regenerate the different urban fabrics present in contemporary Australian cities (Transit Urban Fabric has been divided into inner city transit fabric and the middle suburb transit fabric that forms around railway lines):

- Central city walking fabric;
- Inner city transit fabric (the areas around old tram lines);
- Middle suburb transit fabric; and
- Outer suburb automobile fabric.

In assessing the effects on these four urban fabrics, a framework of seven urban design principles was developed and applied. This framework was developed as part of a project for the Sustainable Built Environment National Research Centre, and the project involved a stakeholder consultation and design process for potential Transit Activated Corridors in four Australian cities, namely:

- Townsville (from the CBD to James Cook University and Health Campus);
- Sydney (from Liverpool CBD to the new Western Sydney Airport site at Badgerys Creek);
- Melbourne (the City of Wyndham, with need for links to heavy rail and for new urban centres); and
- Perth (five local governments from Canning through the CBD to Stirling).

All of these case studies were developed in partnership with the relevant local authorities, for whom high-quality transit was a priority. This project was part of an initiative to develop this new transit and urban development, and so was a precursor to potential live projects.

Year	Type and link	Manufacturer	Countries of operations	Key features commentary	Indicative Image
2001	Guided light rail tram	Bombardier Transportation	France	▪ Rail guided by a single central rail ▪ System costs, reliability and maintenance issues. ▪ Too fewer vehicles to serve the demand.	
2007	Tramways on tyres	Translohr	France, Columbia, China, Italy	▪ Modular design with between 2 and 7 carriages. ▪ Narrow vehicle permanently fixed to guide rails ▪ Cannot divert, similar to traditional steel-wheeled rail vehicles. ▪ Lack of interoperability, and expensive to build and maintain.	
2011	Bus Rapid Transit	Van Hool	Italy, Switzerland, Germany, UK, Spain, France, Luxemburg, Sweden, Norway, French Antilles and Austria	▪ Similar to light rail regarding comfort, smoothness, and stylishness though without a full optical guidance system. ▪ A range of propulsion systems: fully electric trolley, on-board systems, hybrid gas electric, gas and hydrogen fuel cell technology.	
2017	ie Tram	Irizar	Spain	▪ More glass for the carriages ▪ Chrome edge around the body for a stylised appearance. ▪ 200km range on a single charge	
2018	Autonomous Rail Rapid Transit (ART)	CRRC Zhuzhou Institute Co Ltd	China	▪ Resembles a rubber-tyred tram, but with flexibility to move around like a normal articulated bus. ▪ Autonomous rapid rail transit vehicle fully autonomous and bi-directional. ▪ Composed of individual, fixed sections joined together by articulated gangways ▪ Well developed optical guidance system	

Table 7: Examples of the evolution of Trackless Trams.
Source: Caldera et al. 2019.

The seven design principles are shown in Table 8.

Core Principles	Core Practices
1. Precinct safety and accessibility The development should be safe and healthy for people waiting to access transport nodes	▪ Human centred design ▪ Walkable urban design ▪ Place and movement design
2. Carbon neutral - positive approach The development should aim for carbon positive, being at least zero carbon, in both power and transport	▪ Solar passive design ▪ Solar active design ▪ Carbon neutral analysis
3. Local shared mobility The development should encourage diverse local modal services to access the transit service, with defined spaces	▪ Local mobility design ▪ Feeder transport design ▪ Mobility as a service
4. Property diversity The density and urban mix should contribute to urban regeneration	▪ Community engaged planning ▪ Agglomeration economy analysis ▪ Financial modelling
5. Property affordability The development should include diverse property options to provide affordable living as well as affordable housing	▪ Social housing analysis ▪ Life cycle assessment ▪ Sustainability operational analysis
6. Nature-loving and biodiverse spaces The development should include and connect biophilic and biodiverse greenspaces, supporting endemic species and habitat	▪ Biophilic design ▪ Water sensitive design ▪ Landscape oriented design
7. Inclusive, integrated, place-based planning Planning, design and implementation (operation, maintenance) should involve diverse stakeholders and all tiers of government to provide an integrated place-based approach.	▪ Joined up governance analysis ▪ Partnership analysis ▪ Procurement options analysis

Table 8: Framework for Regenerating Urban Centres with core design/planning practices
Source: Caldera et al. 2019

This framework of seven design principles was applied to the four types of urban fabric, informed by the four case studies. These case studies provide good examples of the different types of urban fabric, with all four having both middle suburb transit fabric in need of regeneration, and outer suburban automobile fabric that needs a transit connection and a centre. Two of the four have a central walking city, and two have inner city transit fabric.

The conclusions of this process are presented in Table 9.

Core Principles/ Urban Fabric Examples	Central City Walking Fabric (current rail-based centre)	Inner City Transit Fabric (old tram line area)	Middle Suburb Transit Fabric (infill failing)	Outer Suburb Automobile Fabric (new area needing a centre)
1. Precinct safety and accessibility	Walkability the critical value	Walkability in centre and corridor access both critical	Walkability in centre and corridor access both critical	Walkability in centre and corridor access both critical
2. Carbon neutral – positive approach	Strong transport carbon reductions but harder to do solar on buildings	Easier to do solar on buildings and harder on transport carbon reductions	Easy to do solar on buildings and hard on transport carbon reductions	Very easy to do solar on buildings and much harder on transport carbon

				reductions
3. Local shared mobility	Essential character	Essential character	Essential character	Essential character
4. Property diversity	Essential character	Essential character	Essential character but markets harder on mixed use	Essential character but markets hard on mixed use
5. Property affordability	Important but more difficult	Important but still difficult	Important and easier to achieve	Important and easier to achieve
6. Nature oriented space	Critical with emphasis on biophilic buildings and small pocket parks	Critical with emphasis on biophilic buildings, small pocket parks and green corridor	Critical with emphasis on biophilic buildings, small pocket parks and green corridor	Critical with emphasis on small pocket parks, green corridor and landscape-oriented development
7. Inclusive, integrated, place-based planning	Essential for delivery	Essential for delivery	Essential for delivery	Essential for delivery

Table 9: The Framework applied to four different urban fabrics.

Chapter 4 Discussion

The findings of this research addressed three key themes:

- Value capture and entrepreneurial rail development
- The potential of partnerships
- The effects of emerging technology

The following chapter summarises the findings under each of these key themes.

4.1 Value capture and entrepreneurial rail development

This research began with the problem of public funding constraints as a barrier to developing urban rail. At the time, value capture was gaining widespread acceptance as a policy solution. This involved imposing a tax or levy on private development, to augment the budgets of government transport agencies.

Recent work on the subject, including this research, suggests that better outcomes can be achieved by taking a more entrepreneurial approach, by a wider range of stakeholders. This model is not new, as shown in Publication 2.

There is a rich history of entrepreneurial railway building, including an investment boom and speculative bubble in 1840s Britain, known as the Railway Mania (Campbell and Turner, 2012). Even after the following railway bust, passenger numbers grew exponentially until the start of the First World War. Later, that country moved to a heavily regulated system of four consolidated companies, known as the “Big Four”. This was followed by nationalisation, and a sustained period of decline in passenger numbers. The railway system was re-privatised in the mid-1990s, albeit with the government retaining control of the tracks and auctioning off operating concessions in a particular region for short periods of time. This system can hardly be described as an Entrepreneur Rail Model, but has still resulted in a return of exponential passenger growth in the United Kingdom, comparable to the rate of growth in the Nineteenth Century. The British model of private involvement contrasts with the Japanese re-privatisation, which involved breaking up the national railways into vertically integrated rail and property companies, operating in six regions of the country (Evans, 2010). These new companies joined the already crowded field of private rail operators in Japan. Historical passenger numbers in the United Kingdom are shown in Figure 5, below.

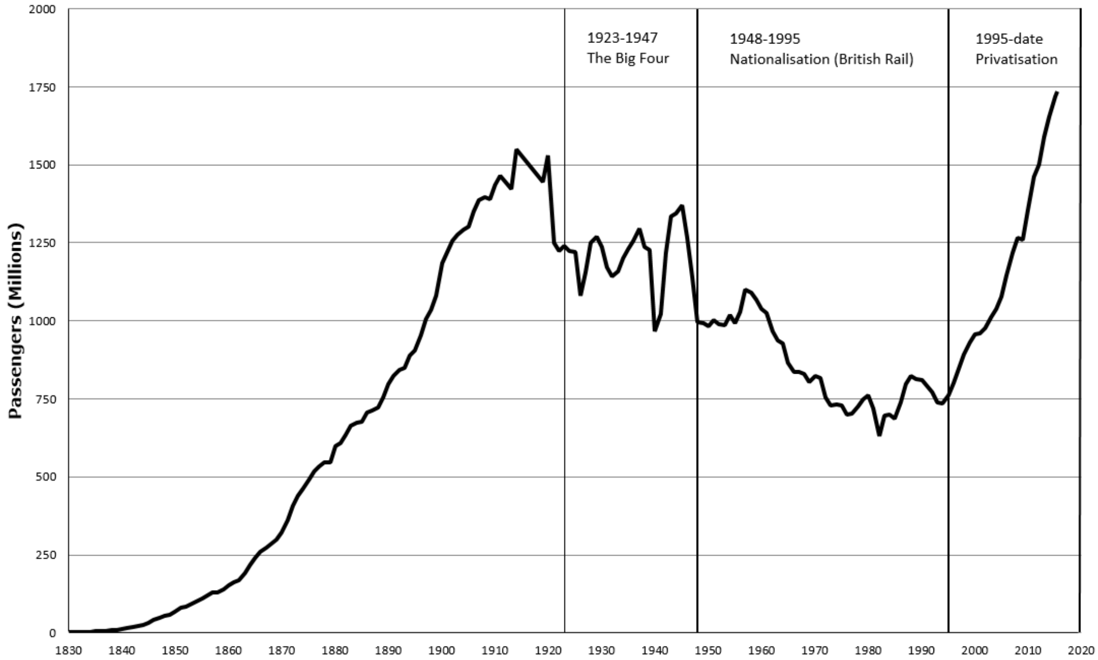

Figure 5: Railway passenger numbers in the U.K., 1829–2016.
Source: Wikipedia Commons.

Urban rail was quickly integrated with the potential urban development that it unlocked on the outskirts of cities. Rail and property development enterprises were common during the construction of the London Underground, and this entrepreneurial model was also widely practiced in Japan, the United States and Australia.

The governance and regulatory arrangements that existed in the past may be able to be revived. This leads to the question: what role for government in an entrepreneurial rail revival? Publication 1 discusses potential roles for town planners and transport planners.

The roles that would remain with government would include zoning or other land use controls, urban design and building standards, and possibly land assembly, if it was an objective of government to develop rail along a particular corridor. Regulation will be needed to prevent the abuse of local market power by a railway operator. Developed countries generally have well-established regulatory regimes for limiting anti-competitive behaviour.

Transport planner roles could include ensuring network coherency between different providers, so that they combine effectively into a networked whole. This could include ensuring an integrated ticketing system, regulating fares or acting as an arbitrator in negotiations between operators who share network boundaries. New assessment tools will need to be deployed, to assess the broader benefits of new rail infrastructure to justify public funding. These include accessibility, agglomeration benefits, amenity benefits and avoidable costs in car-based public infrastructure. Many of these tools already exist, such as the Green Book, produced by HM Treasury (UK) (2018).

Government also manages public land, including road reserves. Allocating this space well is a role for government. This land may be leased to a private proponent, as was the case with the historical tramways discussed in Publication 2.

The level of private involvement in major transport varies between countries. In a European or North American context, a shared neoliberal concern for competition will nonetheless se differences in implementation (Fainstein 2008). Governments will need to be mindful of the potential for land value capture tools to result in reduced affordability, and spatial segregation of the population, and in some less developed countries, issues of land tenure may limit the applicability of value capture approaches. Property-related revenue streams may also experience volatility (as noted by Adair et al. 2000, for example), a concern if these revenues are being used to support transit services, particularly if these services are being undertaken as a matter of social welfare.

Publication 1 suggests new roles for town planners, as a means to address these and other issues. These suggested new roles include:

- Land acquisition and assembly;
- Zoning, or other means of land use regulation; and
- Urban design and building standards.

Town planners might also make requirements for affordable units to be included in major developments, which is already a commonplace town planning tool.

4.2 The potential of partnerships

The conventional model of centrally planned transit has produced mixed results. Often it has resulted in poor land use integration, high construction costs and questions as to the adequacy of project appraisal and funding models. Major new infrastructure under this model also often causes conflict and opposition.

There is promise in developing partnerships between different levels of governments, private proponents (developers and transit operators), the community and possibly major institutions, such as universities. A partnership approach can be seen in some major projects, such as the London Crossrail and City Deals, as discussed in Publications 2 and 4. In the case of Crossrail, funding is drawn from a combination of the national (UK) and London governments, contributions from major landowners along the route and increased fare revenue. The Mayor of London convinced businesses to accept an increment on their property rates, known as the Mayoral Community Infrastructure Levy. Contributions from key stakeholders include the major landowner at Canary Wharf, who are delivering that station on the line (Buck, 2017).

Sarasvathy's (2009) first principle of entrepreneurship is to "create partnerships from the start". This reduces uncertainty and risk, as the various parties involved co-develop the vision for the undertaking. As noted in the discussion of Publication 4, above, such partnerships will vary based on idiosyncratic local conditions. City Deals may present a suitable vehicle for building such partnerships between the different tiers of government, private industry and stakeholders in the community. As Publication 4 notes, partnership-first approaches have begun to proliferate around the world, responding to the limits of the different professional communities of practice operating in isolation (Clark and Clark, 2014; Newman, 2016). This research has found that such partnerships have particular promise for catalysing urban regeneration, rather than simply delivering a large piece of transport infrastructure, which has limited effect on the surrounding urban fabric.

4.3 The effects of emerging technology on urban regeneration

Light rail has become increasingly expensive in recent years. The Sydney CBD and South East Light Rail is a prominent example, with the discovery of previously unknown underground services contributing to substantial delays and cost overruns. More generally, the cost of light rail has become a matter of contention, and comparisons are frequently made with low cost bus services. There is an irony to the emergence of this concern with light rail costs, as the technology was developed in Europe as a low-cost alternative to heavy rail.

The high cost and risk of developing rail infrastructure is a potential barrier to more entrepreneurial approaches to rail building. This technology has become the domain of public authorities in most parts of the world, who will always be less sensitive to costs than a commercial undertaking. Even a single new rail line, much less a new network, is a significant risk, and would require a large increase in development value to be justifiable. Trackless Trams, which can be delivered at lower cost and with much less risk and disruption than rail infrastructure, can alleviate this problem.

As mentioned above, it has been shown that buses have a lesser effect than rail at stimulating development and raising land prices. Trackless Trams mimic the effects of light rail in many ways (passenger capacity, ride comfort, some permanence of the route, electric traction so less noise and emissions), and should be able to stimulate land markets in a similar way. By lowering cost and risk, Trackless Trams reduce barriers to entry, allowing for a wider range of participants into the market, including more local level partnerships.

Trackless Trams can also make use of existing corridors. Many cities globally reserve wide corridors for the purposes of accommodating a large number of traffic lanes. Trackless Trams could be a cheap and effective means to adapt these legacy road corridors to transit urban fabric and large flows of people. Trackless Trams will most likely travel along existing road corridors, so the corridors developed along existing major roads, to avoid the capital cost of constructing new rights of way. This implies an intensification of existing corridors is more likely than the genesis on new ones.

Publications 3, 4 and 5 all address the regenerative potential of Trackless Trams. Compared with general traffic or buses, Trackless Trams allow greater development intensity with less space devoted to parking, as the capacity of road corridors to move people is increased. There is also a reduction in noise, emissions, local air pollution and traffic accidents. Electric, battery-powered traction is much quieter than the internal combustion engine, and produces no local emissions. When coupled with the increasing share of renewable energy being seen in electrical grids (Department of Industry, Science, Energy and Resources (Australia), 2020), the total transport-related greenhouse gas emissions can also be reduced significantly. This is in addition to the savings on energy consumption and emissions that already results from higher urban densities (Newman and Kenworthy, 1989; 1999; 2015).

Transit Activated Corridors can also include autonomous shuttles serving major stations, to provide last mile access to land further than comfortable walking distance, which is currently likely to be quite car dependent. This is shown conceptually in Figure 6.

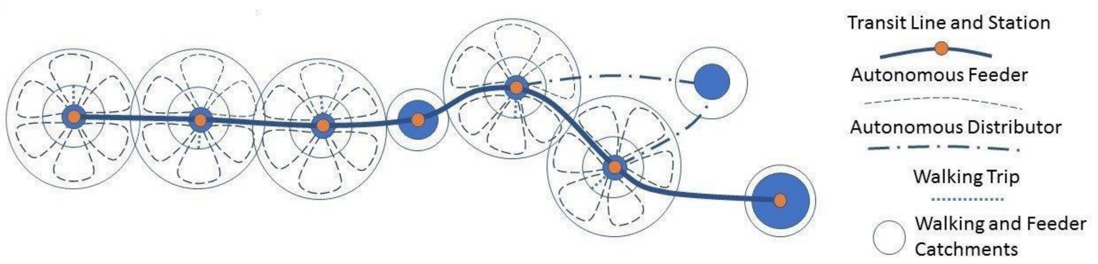

Figure 6: Concept of Transit Activated Corridor.
Source: Glazebrook and Newman, 2018, adapted in Publication 4.

Chapter 5 Conclusion and Recommended Further Work

5.1 Conclusion

The purpose of this thesis is to address the potential for an entrepreneurial approach to transit delivery to regenerate cities, and how new technology, in the form of Trackless Trams, can make this feasible – along with complementary emerging transport technologies, such as mobility-as-a-service and micro-mobility. This research began when "value capture" was a topic of considerable interest among Australian policy-makers. It was envisaged that a new tax might be applied to landowners, to provide a stream of funding for the substantial investment required in new urban rail. This thesis has shown that this was not the approach historically and will not deliver the best results today. It raised the question as to whether Twenty-First Century transit technology could now reinvent the entrepreneurial rail model to help deliver much better cities, more economically and quickly. The answer in this thesis is 'yes', as set out in a growing set of arguments as summarised below.

Publication 1 presented a conceptual framework for the thesis research, namely the concept of the Entrepreneur Rail Model and set about trying to show why this old idea should be reinvented. The ERM challenges the conventional practice of central planning and a monopoly on transit delivery by government planners. It also challenges the notion that ever greater public infrastructure spending is a necessity to provide quality transit in cities that currently lack it.

Publication 2 demonstrated that this proposed new process has in fact been done before, and that this entrepreneurial approach was much more the norm during the first generation of railways and streetcars/tramways. The global history is surveyed and new case studies are presented in detail from Western Australia. These case studies provide details of the regulatory model that enabled a large private tramway network to be developed in what was then a small and isolated city.

Thus, after these two publications the argument that the old ERM should be reinvented was firmly on the table. However, the high cost and disruption that comes with building rail in established cities still presented a barrier. The first two publications set up the model, but it needed some technology to make it possible.

Publication 3 introduced Trackless Trams, and assessed their transport niche, and potential to regenerate cities. This paper explored the advantages of increased capacity along arterial roads, reduced need for parking, increased development densities and reduced noise and air pollution.

The cost of delivering rail has become very high in developed countries, and Trackless Trams may offer both a lower cost means to deliver quality transit, and also an opportunity to lower the barriers to entry sufficiently to bring large scale transit back into the realm of entrepreneurs.

Publication 3 gave a strong suggestion that a Trackless Tram System could be the Twenty-First Century transit technology which invites the use of entrepreneurs. This new mode could fill a niche where quality mid-tier transit is required – lower cost than light rail or a full grade-separated metro rail, but providing a level of service comparable to light rail. It is cheap enough and rapid enough to build around it and make the necessary money from land development that would enable entrepreneurs to make it part of urban development practice. Obviously, partnerships would be needed as with the old ERM and some ideas started to be outlined in this paper to show this could happen.

Publication 4 combined Entrepreneurship Theory with urban planning principles and the Theory of Urban Fabrics to show how a true integration between entrepreneurs and planners could enable much better outcomes for our cities. It develops the concept of Transit Activated Corridors, and five principles for developing them and regenerating cities, built around partnerships between governments, the private sector and communities. The case was just about complete for an entrepreneurial rail model partnered with a Trackless Tram System to offer a whole new approach to urban and transport planning.

Finally, Publication 5 investigated the potential of Trackless Trams to regenerate Australia cities, and developed seven principles for urban regeneration, with reference to the Theory of Urban Fabrics. The detail in this paper was able to present a case for how the entrepreneurial approach to transit and land development could achieve the multiple objectives of urban planning across each urban fabric.

The conclusion therefore is that Twenty-First Century transit technology could now reinvent the entrepreneurial rail model. And moreover, in delivering transit into cities in a more deeply integrated and substantial way, is likely to achieve far better sustainable economic development and urban regeneration in Twenty-First Century cities.

5.2 Recommendations for further research

Below are recommendations for further research that follow on from the findings in this thesis. The key theme is practical delivery of the Entrepreneur Rail Model, Trackless Tram Systems and Transit Activated Corridors.

1. Deliver a Trackless Tram System (TTS) and trial it in a western city, ideally one that is currently car-dependent, as is common in North America and Australia. This should include examination of the issues surrounding exclusive use of a carriageway on a public road by this TTS.

2. Develop practical governance models for the Entrepreneur Rail Model, and use this to demonstrate the first Transit Activated Corridor (TAC). A large-scale urban regeneration project in a car-dependent city would offer the best case study.

3. Deploy the model in a range of other cities, including those with little formal transit provision, to see if it could be a leap-frog innovation. Cities that cannot muster the public resources to deliver a light rail or metro network would be most suitable.

    a) Many cities in Africa and Latin America provide mobility through informal transit: rickshaws, jitneys, minibuses, and other forms of low-technology micro-transit. The stations on a Trackless Tram System/Transit-Activated Corridor could become hubs of activity for the existing informal transit systems. Such a model may be widely replicable.

    b) Learnings from this process of integration could also provide lessons for developed world cities in integrating autonomous vehicles into station hubs, as proposed by Glazebrook and Newman (2018).

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Publication 1

I, Sebastian Davies-Slate, contributed 30% to the paper titled:

> Newman, P., Davies-Slate, S., and Jones, E. (2017a) The Entrepreneur Rail Model: Funding urban rail through majority private investment in urban regeneration. Research in Transportation Economics. Volume 67, May 2018, Pages 19-28. DOI: http://dx.doi.org/10.1016/j.retrec.2017.04.005

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> Newman, P., Hargroves, K., Davies-Slate, S., Conley, D., Verschuer, M., Mouritz, M. and Yangka, D. (2019) The Trackless Tram: Is It the Transit and City Shaping Catalyst We Have Been Waiting for? Journal of Transportation Technologies, 9, 31-55. http://doi.org/10.4236/jtts.2019.91003

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The Entrepreneur Rail Model: Funding urban rail through majority private investment in urban regeneration

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ABSTRACT

The 21st century has seen an unprecedented expansion of urban rail as a response to urban congestion, low carbon mobility and as a seed for urban regeneration. Many cities would like to do much more rail in their futures to create knowledge economy centres but cannot find the funding, including Australian cities that are the focus for this paper. Four approaches to funding are outlined from fully government to fully private with two in between. The Entrepreneur Rail Model suggests a majority private sector funding can facilitate the new markets for urban regeneration as well as providing integrated rail that government's usually find difficult to fund. The process requires transit planning to be seen primarily as a land development tool rather than a transport system. This was the historical function of urban rail in the nineteenth and early twentieth century and signals a significant new 21st century rail market as well as the need for new procurement and governance systems for land assembly and transport planning that can ensure network integration, new assessment models and public good outcomes.

1. Introduction

The 21st century has seen a simultaneous decline in automobile dependence, growth in urban rail and a rapid increase in urban regeneration with positive economic, social and environmental outcomes (Newman & Kenworthy, 1989, 1999 and 2015). However, the process has mostly been funded by governments and now the demand is far outstripping their ability to provide the capital and the on-going operations to fund the required expansion. Many governments across the world, particularly in rapidly growing cities in Asia, are seeking ways of bringing private sector funding into the provision of urban rail. A new model for funding urban rail using majority private investment has been adopted by the Federal Government in Australia. The Minister for Cities echoed the sentiments of many cities when he stated the new policy approach:

> *"It is clear that rapid growth in major capital cities can't be accommodated with existing public funding models. All levels of Government in Australia are facing budget constraints. While there are a number of major infrastructure projects underway or in planning, we are unlikely to be able to sustain this rate of investment in the long-term. If we are to provide the transport infrastructure that Australia's cities will need in the future, we will have to find new ways of paying for its construction. One of the fairest ways to fund new infrastructure investment is for the beneficiaries of that infrastructure to contribute to the cost"* (Hunt, 2016, sec 3.2).

Many other cities are going through a similar transition. This paper will set out the basis for such a new funding approach as proposed for Australian cities, and the potential for it to be applied to any city as well as the way to achieve the best land development, network integration and other public good outcomes.

2. Why cities want urban rail?

The dramatic decline in car use per capita that we have begun to see in the 21st century (Newman & Kenworthy, 2011) is paralleled by an unpredicted and unprecedented expansion in urban rail (Newman, Glazebrook, & Kenworthy, 2013). The reasons for these changes are still being discussed but are now seen to be mainstream urban economics. The value of urban rail to economic activity is based on a number of key overlapping factors. These are outlined in Newman and Kenworthy (2015) but are summarized in five key factors:

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2.1. Time savings

Urban rail can now go faster than urban traffic and thus saves travel time (see Table 1). Traffic has been getting slower and slower as road capacity fills very quickly and most cities have now recognised that it is uneconomic in time and space to try to satisfy this. Urban rail can go around traffic and so the ratio of rail to traffic speeds everywhere (since the 1990s in Australia) have been increasing, and are now greater than 1 in all but North America.

2.2. Increased land values

As urban rail has been built, densities have begun to increase around such systems, as they provide the amenity that creates urban development opportunities. Land value increases around rail are universal. See Table 2 for some examples as well as the data from McIntosh's studies in Perth which showed 42% increase in land value along the new Southern Rail above the other suburbs without rail (McIntosh, Newman, & Glazebrook, 2013).

Land value increases around rail occur because people want to live or work near them so they can have no car or one less car and because they want easy access to the jobs and services attracted to the area. Thus, there is a private value in rail projects that is not usually turned to advantage in building the rail system; those who own the land just receive wind-fall profits. However, governments do get some value flowing back to them through increased land-related taxation (see McIntosh, Trubka, & Newman, 2013, 2014).

2.3. Agglomeration economies in activity centres

Density in activity centres is strongly related to urban productivity. This case is strongly made by Harvard Professor Ed Glaeser (2011) in 'The Triumph of the City', and has been measured in many cities, including Melbourne (See Fig. 1). This phenomenon of agglomeration economies is caused by the clustering of urban activities and jobs that require face-to-face interactions for the creativity and innovation related to urban productivity gains, particularly in the knowledge economy sector.

2.4. Land development efficiencies

By focussing urban activity rather than scattering it, there are significant economic efficiency gains (Newton, Newman, Glackin, & Trubka, 2012). Urban infrastructure is saved for energy, water and transport; around $100,000 per block in Australian cities is saved whenever a residence in the suburban fringe is not built in favour of redevelopment. Urban services are more efficiently provided for health, education, and other social services. Health productivity is increased due to greater walkability and activity when people drive less, and an increase in productivity due to healthy workers of some 6% has been estimated (Trubka, Newman, & Bilsborough, 2010c). As a result of such transit-oriented development there are household cost savings and affordability particularly because TOD residents can reduce their vehicle ownership and associated costs (see Arrington & Sloop, 2009), large reductions in per capita traffic fatality rates, parking facility cost savings, and improved mobility for non-drivers, which reduces drivers' chauffeuring burdens, increased economic opportunity for disadvantaged groups, and increased tax revenue per hectare (see Litman, 2017; TOD, 2016).

Table 1
Rail outstripping traffic speeds.

Comparative speeds in global cities	1960	1970	1980	1990	1995	2005
Ratio of overall transit system speed to road speed						
American cities	0.46	0.48	0.55	0.50	0.55	0.54
Canadian cities	0.54	0.54	0.52	0.58	0.56	0.55
Australian cities	0.56	0.56	0.63	0.64	0.75	0.75
European cities	0.72	0.70	0.82	0.91	0.81	0.90
Asian cities	–	0.77	0.84	0.79	0.86	0.86
Global average for all cities						
Ratio of metro/suburban rail speed to road speed						
American cities	–	0.93	0.99	0.89	0.96	0.95
Canadian cities	–	–	0.73	0.92	0.85	0.89
Australian cities	0.72	0.68	0.89	0.81	1.06	1.08
European cities	1.07	0.80	1.22	1.25	1.15	1.28
Asian cities	–	1.40	1.53	1.60	1.54	1.52
Global average for all cities	**0.88**	**1.05**	**1.07**	**1.11**	**1.12**	**1.13**

Source: Newman and Kenworthy (2015).

2.5. Environmental gains due to reduced automobile dependence

There are many environmental issues exacerbated by low density urban development and improved by increasing density in activity centres around rail stations. Fig. 2 shows how transport fuel decreases exponentially with increasing density and thus reducing all the other issues connected to high automobile dependence such as greenhouse gases, air pollution, and traffic-related accidents.

There is therefore a multi-pronged rationale for why planners want a more polycentric city, where urban activity is better focused and linked into a quality transit system. Whatever the reasons there is a new policy interest in finding ways to facilitate urban regeneration as well as urban rail. This paper proposes a new model for how to do the two policies *together* through a new approach to funding urban rail.

3. Approaches to funding urban rail

There are a range of potential options for funding and delivering public transport infrastructure, with differing degrees of private sector involvement:

- Full public sector capital;
- Some private and substantial public capital;
- Substantial private and some public capital; and
- Totally private capital

Most transport infrastructure (both road and rail) in the latter half of the 20th century and still today is delivered under the first model – full public sector capital – although detailed design and construction work is contracted out under public oversight. All four mechanisms are likely to be used in 21st century transport infrastructure but the latter two seem best able to deliver urban regeneration as well as urban rail in a world where government capital for transport is constrained. The reason for this is explained in terms of land value creation.

3.1. Full public sector capital

In this model, public transport infrastructure is delivered wholly by public sector funding as a largely welfare-based approach though with productivity benefits as the justification. The public sector performs all network and regional planning and oversees the detailed design work that is performed by private sector engineers. The public sector also oversees construction that is usually contracted out.

As most national, state and city governments' finances are constrained and there are other growing demands on public budgets especially health and education, it is likely that new sources of funding will be required to deliver significantly more new transit

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Table 2
Land value increases and LRT systems from around the world.

Land Value Uplift Resulting From LRT Investment	Uplift	Reference
San Diego, USA LRT	3.8%–17.3%	Cervero and Duncan (2002)
Missouri, USA St Louis Metrolink LRT	32%	Garrett (2004)
England, UK Tyne & Wear Light rail	17.1%	Du and Mulley (2007)
Buffalo, NY, USA LRT	2%–5%	Hess and Almeida (2007)
Phoenix, USA Phoenix LRT	25%	Golub, Guhathakurta and Sollapuram (2012)

Source: McIntosh et al. (2014).

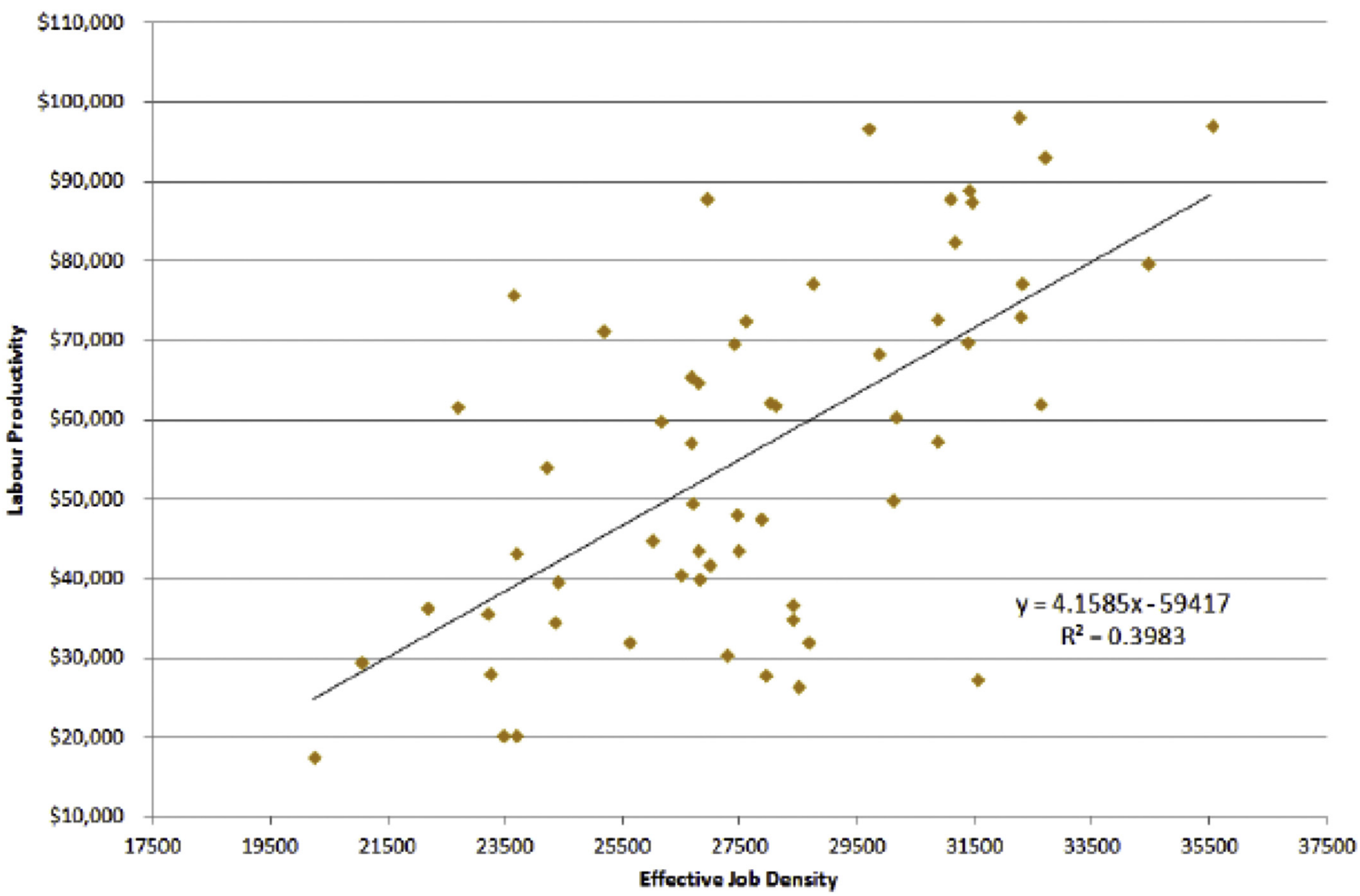

Fig. 1. Job density and labor productivity.
Source: Rawnsley (2014).

infrastructure. One way to do this is by recycling assets, for example in Sydney three new rail lines are being built by the New South Wales government using full public sector capital from the proceeds of selling the Port of Botany.

There is a range of potential mechanisms for raising revenue from the increase in land values created by public transport infrastructure, which are collectively known as value capture. This hypothecates government revenue that has been generated by the increase in land value flowing through to rates and taxes at all three levels of government. The US uses this approach and recently the UK has started to do this also. One recent Australian example of this is the Gold Coast Light Rail, which was partially funded by a levy on all Gold Coast properties though many people live nowhere near the railway so it's a very blunt value capture instrument rather than targeting the main beneficiaries of the railway. Similar blunt funding is done through sales taxes in American cities.

Despite being described as an alternative funding mechanism value capture is still generally a full public sector capital mechanism for funding urban rail (McIntosh, Trubka, Kenworthy, & Newman, 2014, 2015). Perhaps the biggest failing in this model is that there is no guarantee that urban regeneration will occur and that the density of activity around the train stations will be facilitated. There are often reactions from local communities and local governments after the rail is delivered to any increases in density near stations. As well transport planners frequently use the highly attractive and

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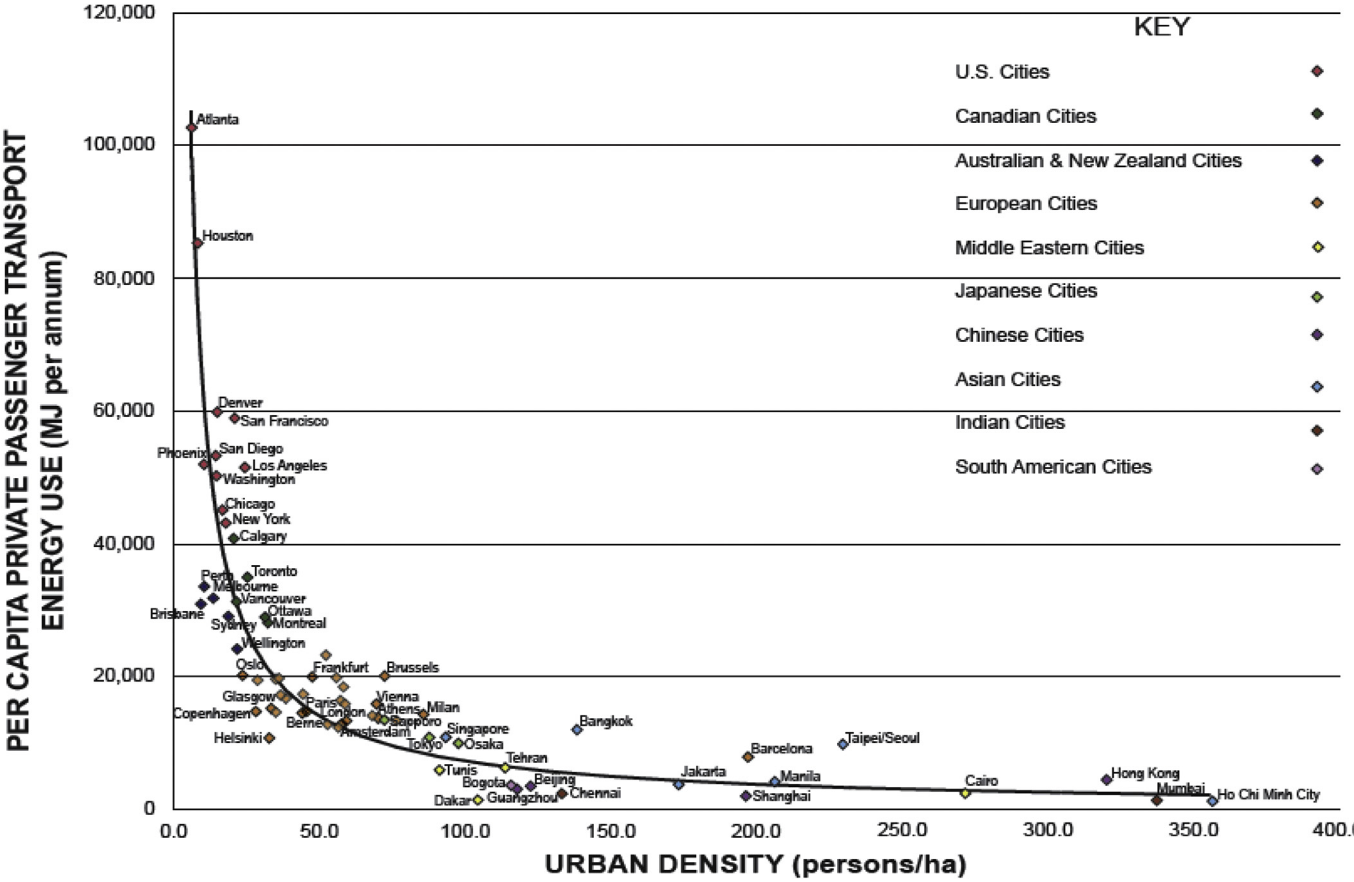

Fig. 2. Transport fuel vs density.
Source: Newman and Kenworthy (2015).

contested spaces around stations as park and ride for cars. Thus, this full public sector approach, if dominated by transit planners, may not facilitate the productivity benefits of transit-oriented development.

3.2. Some private and substantial public capital

This approach seeks help from private sources through land development, but primarily raises government capital through a mixture of sources such as parking levies, tolls on associated private traffic, developer contributions, an increase in registration fees or some other form of tax hypothecated to the rail project. This could include a new levy on the land value uplift associated with a new project, especially if it is targeted to the land owners around new stations.

A successful example of this approach is London Crossrail. Crossrail is an underground heavy rail project joining up major parts of the city, with substantial contributions from developers and the Business Rate Supplement, an increment on the rates paid by London businesses. Of the £14.8 billion funding for Crossrail, £4.1 billion is sourced from London businesses through various mechanisms, including the BRS. Financial contributions from key private investors include a £70 million contribution from the operator of Heathrow Airport, which Crossrail will serve, and £150 million from Canary Wharf Holdings, a developer, towards the cost of the new station at Canary Wharf. Canary Wharf Holdings will also design and build the station.

This mechanism is providing some new urban regeneration value through private investment but in general the value is achieved in linking the city to achieve major agglomeration benefits (BCR went from 1.5 to 3 after including agglomeration economies) and these therefore justify major public investment through value capture.

3.3. Substantial private and some public capital

In this model, substantial private capital can be supplemented by some government capital. Government's expected land value based tax flow-on could be hypothecated to cover their contribution. This approach would have government playing a key role in ensuring that the rail project is still generating all the capital required though only some would be from public sources at the three levels of government.

At the network level, this model can combine wholly private lines with publicly-funded ones where there is a compelling argument for the project to be built. Such reasons could include providing an improved service to a particular community, or for a particular major event, or to enable major urban productivity advances in a particular corridor.

The Portland tram built to the Pearl District was funded substantially by private sources to unlock urban regeneration potential, as was the Vancouver Canada line and its Olympic Station that was privately funded along with the Vancouver City Council to develop land around the station.

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Photo 1. Artists impression of Valley Line in Edmonton, a PPP with substantial private funding.Source: TransEd Partners (2016).

In February 2016, the Edmonton Valley Line was awarded to a consortium based around Bechtel and Bombardier to build a C$1.8 b LRT over 13 km. The private sector contractor is responsible for designing, building, financing, operating and maintaining the new Light Rail Transit project over a 30-year period. While the ultimate source of funding for the Valley Line is public, financing and associated risk is the responsibility of the private partner, the TransEd consortium. TransEd is required to raise the capital for project construction, gaining a return from the 30 years of concession payments.

This is perhaps one of the first lines in a car-based city to have created urban rail down a whole new corridor using ‘substantial private funding’. The role of land development in the Edmonton project is not clear.

3.4. Totally private capital

A fully funded private urban rail will only happen if there is substantial TOD-based urban regeneration at its heart. In this approach government's role would be kept to in-kind activity to ensure land assembly and land acquisition, zoning and other transport planning integration is fully covered, perhaps with assistance in the risk management side of the procurement process. The fully private approach depends on sufficient land being available to generate the capital and on-going operations; the land development thus must be fully integrated with the rail building and operations to generate the necessary private investment. It would mean that the project could be off balance sheet and hence would help with government credit ratings. This we have called the Entrepreneur Rail Model (Newman, Davies-Slate, Green, & Jones, 2016) and along with the ‘substantial private funding’ approach will be the focus of this paper.

The Hong Kong MTRC is a government-majority business enterprise that makes substantial profits and invests new capital based on land development. The MTRC is required to operate on commercial principles, and is listed on the Hong Kong Stock Exchange, with a significant portion of private ownership; the intention is that it behaves as a private company, albeit with government oversight. In this way, it can be seen as a totally private rail model as there is no cash contribution from government though its risk management is assisted by government backing.

Probably the only place where this totally private model happens regularly is in Japan where the rail system is fully privately run and a substantial part of any profit and capital for new lines is obtained through land development (Suzuki et al., 2015). A market for urban rail has been well established in Japan for many decades and it does suggest that it may work in other cities that are now reaching the stage where a market process can work.

A project in Florida called the Brightline High Speed Rail Project is perhaps the first fully private rail and TOD-based project in North America. The company is in the fortunate situation of owning a whole rail corridor through its freight business but has now created an integrated approach to building a series of TOD's between Orlando and Miami; this has attracted a major source of finance from a US hedge fund. This funding, together with the fare box returns, will enable a fast urban rail service along the South East Florida urban conglomeration. The system will begin in 2017. The need for cross connections of light rail is now being investigated to provide a truly integrated urban-TOD rail system.

Regional transport network planning was required in the Bright Line project and would need to change everywhere under this model of public transport delivery, as private capital would be attracted to corridors where there are development opportunities, rather than following public sector transport planning criteria, however the two are generally the same as land development is primarily a private sector function. If land is zoned for high density activity centres it does not mean it will happen unless the amenity is there to unlock the private investment. Thus, the public role needs to be how to facilitate this amenity and a new urban rail line can do that. The value of land around stations is created when such partnerships are created.

Transit network integration can still be a required part of any private rail project and would be needed for both public and private benefit in achieving new activity centres around rail stations. This transit-land use integration is not easily achieved but whenever land-related benefits are being sought the private financing will ensure it is fully integrated or the consortia involved would not achieve their necessary returns. Of course there is a risk for government if they do not ensure through the PPP process that all the necessary public good outcomes in terms of quality design, integration of services, fares and affordable housing, are clear.

All four mechanisms need to be assessed for any urban rail project to add to a city's reduced automobile dependence and hence to help create more enduring productivity gains (Newman & Kenworthy, 2015). Without this growth in rail and associated land development any city will just continue sprawling or adding to its congestion problems.

The various funding mechanisms that underlie the four models above are outlined in Fig. 3 emphasising the difference between value creation, value capture and general tax approaches.

4. Land value creation: the Entrepreneur Rail Model

The Entrepreneur Rail Model is a proposal developed to plan and deliver urban rail infrastructure on commercial principles – funded by land development and built, owned, operated and financed by the private sector. It is based around the notion of land value creation.

This model is designed to produce public good through delivering necessary rail infrastructure, as well as achieving urban regeneration goals and equitably distributing the economic value generated by quality rail infrastructure. However, it is an entrepreneur's approach to rail as it is based on finding a new market for the combination of urban rail and land development. It cannot be done simply by government planners as land development is mostly a private enterprise activity. This was in fact the historic process of how tram and train lines were originally built. The model is displayed graphically in Fig. 4.

Proponents need to provide an estimate of private capital to be contributed by combining land redevelopment potential and patronage potential for capital and on-going costs, then (and only then) produce transit numbers and detailed routes and urban regeneration plans.

This is instead of the conventional business-as-usual approach

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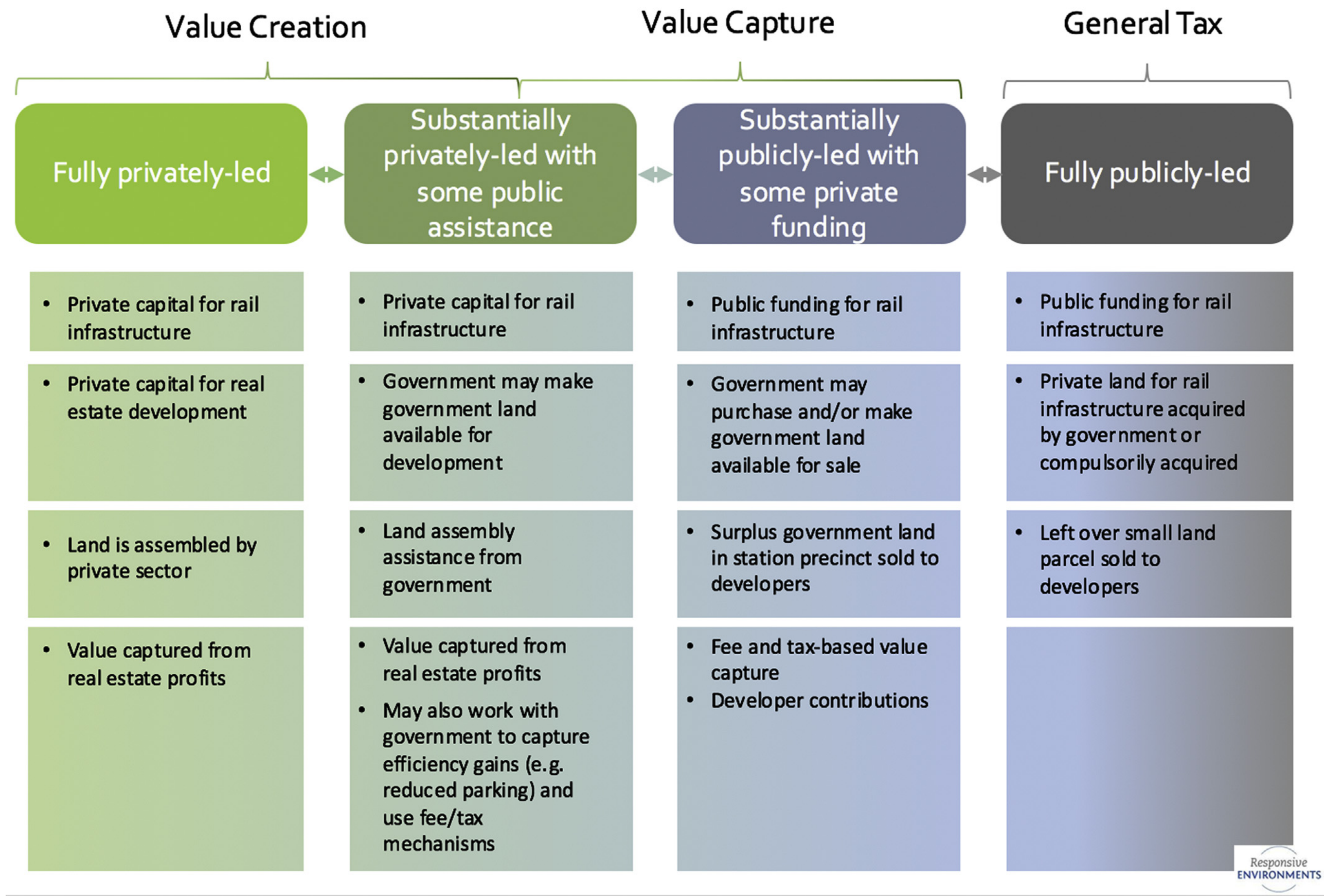

Fig. 3. Funding mechanism that involve value creation, value capture and general tax approaches.
Source: Evan Jones.

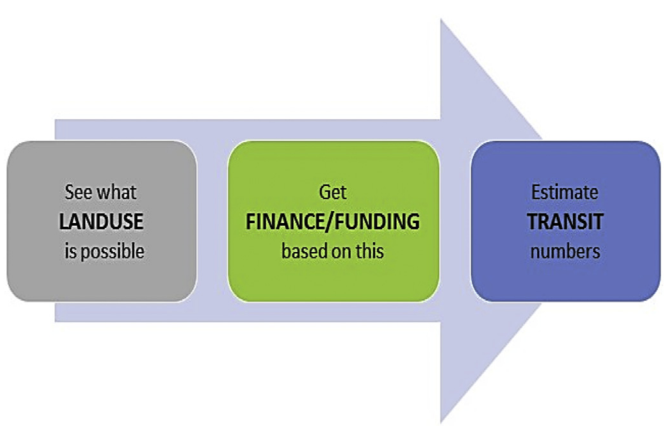

Fig. 4. Graphical representation of the entrepreneur rail model.
Source: Newman (2015).

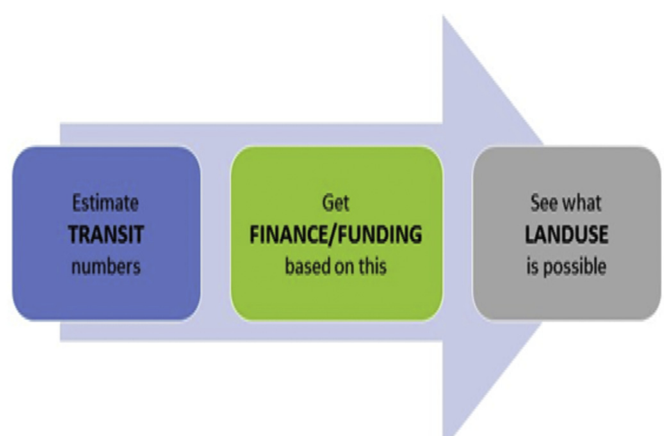

Fig. 5. Graphical representation of the conventional rail model.
Source: Newman (2015).

(see Fig. 5) of predicting the number of people who could use a railway line based on present land use and the best potential transit route based on the least resistance and least costs; then, after finding government funding, seek how land development may be facilitated. Generally, this last step is not successful as the route is not determined to optimise land development but to optimise the route for transport planning.

The importance of reversing the order is because it *guarantees* transit and land use integration through the necessity of delivering a return to the source of the financing. This return could not be generated from the separate building of a rail line by itself or by the separate development of urban regeneration without the increased amenity provided by a rail spine to the land involved. Rail infrastructure generates significant positive externalities through increased land values and improved business productivity and thus the model seeks to find the best partnerships that can enable integration of the rail and land development functions in urban economic development.

If built under the old model – a welfare model – then investors come in and take windfall profits from the land around stations thereby capturing much of the economic value.

It is an unearned transfer of wealth, from ordinary taxpayers to a fortunate few land owners. As well, the opportunity to link land development into rail stations is an afterthought. It is therefore rare and difficult. By contrast, in the Entrepreneur Rail Model activity centre development can be built into the project, and indeed it is imperative.

The Entrepreneur Rail Model would diminish the public financial burden of providing rail infrastructure and services and enables finance from groups like superannuation funds to provide the investment. It would also radically change how our cities are planned and shaped. Currently, cities are mostly built to central government plans – for land use and activity centres, transport networks, water and power, among others. Under the Entrepreneur Rail Model a city's rail network would instead be shaped much more by the value of urban regeneration and land value creation in the urban economy.

Cooperation between National, State and Local Governments will need to be developed to make this model work but most of all new ways of working with the private sector in planning a rail line will be required. Only in this way will the true agglomeration benefits, amenity and accessibility gains associated with this land value creation be obtained across the whole city. There is evidence that this value creation is not just shifting land value increases from one area to another but is creating value for the whole urban economy that would not have been created without such investment (Sharma & Newman, 2017).

This paper sets out the concepts behind such a funding model, supporting the benefits of private sector involvement in urban rail, and proposes a procurement process and governance system to enable this to happen.

Photo 2. Lyon tramway.Source: Trams DownUnder (2010).

4.1. How can the ERM be procured and governed for the public good?

Delivery is proposed through a DFBOOM - Design Finance Build Own Operate Maintain - model. If sufficient land for redevelopment can be made available through government land assembly, it should be possible to fund a rail line entirely with private capital. As suggested before, other levels of government funding can also be used but where possible it is best to use a market-based approach through the land value creation process if a fully integrated set of land use outcomes are desired.

The Entrepreneur Rail Model cannot work without an active and engaged government at all levels. In particular, several functions need to be creatively applied by government if both private and public goals are to be achieved in urban rail and in urban regeneration. These are:

- Land acquisition and assembly;
- Zoning land use changes, so as not to prohibit re-development;
- Urban design and building standards;
- Network coherency and integration;
- New assessment tools;
- New institutional arrangements; and
- New risk management approaches.

These are explained in more detail below in terms of the new roles for town planners and transport planners as well as new governance.

4.1.1. New roles for town planners

4.1.1.1. Land acquisition and assembly. In order to link together land development opportunities along a potential rail corridor it may be necessary for government to compulsorily acquire some land parcels to enable the station precincts to be large enough for transit-oriented developments (TODs) to be built, as well as some land for the rail lines.

Land assembly is also needed to enable development to occur. Private sector proposals can suggest how best to do land assembly to make the most out of a site.

The process of purchasing land for government purposes has various mechanisms across cities and nations. In Australia, this process has been mostly used to enable road construction, rather than rail, though examples are now emerging as cities begin building new rail lines such as the light rail in the Gold Coast and Sydney and other examples given earlier.

The recent trends in urban transport and land use (Newman & Kenworthy, 2015) would suggest that there is a growing market for rail as opposed to road projects and hence governments should be facilitating this market rather than just roads. Such a mechanism would be well suited to long-term strategic land assembly for the purposes of rail-based redevelopment in the Entrepreneur Rail Model. Redevelopment authorities generally have such power and as redevelopment opportunities and rail projects are clearly a major agenda for most cities, it is not hard to see how they can be part of the implementation of a rail and TOD-based metropolitan plan. It is just a matter of having such agencies integrated more fully into the transport planning process.

4.1.1.2. Zoning. The Entrepreneur Rail Model relies on land use change to capture the potential benefits of rail infrastructure. Land use zoning restrictions are often hard to overcome as low-rise and low density development is seen to be the only desirable urban form in many parts of Anglo-Saxon cities (see Newman, 2014). However, community support for increased zoning at proposed activity centres will be considerably enhanced by having a rail service as part of the positive benefits. Government's role in relation to zoning is to ensure that projects are not prevented from going ahead due to land use planning restrictions and will need to engage the public in detailed design discussions as well as showing the advantages of the new rail line and activity centre. In some cities like Vancouver a portion of the land investment is returned to local communities so that local value increases are fine-tuned to provide local benefit (Newman & Kenworthy, 1999).

4.1.1.3. Urban design and building standards. A high quality public realm and enduring urban design are vital to ensuring public acceptance of rail-based redevelopment. Such high quality is

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usually in the immediate commercial interests of developers as well as redevelopment agencies who are experienced in ensuring there are detailed design guidelines that cover all the issues such as density, diversity of housing type and mixed use, reduced parking requirements and improved walking and cycling conditions. These should include a proportion of social housing, to ensure access to such quality living is not just for the wealthy.

4.1.2. New roles for transport planners

4.1.2.1. Network coherency and integration. There is the potential for multiple private sector organisations or consortia to be involved in rail development under the Entrepreneur Rail Model. It is vital that these different lines, and any legacy publicly-owned infrastructure, are effectively integrated into a single network. This can be done at the procurement stage.

Ensuring network coherency and integration would involve:

- Ensuring an integrated ticketing system. This would require a process for sharing revenue between lines when passengers transfer;
- Regulating fares, ideally by a statutory or judicial body, rather than through a political process; and
- Potentially facilitating negotiations between different proponents whose lines should interconnect, or otherwise interact with each other. Also, ensuring that these interchanges run smoothly and are well maintained.

Since integration already occurs in most urban transit systems between different private sector operated services, it should not be too difficult to manage as long as it is clearly specified from the start. Transit operations will need to be well connected between services. Many cities have several different operators required to integrate with each other across the whole bus and train system. There is no evidence that city transit systems have suffered from private operators in their public transport systems (Newman & Kenworthy, 2015). Hong Kong and Tokyo's bus and rail lines are all examples of private integration required through regulation and they are among the best in the world in terms of service provision and patronage outcomes.

4.1.2.2. New assessment tools. The emphasis on conventional transport systems is on time savings at the start of system operations as the central factor in a benefit cost ratio (BCR). Some new assessment tools now include agglomeration economies as in the UK and which has tentatively begun in Australia including an Urban Regeneration Agglomeration factor (Newman, 2015). Transport planners with the task of assessing rail projects under the Entrepreneur Rail Model will need to have a new set of tools with which to calculate BCR's that include:

I. Accessibility benefits - Time savings at the start and over the next 30 years as the land development created by the rail project come into being providing new access advantages for people who are living and working and visiting the corridor;
II. Agglomeration benefits - economies that can be gained by the new density and mix of land uses that are facilitated by the project. Such elasticities are estimated in many cities such as those developed by Trubka (2012) on Australian cities;
III. Amenity benefits – economies associated with the whole package of quality design creating walkable urban areas; and
IV. Avoidable costs and benefits that are associated with any urban regeneration replacing development that is car-based on the urban fringe. There will be a need to replace or renew urban infrastructure in any urban regeneration project and this may be included in the costs covered by the private investors. If governments are assisting in this because of their energy, water, waste systems the costs will also have to include the costs of doing the same development on the urban fringe which over many decades have been subsidized by governments. Such headworks and substations in the Australian urban system amount to over $100,000 per new dwelling in the outer fringe developments compared to urban regeneration (Trubka, Newman, & Bilsborough, 2010a, b, c).

4.1.3. New governance arrangements

4.1.3.1. New institutional arrangements. The importance of enabling private sector investment in both a new rail line as well as the associated urban regeneration is the critical step in unleashing an Entrepreneur Rail project. This is not usually an integrated part of government thus there needs to be a new governance instrument. Without this the rail lines will not happen and the activity centres will not be built.

It is important that a government bidding process is controlled by a central agency, preferably Treasury, as the process is designed to ensure private sector funds are attracted to achieve public-good goals as well as the necessary profitability of the private investors like Superannuation Funds. It also has powers to extract information from other government agencies if required. Treasury would ensure consortia are evaluated by financial criteria, land development criteria and transit criteria, in an integrated way. This cannot be done by a transit agency as their emphasis on choosing the routes in detail first does not optimise land development opportunities so the rail frequently does not get built as no other funding can be found. A transit agency's primary task in our model is to ensure transit system compatibility with any new rail lines and to ensure they do not prevent the land development-based approach from happening.

Planning agencies should also only be there to ensure land assembly, zoning and building design are compatible with overall goals for the city, rather than picking the most appropriate development strategies and markets for urban regeneration. The delivery process will require the powers of a redevelopment agency to provide government's role in land acquisition, zoning and land assembly to unlock the latent value in land development around the stations. Only by enabling such partnerships is land value created.

It is therefore suggested that two new government roles are established. The first is something like a Transit Investment and Land Development Unit established in Treasury to oversee the bidding process for Entrepreneur Rail projects. State and City Governments should not need to have well developed plans for corridors otherwise opportunities can be missed by not seeking market-based judgements on where the best redevelopment could happen. Thus a Transit Investment and Land Development Unit can immediately call for bids from consortia to establish a private rail system based on development of activity centres along a particular corridor. The three criteria by which these could be evaluated would consist of:

1. Financial - the project should aim to be self-sufficient in capital and operating expenses based on land development, fares and other means such as advertising;
2. Land - the project should aim to utilize government land provided as part of the bidding process as well as private land that will need to be built into development partnerships or purchased as part of the project's financing. Land acquisition, zoning and assembly will be assisted by government to achieve

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required activity centre goals as well as sufficient funding outcomes to enable the rail line to be built.
3. Transit - the project should provide a high-quality transit service that is linked into the rest of the system and generates its own patronage from the land development activity centres. The quality of the system should be high enough to unleash the potential for development of the activity centres.

After a private sector consortium has been chosen to lead the planning and delivery of the urban rail infrastructure and the development of available government and private lands, there will need to be another coordinating government entity. We are suggesting the formation of a new Entrepreneur Rail Delivery Agency to facilitate the planning and delivery process. The delivery agency would be similar to development corporations and authorities that have been created in many cities over the last two decades for undertaking the planning and development of urban renewal projects. It would generally not need new legislation to establish and could be made part of a current redevelopment authority.

The development authority model is a tested method for delivering redevelopment through public private partnerships and thus is likely to apply to the Entrepreneur Rail Model. Thus, sufficient powers are likely to be available to help unleash the new governance instrument inherent in the Entrepreneur Rail Model. The potential for privatising present rail lines in order to create better TOD options would also be possible in the future under this model.

The potential mechanisms for managing an Entrepreneur Rail Model are summarized in Fig. 6.

4.2. Risk management

The final part of enabling the Entrepreneur Rail process would be to assist with risk management. As governance systems and private company systems are attempting to create a new approach to how urban rail can be built without government capital and operational funding, it is necessary to help provide a level of risk management. There are various ways that can be done but perhaps a key mechanism would be to reduce the number of consortia down to two key bidders and then fund them for the detailed planning phase where they need to create the land development opportunities and integrated plans involving multiple stakeholders. Such a risk management mechanism could be lifted when the governance systems are established and are providing confidence for all concerned. Such assistance could also be applied to a community engagement process that ensures value is shared in the project (Jillella & Newman, 2015).

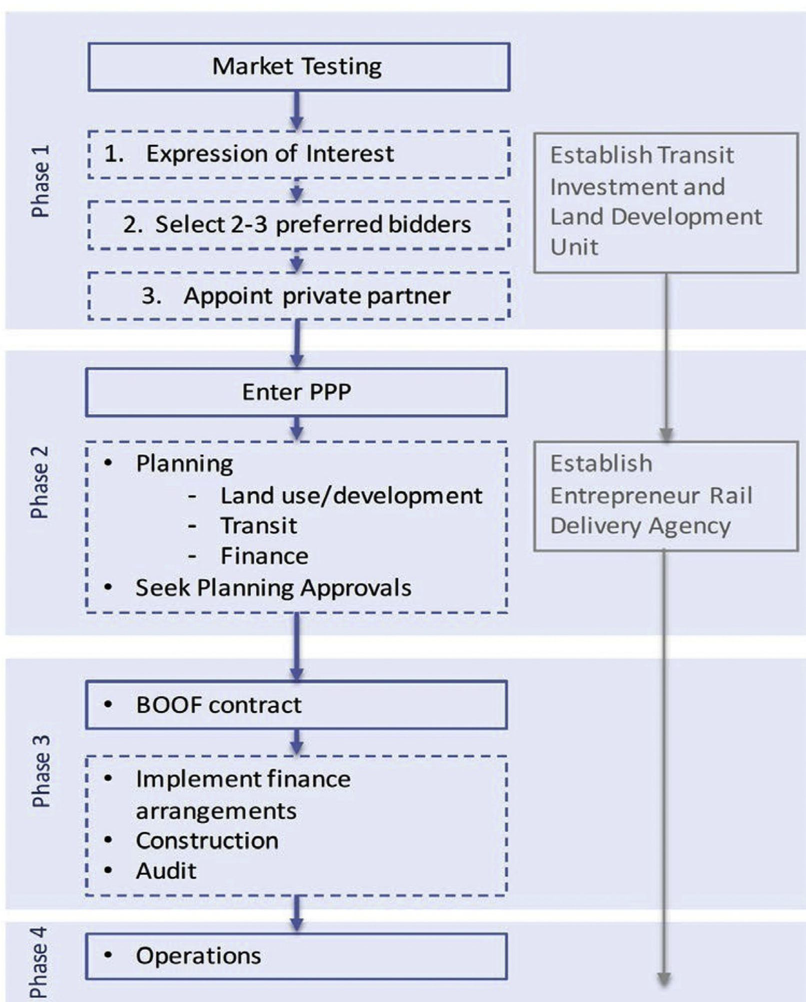

Fig. 6. Entrepreneur rail model potential delivery framework.
Source: Newman (2015).

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5. Conclusions

Urban rail projects across the world are now being owned and operated by private consortia (e.g. in Australia the new light rail in the Gold Coast, Canberra and Sydney as well as Melbourne trams and trains). This is not unusual. What is unusual about the Entrepreneur Rail Model is how land development becomes the cornerstone of its funding, how the integration of private land development entrepreneurial skill unlocks access to private capital and creates land value. The power of this model is that the unlocking of private development in new activity centres could not occur unless it was completely integrated with the amenity-creating, value-creating power of a new urban rail service. Finding ways to enable this model through government is a challenge as transport planners have been trained to see transit as a welfare model where they control the whole process. This will need to change as there is now a growing market for integrated urban rail and urban regeneration which cannot be done without involving the private sector. Various models for creating value through partnerships between transit, land development and finance, are likely to emerge but some of the key principles outlined here are likely to be needed to enable full public and private gains from the new markets for urban rail and urban regeneration.

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Article

Partnerships for Private Transit Investment—The History and Practice of Private Transit Infrastructure with a Case Study in Perth, Australia

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Abstract: Urban transit planning is going through a transition to greater private investment in many parts of the world and is now on the agenda in Australia. After showing examples of private investment in transit globally, the paper focuses on historical case studies of private rail investment in Western Australia. These case studies mirror the historical experience in rapidly growing railway cities in Europe, North America, and Asia (particularly Japan), and also the land grant railways that facilitated settlement in North America. The Western Australian experience is noteworthy for the small but rapidly growing populations of the settlements involved, suggesting that growth, rather than size, is the key to successfully raising funding for railways through land development. The paper shows through the history of transport, with particular reference to Perth, that the practice of private infrastructure provision can provide lessons for how to enable this again. It suggests that new partnerships with private transport investment as set out in the Federal Government City Deal process, should create many more opportunities to improve the future of cities through once again integrating transit, land development, and private finance.

Keywords: entrepreneur rail model; value capture; city deals; private railways; Western Australia; tramways; streetcars; land grants; future cities; urban planning

1. Introduction

After decades of strong government control of urban public transport infrastructure, transit planning is going through a transition to greater private investment in many parts of the world [1]. This is based on demand for a rapid transit system that can overcome traffic problems [2]. The process for doing this through private investment is obviously one that requires a partnership between all levels of government and the private sector and these are increasingly being labelled 'city deals' [3,4]. The focus on bringing private investment into transit funding is now on the agenda in Australia as it is required by city deals from the federal government [5,6].

This paper sets out to show how this global process is happening, how it could indeed follow the historical process that first set up transit systems using private investment, and how historical case studies from Western Australia suggest two means to enable the new transition. Examination of these new case studies adds to the global body of evidence of the entrepreneur rail model [1] and provides some insight into how such models might be reintroduced. It concludes by suggesting that the city deal governance process may be able to mimic the historic integration of transit, land development, and private finance so eagerly sought after by cities.

1.1. New Investment in Urban Transit

Rail transport is going through a renaissance globally, in what [6] calls "the Second Rail Age", with a concomitant peak and then decline in car use per capita [7]. This rail revival has involved new rail investment in the dense cities of Europe, the Middle East, and Asia, but also in the more car-dependent cities of the United States, Canada, and Australia [2]. The reason for this renaissance is the demand for better accessibility in cities where traffic speeds are no longer competitive with fast transit that can go under, over, or around the traffic [2]. Cities are now having to respond to this increasing demand by trying to find alternative funding sources and private participation, with a number of new models emerging.

In southern Florida, the Brightline, a privately funded and financed regional railway, recently began operation. This project has drawn substantial funding from transit-oriented developments around its stations (see Figure 1) [8]. This privately delivered model is favoured by the state administration, as a means to deliver infrastructure without a financial burden or financial risk to the public sector. In announcing a Brightline extension between Tampa and Orlando, the Governor of Florida stated that "through private investment, we ensure that this major project has zero financial risk to Florida taxpayers", comparing this model with the California High-Speed Rail project, which was federally funded. The Florida Department of Transportation is to run an open procurement process for the right to lease government-owned land along the corridor, rather than offering any funding support [9].

Figure 1. Miami Brightline. Source: All Aboard Florida, Brightline.

In Montreal, the provincial pension fund—the Caisse de dépôt et placement du Québec—is developing an elevated light rail line, with substantial funding from its depositors. The Caisse sees this as an opportunity for a long-term investment in "tangible assets that generate stable, predictable returns", in addition to delivering a public good outcome [10].

In Australia, the Consolidated Land and Rail Australia (CLARA) group is planning a high-speed rail line between Sydney and Melbourne, building new cities along the route. This new development will be used to service the project's finance. This project was a private initiative, but was undertaken in response to a long-running policy objective, which conventional public funding models had not been able to deliver [11].

In London, the £14.8 billion Crossrail project has sourced funding from a variety of sources, including the Greater London Authority, Department for Transport, and the private sector [12]. The UK Government's contribution had been capped at one-third of the total cost, so alternative sources of funding were required for the project to proceed [13].

Private funding is not that unusual in transport as toll roads are a common form of alternative funding; Regan et al. identify eight toll road projects implemented since 2003 in Australia alone [14]. Several of these have failed financially—the Cross City Tunnel, Lane Cove Tunnel, Clem 7 Tunnel, and the Brisbane Airport Road Tunnel failing to live up to their forecast traffic volumes [15]. However, railway capital funding has not been easily able to achieve sufficient return just from tolls (fares). The new approach has been a rediscovery of the insight that funding for rail is more likely to be raised from the increase in land values. The mechanisms for doing this have been found to vary across the globe either through various forms of additional levies or taxes [16–20], business improvement districts or special improvement districts [20–22] or transit-oriented development by the rail provider. The latter can involve joint development, in which a public transit agency's land assets are leased to a private partner [23–25] or more privately-led initiatives, such as the Japanese railway conglomerates, or London's Metropolitan Railway [26].

This paper considers how private funding of rail projects has happened in history and could be reintroduced into contemporary cities. Australia is somewhat lagging in developing more entrepreneurial rail building models compared with other parts of the world, but this paper shows there are historical models of railway development which were previously not well documented and which could help inform a future model of entrepreneurial rail-building in Australian cities. These case studies add to the literature on privately developed railways, integrated with land development, and provide further evidence of the effectiveness of this model.

Infrastructure planning and delivery in Western Australia is not averse to private investment, except in urban transport, both in roads and public transport. Perth Airport is run by a private company financed mostly by superannuation funds, including being 30% owned by a subsidiary of the Australian Government's Future Fund [27]. The mining community are structured to provide their own rail and road systems without government investment, including railways and roads. The government instead performs a regulatory function, through regulating third party access to railways and rail safety. There also is increasing involvement of private investment in health and education. However, in urban areas, including the capital city, there is no private investment in transport, just private involvement in the construction of the road and rail systems under government supervision. This is being challenged by the federal government's new involvement in Australian cities through city deals.

1.2. Land Value Uplift and the Entrepreneur Rail Model

Railway operations have often been difficult to make profitable through fare revenue alone [28–30], and there have been many attempts to address this deficit by taking advantage of the effect of railways on the value of surrounding land.

The land value effects of railways have been estimated by numerous prior studies. The common method of undertaking these estimates is hedonic price modelling, which estimates the willingness to pay for certain features of a property [31], such as its proximity to schools, parks, or in this case railways. The body of empirical evidence for the effects of the presence of railways on land values is substantial, with useful summaries of this research published [30,32].

Many forms of value capture have been documented. These include compulsory land-based levies, such as the "impact fee" in the United States [18], increments on property rates paid by business [15], special area levies [18]; tax increment financing [20,32], special improvement districts [20,21,33], and various forms of joint development programs [25,30].

The mechanisms listed above involve additional revenue being raised from land to fund infrastructure delivery by government agencies. In addition to these public funding models, there is a substantial amount of rail building by private companies and commercially-motivated government-owned businesses that we have called the entrepreneur rail model [1]. These invariably make use of land assets to increase their profitability. The Hong Kong MTR Corporation is well documented [24] and the Japanese railway companies have been particularly adept at finding alternative sources of revenue, with real estate development and management being particularly significant [34].

As will be shown below, this entrepreneur rail model was practiced in many parts of the world in earlier times and it is the purpose of this paper to see what can be learned from this as cities across the world look to build a lot more urban rail.

1.3. Theory, Purpose, and Structure of the Paper

This paper is part of two urban science theories: the theory of sustainable cities and urban fabric theory. The first, developed by [35], suggests that cities become more sustainable when they reduce their metabolism (resource consumption and waste production) whilst simultaneously improving their livability (economic and social factors like jobs, health and community). The theory shows how this cannot be done without restructuring the city and this primarily is determined by transport priorities. The second theory [36] pursues this concept in more detail by showing that every city has a combination of three cities, based on their history of development: walking city, transit city, and automobile city. The three eras are based on transport priorities and create three different fabrics: walking fabric, transit fabric, and automobile fabric. The relevance to this paper is that global priorities have shifted to seeing the significant economic, social, and environmental benefits of having more walking and transit fabric; this cannot happen unless cities find new ways of restoring the transport priorities and investment in these modes whilst at the same time building in their associated urban fabrics. Thus, the urban science of transport and land use planning needs to understand the history of transport and how to learn from it in delivering more sustainable cities.

The paper brings new case studies to the global body of evidence on the entrepreneur rail model, in the form of urban tramways (as streetcars are referred to in Australia) and land grant railways in late-19th and early-20th Century Western Australia. It examines the regulatory regimes prevailing at the time of these projects, offering potential guidance to future policy makers.

These case studies are notable for the small and isolated settlements involved. The paper also discusses the urban contexts in which these projects took place, noting the rapid population growth during the time of the streetcars. There is extensive literature on the viability of transit in terms of urban density, but the rate of population growth will also be a relevant variable for entrepreneur rail model projects (see discussion below).

The remainder of this paper is set out as follows:

- Section 2 provides a series of global historical case studies of entrepreneurial rail building. Rather than being a comprehensive history this is intended to demonstrate the breadth of this model of railway building—commercially-motivated and linked to land development.
- Section 3 examines the Western Australian case studies, being Perth Electric Tramways Ltd. and the earlier land grant railways.
- Section 4 draws conclusions on the potential for this model of railway building to be revived in contemporary western cities, potentially incorporating the more recent governance innovation of the city deal.
- Section 5 contains concluding remarks.

2. Global Entrepreneurial Rail History

Linking land development with railways is almost as old as the technology itself. A brief overview of railway history in Britain, North America, and Asia will set the scene before further pursuing the Australian and Perth rail stories.

2.1. Britain

In Britain, a period of rapid railway expansion took place during the 1840s, after several technological developments during the 1830s and 1840s. This peaked in a speculative frenzy called the "Railway Mania" [37]. This ended in a crash in the late 1840s and early 1850s, with a sharp decline in revenue per mile of track. There have been widespread suggestions of accounting fraud during this period, although hard evidence for this is limited, and overly optimistic predictions or obfuscations regarding construction cost and revenue are more substantiated [38]. However, the resultant spread of railways around the country resulted in exponential growth in passenger numbers over the following decades (see Figure 2) followed by a downturn in the 20th century, until its recent privatization which has taken rail into a new period of substantial growth. It has been suggested that the losses associated with the Railway Mania were exacerbated by inefficiency in the route planning of the early railways, based on the assumptions of proponents that their business would be dominated by travel between major cities, rather than taking account of demand in smaller places [39]. With demand now settled and big cities growing, the second rail revolution is now well underway.

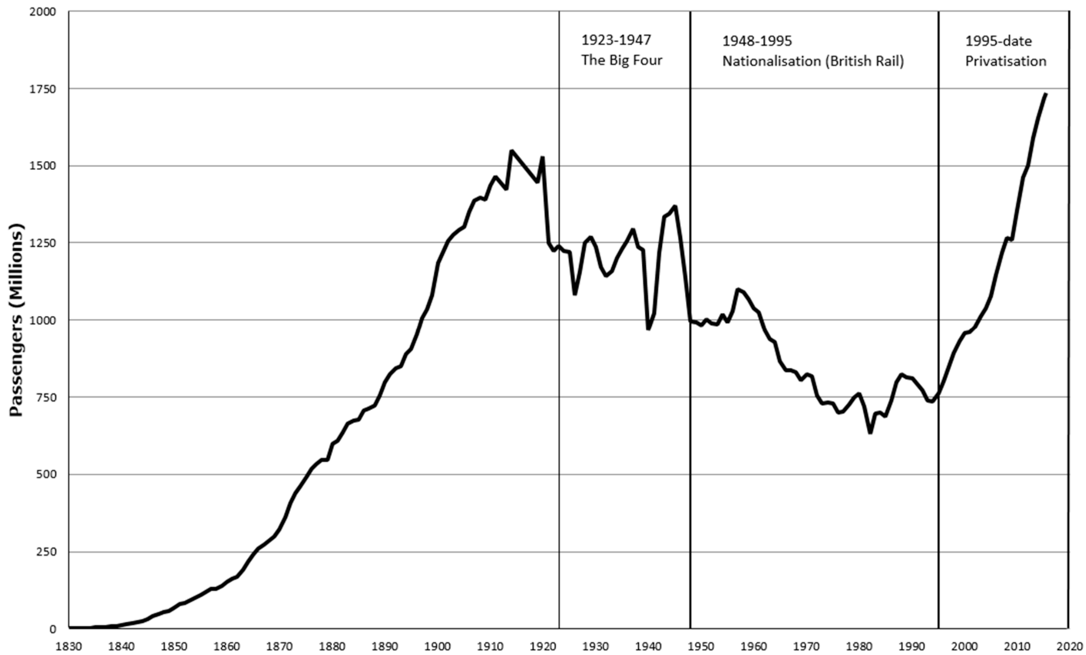

Figure 2. Railway passenger numbers in the U.K., 1829–2016. Source: Wikipedia Commons.

The effects of railways on real estate was quickly realised in the 19th century and was particularly prominent in development of the London Underground with much of what became the London Underground being built as joint railway and suburban development projects.

The Metropolitan Railway began as a public–private partnership, with the City of London purchasing £200,000 worth of shares in the company and the company concurrently purchasing land of £179,000. A railway was opened in 1863, built with these funds, and with high ridership. Over time, the company consolidated several other railway companies as well as acquiring bus and tram operators and integrated these services with its railway business [40]. As shown above the first signs of a return to greater private investment in UK rail is now beginning.

2.2. North America

In the United States, land grant railways were used as a means to settle and develop the interior and west of the country, and link the two coasts by rail. The US Federal Government operated a land grant system between 1855 and 1871, giving millions of acres of land in the west to railway companies. Private railway companies built an extensive network across the country, providing access to farms and connecting cities [41]. There was a period of reorganisation of the industry, with J.P. Morgan, a New York financier, playing a prominent role. He both raised funds in Europe, and helped the railway companies reorganise and thereby operate more efficiently.

In addition to long distance railways enabled with federal land grants, streetcars were introduced into many American cities by private operators, expanding them beyond the range of the old walking city. Warner gives a detailed account of the development of Boston from around 1850 onwards, during which streetcars were introduced, initially horse-drawn, and the metropolis expanded from the core walking city of approximately two and a half miles in radius [42]. These streetcars were often built as a device for marketing land on the outskirts of the old walking-based city [36].

In Canada, the Canadian Pacific Railway was built in the early 1880s to link the then populated eastern part of the country with the under-developed west. Challenging terrain and the great distances involved almost bankrupted the Canadian Pacific Railway Company, but the line was ultimately completed in 1885.

The company was involved in a range of related businesses, including land sales and settlement. This began in 1881, before construction was even complete [43]. The Canadian Government had granted the company 25 million acres (100,000 km^2) of land, and it was sold on to settlers, whom it actively recruited [44]. The company campaigned to attract settlers to the area, advertising in various countries. The settlers were often sold a package that included the land, sometimes ready-made farms, and transport by the company. Under this railway-led immigration scheme, the population of Canada increased by one-third in the first decade of the 20th Century, from 5.3 million people to 7.2 million people [45].

Canadian Pacific is still in operation, and offers land along its network for lease [46]. With the advent of the motor car and bus, the era of railway development went into hiatus, but investment in rail has increased in recent years, in the Second Rail Revolution [4] though it is only very isolated compared to the historic era of rail growth.

2.3. Asia

While the practice of entrepreneurial rail building mostly ended in Europe and America during the period after the first half of the 20th Century, several Asian countries have continued the practice in developing their rapidly-expanding cities. In Japan, the railway network is a complex mix of public, private, and privatised railways. Several companies have used railways to enable new town developments on the outskirts of the major cities, with a large number of lines branching off the Yamanote Line to the west of Tokyo, and a number of such lines having been built in the Kansai region. This model was pioneered in the early 20th Century by the Hankyu Railway Company, Osaka. Hankyu struggled to profit on railway fares alone, and so began building housing estates and later office towers along their railways.

The land into which Tokyu expanded was often broken up into a large number of farming lots, creating a complication for land assembly. The solution that evolved to deal with this issue is known as land readjustment. Under this model, land owners would contribute their land to the development project, and in return would receive back a smaller portion of improved land, with services installed and a new railway connection. The original land owners were also placed on a committee that oversaw the urban design outcomes that occurred as part of the new developments. Interestingly, one of the pioneering companies was Tokyu Corporation, originally a town planning firm, and whose founder was inspired by Ebenezer Howard's vision of a series of garden cities for the working population. It was Tokyu's reputation as an ethical business that enabled it to gain the trust of the farmers when seeking to redevelop their land [34].

In Hong Kong, the Mass Transit Railway Corporation (MTR) is a semi-public, semi-private organisation listed on the Hong Kong Stock Exchange, but majority owned by the government [39]. The MTR receives land from the Hong Kong Government at pre-rail prices, and then builds the railway infrastructure and develops the land in partnership with private developers. This model is known as 'rail + property'. Property rental and management is a large part of the MTR's business, accounting for more of the company's operating profits than its heavily-patronized transport operations [47]. Property-related businesses operating in Hong Kong accounted for 57% of total operating profit on average between 2012 and 2016 (see Figure 3).

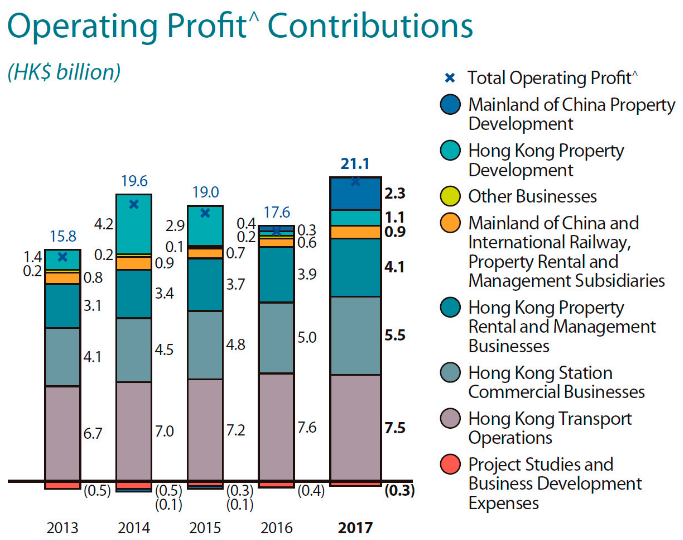

Figure 3. Hong Kong MTR Corporation operating profit. Source: MTR Corporation [48].

In Singapore, transport and land use planning is much more centrally controlled, although there is still considerable private involvement and a core function of returning money to government through land development. The Singapore Government, through the Land Transport Authority (LTA), owns the entire railway network [49], but contracts out operation of different sections of the network to two companies: Singapore MRT (SMRT) and SBS Transit [50]. Bus operations are also contracted out under a contracting model begun in 2016, with the LTA owning all the buses, collecting all the fare revenue, and then leasing the buses to operating companies [51]. SMRT has previously been partly privately-owned, similar to Hong Kong MTRC, but is now 100% owned by Temasek, the Singapore Government's investment company [52]. Responsibility for planning, designing, and building the network lies with the Land Transport Authority, a statutory authority under the Minister for Transport [53].

Large scale land development is undertaken by two public organisations: The Housing and Development Board and the Urban Redevelopment Authority. They earn revenue from rental payments, car parking, sales, and interest [54]. Land development-related funding is therefore a strong part of the success in Asia's most successful rail systems.

2.4. Australia

Rail building in Australia began in the middle of the 19th Century, and was a mix of private and government schemes, depending on the colony. The first railway track in New South Wales began construction in 1849, built by the Sydney Railway Company. This ran for 22 km between Sydney and Parramatta and opened in 1855. The line was not financially successful and was taken over by the colonial government of New South Wales. In Victoria, the Melbourne and Hobson's Bay Railway Company opened a line between what is now Flinders Street Station and the Port of Melbourne in 1854. In Queensland and South Australia, the respective governments began railway construction in 1864 and 1854 in rural mining areas. In Tasmania, the Launceston and Western Railway Company opened a line between Launceston and Deloraine in 1868 [55]. In Western Australia, the Department of Works and Railways was formed in 1877, and Western Australian Government Railways built the Geraldton to Northampton railway in 1879 for mining-related activity. This was followed by passenger railways connecting Perth to Fremantle and Guildford in 1881 [56].

Western Australia's rail history provides two case studies of entrepreneurial rail building: the privately-built tramway network and the land grant railways running from near Perth, the state capital and principal city, to the regional centres of Albany and Geraldton.

3. Historical Case Studies from Western Australia

Western Australia had a history of entrepreneurial rail building in the late-19th and early-20th centuries, and these historical examples provide some insights into how rail infrastructure might be procured today without resort to public funding.

The case studies presented in this paper are:

- The Perth Electric Tramways Limited, a British company that laid down the core of the extensive tramway network in the capital city, Perth, which was later subject to state takeover.
- The land grant railways—two railways were developed in Western Australia with grants of undeveloped land that the government was unable to bring under development on its own. This model was essentially the same as the American railways and the Canadian Pacific.

All of these lines were funded and financed from private money, with land development as the ultimate source of funding. These privately-funded lines carried both passengers and freight, including building materials to the developments they serviced, and in the case of the tramways, 'night soil', as this was prior to sewerage systems being installed in many parts of the city.

3.1. Perth Electric Tramways Limited

Perth once had an extensive tramway network, much of it built by a private company, the Perth Electric Tramways Limited. The system was taken over by the state government in 1913 (Tramways Purchase Act 1912), and progressively closed down in the 1950s and 1960s (pp. 153–161, [57]).

The individual lines were built under a well-established regulatory framework. This involved the tramway company and relevant local authority reaching an agreement on the new route, and then seeking an order from the state government, ending by being ratified by Parliament.

At the time of the state takeover in 1913, the Perth Electric Tramways Limited was running a substantial network, including lines used to enable real estate development on the then urban fringe. This model was strikingly similar to that used by the Japanese railways and was roughly contemporaneous with the establishment of the Hankyu railway company in Osaka. This model's success in Perth is particularly noteworthy given the relatively small size of the settlement at the time, albeit growing very rapidly, from approximately 71,000 people in 1901 to 111,000 people in 1911 [58], an annualised growth rate of 4.7%.

3.1.1. Tramway Regulatory Framework

Tramways in Western Australia were built under a regulatory framework laid out in the *Tramways Act 1885* [59]. This Act was modelled on the United Kingdom's *Tramway Act*, and also mirrored the acts in force in the neighbouring colonies (that is, the rest of Australia, and possibly New Zealand) [60].

This act created the regulatory framework for private or municipally-led tramways. A potential private promoter or a local council could apply to the Commissioner of Railways (a political rather than bureaucratic role) for the authority to build a tramway. This authority was known as a provisional order, and the Commissioner had extensive powers to mandate various design and operational standards (for example, track width, track slab material, minimum service frequencies, maximum travel speeds, and others). This provisional order required a further Act of Parliament to come into effect, and was sometimes amended by Parliament.

The Commissioner retained significant powers over the tramway, including the right to vary a section of its alignment, and to force the tramway operator to pay for a bridge over a railway track, if the government decided to build a railway that crossed the tramway in the future.

The government also took a bond from the promoter, as a guarantee that work would progress, and there were tight construction timelines included in the provisional orders, within which construction was required to be commenced and completed.

There were protections for the local communities from tramway development, with consent generally required by local authorities, and tramways were not to be built within 10 feet of the foot path, if one-third of the property owners abutting this section dissented. These protections would have required significant negotiation by the promoter with local stakeholders, which is also a feature of Japanese railways and the associated land assembly and redevelopment.

The first tramway was opened in 1899 [57]. Well-preserved records survive for two integrated tramway and real estate developments: the Nedlands Park and Osborne Park tramway estates.

3.1.2. Nedlands Park Tramway Estate

As noted above, streetcars were privately developed in many American cities, and this process became closely linked with real estate development. The beginnings of a similar process also occurred in Perth, with the Nedlands Park Tramway Estate the most prominent example.

The Nedlands Park Tramway Estate was built on approximately 240 acres of land, which was subdivided into 800 lots [61]. The site was on the boundary of two municipalities, and there was a complicated arrangement with the two local authorities in question. The terms included the following:

- The two authorities would receive 3% of the gross profits of the tramway operation between them, in lieu of rates payments and in return for the right to use the roadway.
- The developers were to build a public jetty on the river foreshore at the end of the tramway, as well as public baths. The jetty was to be handed over to the one of these municipalities, who would also have the option to purchase the baths at any time. The baths were to be ceded to the municipality at the end of three years regardless.
- A substantial area of river foreshore land was ceded to the two authorities, to be maintained in perpetuity as a reserve for the local community (this foreshore reserve was used as a selling point in marketing the estate).
- The two authorities had responsibility for building and maintaining various roads, and maintaining the foreshore.

While the development obviously was expected to be profitable for the promoter, there was also a benefit to the public finances due to an increased property tax base. The Claremont Roads Board strongly favoured the development and estimated that it would increase their property rates revenue in the area due to raised land values and an increase in building activity (p. 974, [62]). Although the agreement granted considerable concessions to the local authorities, they spent a substantial sum on works in the area, particularly on upgrades to the foreshore.

The proposal was politically contentious, with the opposition party claiming the line should not be built by private enterprise. The reasons given for opposing the plan were that the revenue should be retained by government, if the tramway was profitable, and also that a private tramway should not be allowed to compete with the government railway. The record of parliamentary debates also shows there was concern that the promoters would gain the right to build a tramway as a means to sell the land and then not proceed with construction (p. 1700, [62]).

The Nedlands Park Tramway Act 1907 was passed despite opposition, with a number of conditions imposed on the promoters, including:

- Construction on the tramway was to commence within nine months of the bill being passed, and to be completed within nine months.
- There was to be a minimum service level of nine cars per direction per day.
- Maximum fare levels were set.
- There were certain construction standards, including the materials used and gauge of the tracks—which were the same as on the existing tramway network, $3' 6''$.
- The promoter was required to pay a deposit of £1000 into the Colonial Treasury, a substantial sum at the time. If the promoter did not meet minimum service levels over the course of the following 10 years, or failed to complete the tramway on time, then this deposit would be forfeited [63].

The tramway was completed in 1908, shortly followed by the public baths and hotel. These facilities were all advertised in the estate's promotional material (see Figure 4). Similar to the department stores and amusement parks built along the Japanese private railways, these facilities were intended to draw visitors to the leisure area at the end of the line, while also acting as an advertisement to potential buyers of the land. These attractions at the end of the tram line would also have generated additional patronage, beyond that of the workers commuting to the central city.

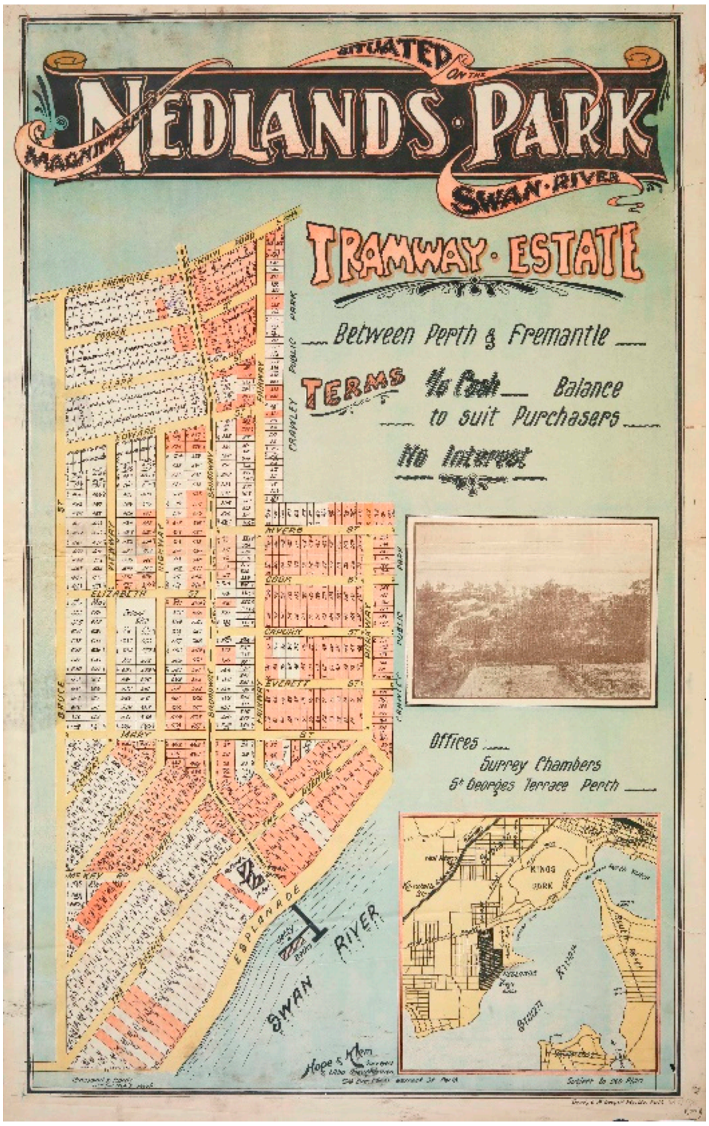

Figure 4. Nedlands Park Tramway Estate map. Source: Battye Library.

3.1.3. The Osborne Park Development

The Osborne Park line was built by Town Properties of West Australia Ltd., to promote sales of their 7000-acre land holdings on the northern outskirts of Perth (see Figure 5) [64]. This was prompted by the company having had difficulty selling its lots as they were felt to be too isolated from the city [65]. The company gained authority to build the line through the North Perth and Perth Road Board Districts Tramways Act 1902 [66].

The line was an extension, running from the end of a line in an existing tramway suburb, and terminating outside a hotel and tavern built by the company (p. 47, [67]). This totaled 2.5 miles of new track (4 km).

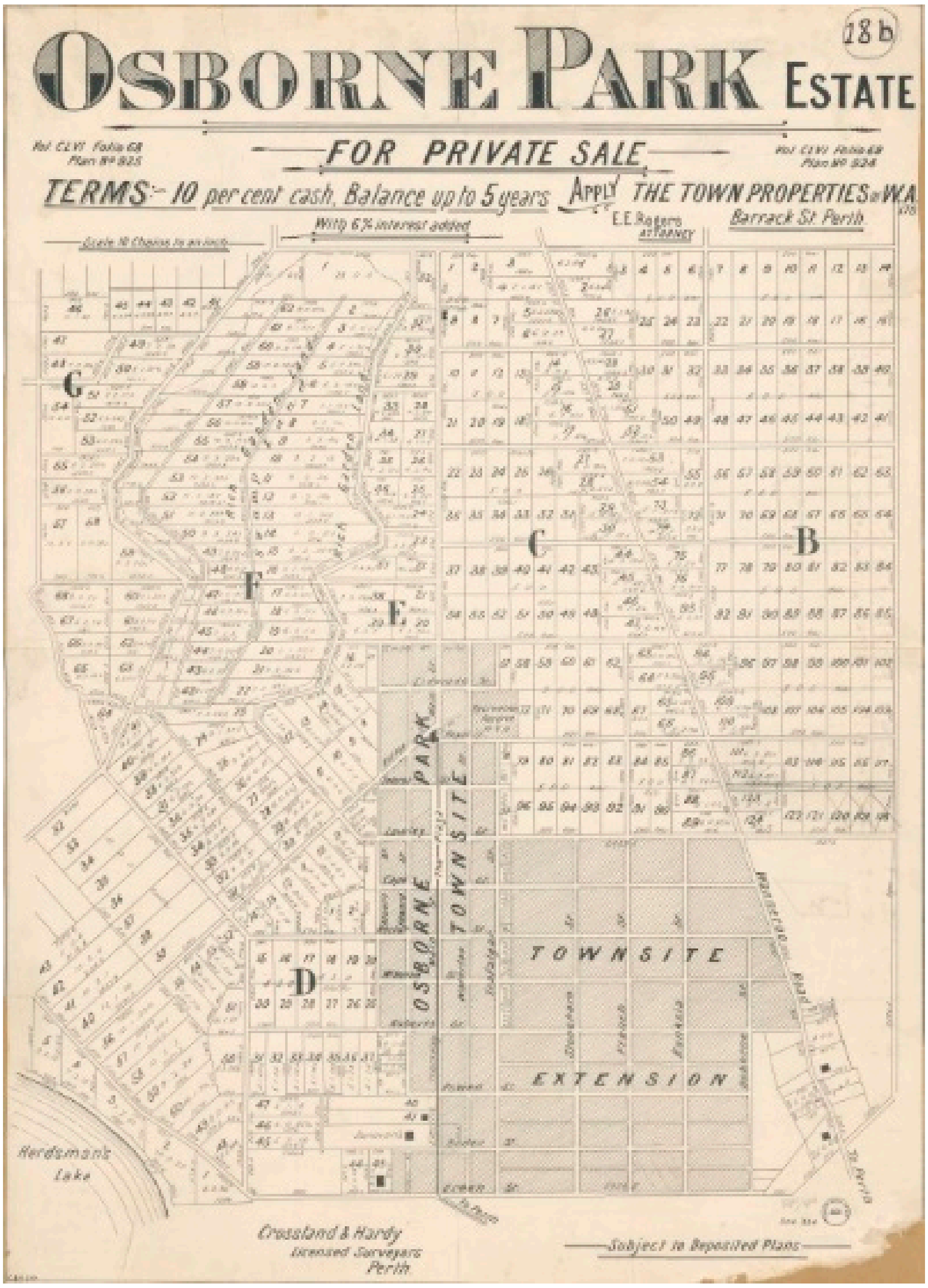

Figure 5. Osborne Park Estate Map. Source: Battye Library.

As was usual for tramway legislation in Western Australia, the local authority had options to purchase the tramway, in the case of the Osborne Park line, after 21 years from the date that the company was required to have completed construction under the act. If this option was not exercised, another option was available after 28 years, and after 35 years the line would have reverted to the local authority anyway, free of charge.

3.2. Great Southern and Midland Land Grant Railways

Similar to the United States and Canada, government land grants were provided to a private railway company in Western Australia, to promote government strategic objectives. In the case of Western Australia, there were two objectives: to open up undeveloped land for agriculture and town-building, and to connect Perth with a deep-water port in the town of Albany, over 400 km away.

One of these railways, the Great Southern Railway, connected Perth and Albany, while a second land grant railway, the Midland Railway, connected Perth to the port town of Geraldton, a similar distance to the north (see Figure 6).

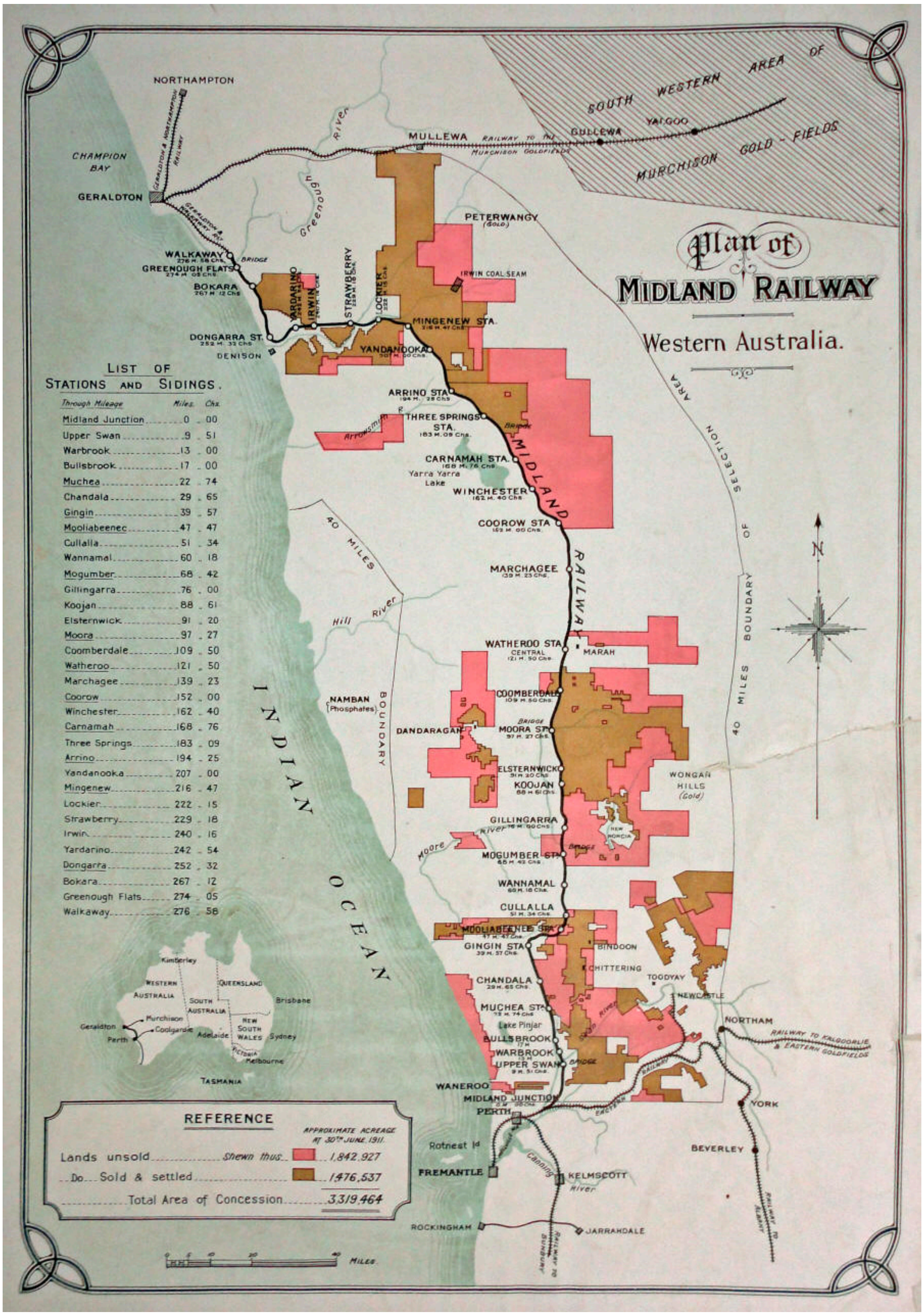

Figure 6. Map of Midland Railway, Western Australia. Source: Carnamah Historical Society.

Under the land grant system, the colonial government granted the companies 12,000 acres of crown land for every mile of track constructed (approximately 3000 hectares per km). This land was undeveloped, and the companies sold the land on in small parcels as town site lots, as undeveloped parcels, and as ready-made farms, the latter being particularly prevalent on the Midland Railway. The Great Southern Railway resulted from an agreement between the Governor and the West Australian Land Company in 1884, and the Midland Railway in 1886 [68].

This system addressed two issues facing the government at that time: the desire to develop the colony and expand its population, but with the railways being beyond the Government's limited financial means at the time (p. 933, [62]). The land grant system achieved both of these goals, with the companies both raising private capital in London, and advertising the land to potential immigrants across the British Empire (see Figure 7). The companies also provided finance to their purchasers.

Figure 7. Midland Railway advertisement for farmland. Source: Carnamah Historical Society.

The Midland Railway Company remained in private operation until the 1960s, but the Great Southern Line was taken over by the State in 1896, only 12 years after the original agreement was entered into. The justifications for the acquisition was that land development was proceeding fast enough, as well that the railway should be publicly owned on principal. Many of the farmers who bought into the Midland Railway farmland struggled to make the necessary payments, as the farmland was not of the high quality stated in the company's advertising material. Eventually, the company had to write down the value of the land in the scheme by 40%, in order for the individual farmers to be able to meet their obligations.

The government agreed to pay £1,100,000 for the tracks and remaining land. The Premier estimated that the company would expect to make approximately £75000 in revenue that year, of which costs would consume 51% (p. 934, [62]). This implies a margin of £36,750, before taxes (and taxes were comparatively low at that time), or a 3.3% return, if this government offer was considered the market value of the enterprise. This was close to the government interest rate at the time of 3%.

4. Reinventing Entrepreneurial Infrastructure

Clark and Moonen [5] note that Australian cities are lagging behind in terms of infrastructure, particularly transport infrastructure, and link this to a relatively undeveloped public transport system. Specifically, they state that "as the metropolitan century unfolds, Australian cities continue to attract population growth that surpasses the capacity of their infrastructure systems". The necessary solution is "high-capacity public transport that underpins and supports superb urban amenities with high quality, medium density living", and the authors note that all of the cities that are celebrated today followed this path. Almost all of these cities' railway networks were built by commercially-focused organisations.

In addition to the existing models in Asia, there are emerging examples of development-funded railway building in the cities in North America (Brightline), Europe (Crossrail), and Australia (CLARA) as outlined above. There is also a large body of evidence that railways still raise land values in sprawling, car-dependent cities [32,69–71], suggesting that motorisation is not an insuperable barrier to substantial development-sourced funding.

4.1. Lessons from Western Australian History

The Western Australia tramways present a potential case study of how a small but rapidly growing area could fund rail development through real estate. It also suggests a possible regulatory framework for private rail developers, with some of its key features being:

- The requirement for government approval, first through the responsible minister, and then by the legislature.
- Control of building standards and track gauges, to ensure standardisation and integration between the lines of different proponents.
- Prescribed construction timelines and a cash bond, to ensure the promoter delivers the promised infrastructure, and in a timely manner.
- Protections of the rights of adjacent property owners.
- Powers for government agencies to modify or otherwise interfere with the rail infrastructure, if required for some public purpose.
- A strong local government involvement, early on in the process.

Land grant railways demonstrate how publicly-owned land can be used to deliver strategic government objectives, without direct government funding.

As an alternative to granting strategically-located parcels of urban land, long-term leases or the sale of development rights are a common mechanism to retain ultimate government control, while providing land for development. This has been done effectively in Hong Kong (by MTR Corporation); Portland, Oregon (a light rail extension to the airport); and Washington D.C. (Washington Metro's joint development program). The Government of Florida has also begun to offer public land for lease for rail extensions, as noted above.

In addition to a suitable governance model, successful transit infrastructure requires certain conditions to prevail in a city [30]:

- The increment in improved accessibility offered by the new transit.
- The rate of growth, with new transit infrastructure is more likely to affect land development in rapidly growing cities than in those where growth is slower.
- The ease or difficulty in assembling land parcels within close proximity to stations.
- The severity of zoning, or similar political or legal barriers to development.
- Transit-land use integration.

Against the first of these considerations, the improvement in accessibility created by new transit, motorisation and urban sprawl often undermine transit in developed world cities. For example, in contemporary Western Australia, motor vehicle ownership was 863 vehicles per 1000 population [72] almost one vehicle per person. This prevalence of motor vehicles dilutes the accessibility benefits of new transit, however fixed guideway transit still has a measurable effect on land values in car-dependent cities [32].

Effectively, all developed countries show high rates of motor vehicle ownership, and there are a range of implicit subsidies to driving. Examples of these implicit subsidies include publicly funded, un-tolled highways, mandatory off-street parking as a development condition and designed to meet peak parking demand [73], land use controls that restrict density and separate land uses, and taxes levied on the existing city being used to fund infrastructure construction in new suburban developments.

The Western Australian case studies support prior findings on the effects of growth in transit provision. The cases presented in this paper are of interest for the small size of the settlements involved suggesting that it is growth in land values that is the core factor in attracting a potential rail project. In addition to growth, urban density is a major determinant for the success of such models. Urban density improves the cost efficiency of rail [74] and its modal share [75]. Estimates have been made of the minimum density required to run viable transit services, although there is some variance in these estimates [76,77]. Zoning will be a critical issue in the success or failure of entrepreneur rail model projects, as there will be a strong link between development yield and project funding.

4.2. Can City Deals Mimic Historical Rail Governance?

Historical rail governance models match Newman et al.'s definition of the entrepreneur rail model [1] and raise the question of whether current thinking on PPPs and other policy innovations can be used to mimic these historical models. The obvious candidates to examine are city deals, which are generally delivered as a partnership between different tiers of government, and facilitate greater private sector involvements. There is some justification for public sector support of the entrepreneur rail model, and even in the early days of railway building, government support was not unknown, such as Japan's Light Rail Subsidy Law of 1911, which provided a subsidy of up to 5% of construction costs (limit later raised), depending on profitability [78].

Such support may be necessary to compensate for the effects of motorisation in undermining efficient transit provision, as discussed above, which has been encouraged by government policy in many countries. It is uncertain whether a completely unsubsidised entrepreneur rail model is possible given the historical automobile urban fabric resulting from the 20th Century period of motorisation and ongoing indirect government support for motorisation.

There are several ways in which a city deal arrangement could support an entrepreneur rail model:

- Demonstration of government commitment: explicit government support can give investors confidence about political and regulatory risk. This is often given as one of the explanations for rail projects' increasing land values.
- Regulatory and compliance burden: one potential role of government is to simplify or otherwise manage its own regulatory approvals processes for a project, including land use planning approvals. In some jurisdictions, approvals can be time-consuming and can create uncertainty. This is a concern raised by the Australian property industry [79].
- Risk: A joint railway and large-scale real estate development is a large project, representing a substantial risk for a private company. In particular, this model requires a large upfront capital for development costs and to build the infrastructure. The returns come later, as the developments go to market, and final sales are uncertain. Government can provide financing guarantees to lower the cost of finance for potentially high-risk undertakings.
- Several roles suggest themselves for different tiers of government in Australian cities:
- Land assembly for redevelopment: this role could be filled by state and local government. In Western Australia, a state government mechanism already exists for acquiring land for long-term strategy infrastructure planning. This is the Metropolitan Region Improvement Fund, which uses revenues from an increment on the state's land tax to fund land voluntary acquisition for public purposes [80].

- Concessional finance or underwriting: for large projects, this role might be filled by the national government, whose larger financial resources allow it to better absorb this risk. Concessional finance was provided to the Tsukuba Express project in Japan [81].
- Community and stakeholder engagement: this role can be undertaken by the relevant local governments, and the project proponent, as has been done by the CLARA consortium in Australia.
- Regulatory co-ordination: all tiers of government have regulatory functions. Simplifying this process can result from a partnership between different levels of government. City deals are particularly suited to this function.

City deals are one potential mechanism for government support of an entrepreneurial rail project, and they are currently on the political agenda in Australia. These city deals are predicated on collaboration between the different tiers of government, and "aim to integrate transport, housing and land use policies" [82].

Several agreements have already been signed in Australia, including the Perth City Deal, which is intended to deliver the METRONET railway and transit-oriented development project. The memorandum of understanding covers a wide range of domains of action, but specifies cooperation with local government, communities, and the private sector.

5. Conclusions

The early railway building history in Western Australia provides two new case studies of privately-funded railways, integrated with land development. This adds to the body of evidence from Europe, North America, and Asia.

These new case studies are particularly notable for the small population of the settlements involved, combined with their isolation from other major population centres. However, similar to Victorian-era London and the mid-20th Century Japanese cities, rapid population growth and economic development was taking place. This suggests that urban growth, rather than absolute size, is more important for the economics of integrated railway and real estate development.

Similar to the land grant railways in North America, the Western Australian land grant railways are a demonstrated model for partnering with the private sector to achieve government's strategic objectives, particularly when those objectives are beyond the capacity of government to achieve with its own resources. The tramways are another example of urban rail public transport co-developing with and being funded by expanding development.

These provide potential governance/procurement models for increasing private involvement in contemporary cities. The city deal process as suggested by the Australian Federal Government is largely following the governance process created for the original tramway and railway system in Australia and could once again enable a boom in integrated transit, land use, and finance.

However, the historic systems were built prior to motorization, and the question remains as to what extent this would compromise the economics of a similar model in a contemporary city. Numerous recent studies from car dependent cities have shown that land values still respond strongly to railways. The next step is to trial some of the historic models in growing western cities, like Perth, to see if there is potential to accelerate private investment in building urban rail.

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The Trackless Tram: Is It the Transit and City Shaping Catalyst We Have Been Waiting for?

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Abstract

Recent innovations in transport technology are now providing mobility that is cheaper, autonomous, electric, and with improved ride quality. While much of the world's attention has been on how this can be applied to cars, there have been rapid adoption of these and other technologies in High Speed Rail and Metro Rail systems that run between and across cities. This paper shows how such innovations have now been applied to create the next generation of urban transit system called a Trackless Tram. Trackless Trams are effectively the same as traditional light rail except they run on rubber tyres avoiding disruption from construction for Light Rail, but they retain the electric propulsion (with batteries) and have high ride quality due to rail-type bogies, stabilization technologies and precision tracking from the autonomous optical guidance systems—with infrastructure costs reduced to as low as one tenth of a Light Rail system. As with Light Rail, a Trackless Tram System provides a rapid transit option that can harness the fixed route assurance necessary to unlock new land value appreciation that can be leveraged to contribute to construction and running costs whilst creating urban regeneration. The paper considers the niche for Trackless Trams in cities along with its potential for city shaping through the creation of urban re-development along corridors. The paper suggests that the adoption of Trackless Tram Systems is likely to grow rapidly as a genuine alternative to car and bus systems, supplementing and extending the niche occupied by Light Rail Transit (LRT). This appears to be feasible in any medium-sized or larger city, especially in emerging and developing economies, and case studies are outlined for Perth and Thimpu to illustrate its potential.

Keywords

Trackless Trams, Trackless Operation, Autonomous, Self-Guiding, City Shaping, Urban Regeneration, Entrepreneur Rail Model, Transit Activated Corridors, Congestion Relief, Job Creation, Sprawl Relief, Environmental Benefits, Social Benefits

1. Introduction

1.1. Overview

Cities around the world now have a range of new technologies related to transport to choose from, such as electric vehicles and charging infrastructure, driver-assist and self-driving vehicles, low-cost sensors, increasing travel data sources, Big Data analytics software, internet-of-things platforms, and even more recently, artificial intelligence, machine learning and distributed ledger technologies. Considering the innovation of autonomous vehicles, Kim [1] suggests that such technologies will have "*tremendous implications to the socio-economic environment in the future world*". The way that these types of technologies are navigated will have a direct impact on the very functioning of a city, affecting quality of life, accessibility, commuting times, and the level of urban regeneration that can be unlocked by effective and efficient transport networks. The autonomous transport technologies that have come out of motor vehicle research combined with new information and communications technologies (ICT) and smart systems, have not yet found a proper niche in any city. The claims being made based on time savings, safety and environmental grounds include the idea that no other forms of transport will be needed other than autonomous automobiles. Newman and Kenworthy [2] have pointed out that there are already signs that such claims may in fact not live up to this initial hype as visions of cities given over completely to driverless vehicles are unlikely, meaning that the positive benefits of these new technologies may never be fully realised.

On the other hand, the autonomous, electric and stabilization transit technologies developed for High Speed Rail (between cities, over 300 kph) and Metros or Suburban Rail (within cities, 80 - 150 kph) have developed the speed, capacity and ride quality that have led to spectacular increases in ridership [3] [4]. These technologies are able to guide trains at high speed to provide passengers with a level of comfort and safety that is unparalleled in the history of mobility. However, the ability to compete with private cars within cities requires mobility systems that can provide transit capacities and speeds similar to or greater than cars (such as light rail or bus rapid transit) so that connection can be achieved along unserved corridors or between corridors. This is usually a missing link in transit systems as light rail transit (LRT) and bus rapid transit (BRT) can be highly disruptive to urban streets and their associated economies in their construction and can be very expensive compared to a normal bus line. According to Kenworthy and Schiller [5], the resulting emphasis on buses that rarely generate the speed or ride quality that would compete with a car, has meant the cities of the world have been allowing cars to fill this transport niche and enabling them via expensive, publicly-funded urban infrastructure and highways. Newman and Kenworthy [3] show that the results can now be seen in urban congestion, air pollution, a large part of global greenhouse gases, road accidents and urban sprawl as well as many social and economic issues associated with car dependence.

The response in recent years has been the development of autonomous mass transit that can be implemented in car dependent cities to complement and extend the effective catchment of traditional heavy rail or metro-based commuter systems. This is the niche of LRT and BRT, however in order to provide effective solutions for the world's growing cities the technology used must overcome the issues of street disruption and capital costs as well as keeping all the good qualities of an LRT or BRT. This has meant merging innovations from High Speed Rail such as autonomous operation, stabilisation and ride quality, with the best parts of a light rail and a bus, to create a new form of urban transit technology. This paper will examine such a technology, which has been called Autonomous-Rail Rapid Transit (ART) or what we are labelling a Trackless Tram System (TTS).

Both bus and light rail technologies have been developing in recent years. For example, there are now many manufacturers of electrically powered buses, and many cities which are adopting them, to reduce the air pollution, noise and vibration problems associated with conventional diesel buses. A number of guided bus systems have also been installed using a variety of guidance technologies, from mechanical (as in Adelaide's "O-Bahn") through to optical and magnetic systems. Recent light rail vehicles also now feature on-board batteries or super-capacitors enabling wire-free operation (with re-charging at stops), as well as regenerative braking (to save energy), 100% low floor access (improving customer convenience and accessibility) and improved steering technologies for improved ride quality.

China's CRRC (now the world's largest rolling stock manufacturer) has combined all of these advances into its new "Trackless Tram". This is an articulated, high capacity "Tram" running on rubber tires but with an in-built guidance system offering autonomous optically-guided running and operation. It is battery powered (with recharging at stops or at the end of the trip), avoiding the necessity for overhead wires along the route. It is fully low-floor, but uses improved suspension systems providing high ride quality. It has low axle loads, minimizing the need for expensive guide way infrastructure. It can also operate on regular streets because of its tight turning radius and high hill-climbing ability. **Figure 1** shows a popular photo that has been spreading through much social media on the Chinese Trackless Tram System.

Figure 1. The Trackless Tram System developed by CRRC and demonstrated in Zhuzhou, China. Source: Compliments of CRRC Corporation.

Three of the authors of this paper were able to visit China in August 2018 and ride the Trackless Tram as well as receive detailed explanations about how it works and how the transit system is constructed and operated. The paper is therefore based on this transit technology though it is not excluding other manufacturers such as Alstom, Van Hool, Irizar, and others. The technology was first taken to scale in China in 2016 on a straight 3.6 km line with 4 stations. Based on findings from the study tour to Zhuzhou, China it is the intention of this paper to not only demonstrate that the Trackless Tram is a superior technology for many corridor connections in urban transit systems but to explore the notion that it is potentially the public transport catalyst that many city planners have been waiting for since the dominance of automobile dependence, as it can unlock urban regeneration. It is the conclusion of this paper that not only is this technology a potential game changer for cities struggling to attract investment in traditional light rail projects, if implemented through an entrepreneurial approach in collaboration with the private sector it stands to unlock significant urban re-development options.

It is important to realise that the Trackless Tram System lends itself to an entrepreneurial approach where secure private sector investment can be attracted to create new development around station precincts, referred to by Newman *et al.* [6] as the "Entrepreneur Rail Model". This rail development model has a long historical precedent, in both western and Asian cities, and has continued in such places as Japan and Hong Kong. Rail was jointly developed with real estate along both heavy rail lines and tramways/streetcars [7], with the latter filling a similar transport niche to the TTS. This is particularly relevant where cities are growing and hence private investment is likely to be looking for opportunities for urban development that can include a new transit system like a Trackless Tram; this can apply to cities all around the world but especially in developing economies where population growth pressures are high [8]. Such an approach can allow both emerging and developed cities with inadequate legacy transit systems to "leap frog" the currently adopted transport technologies and strengthen their economic development whilst assisting in the Sustainable Development Goal of providing an "*inclusive*, *safe*, *resilient and sustainable city*" [9].

1.2. What Makes a Trackless Tram Different?

Table 1 sets out the general specifications for a Trackless Tram based on a 3-car set developed by CRRC in China. A Trackless Tram based system blends the best features of bus and train systems, both in the carriage technology and the system configuration to deliver a substantially more affordable option. For instance, the Trackless Tram carriage effectively starts with a standard light rail carriage that is narrow and has multiple entry doors with a turning radius and grade-climbing ability comparable to a bus, and then provides four new attributes:

1) It harnesses electric drive systems and on-board battery technology to avoid the need for overhead cabling or a fossil fuel engine, with recharge at either stations or end of run areas for longer periods;

2) It substitutes the steel wheels of a train with rubber tyres. This avoids the need for rails and reduces the associated disruption of local economies due to extensive period of construction works on roads and underground services for traditional light rail systems;

3) It provides stabilization technologies through train-type bogeys with low set axles and hydraulic systems designed to prevent sway and bounce; and

4) It adopts autonomous technology through optical guidance systems to provide a precise and smoother ride quality and precision entry to stations and ease of boarding and lighting at platforms by passengers.

Considering the system configuration, the Trackless Tram System uses a dedicated corridor to provide rapid transit services that is supported by fixed stations and a Control Centre, much like light rail or traffic management centres. This provides the benefits in terms of city-shaping provided by traditional light-rail systems. However, the technology provides the flexibility to enable Trackless Trams to be diverted around blockages or quickly recalled should the need arise, unlike an LRT.

2. The Trackless Tram Transport Niche

2.1. Trackless Operation Requirements (Rubber on the Road)

A Trackless Tram uses rubber wheels that drive on the surface of the road which avoids the need for a substantive part of civil works associated with rail infrastructure. Rubber-tired transit vehicles are a well-established technology. For instance, Michelin patented a steel-belt rubber tire in 1946 which was introduced to regular service on the Paris Metro from 1956. Other cities have developed rubber-tired mass transit systems, including Taipei's Wenhu Line which is an automated rubber-tired train service running on metal plate as part of an elevated track, as shown in **Figure 2**.

This switch in the design avoids the majority of excavation of the road surface to construct concrete foundations and lay rails, as shown in **Figure 3**. To ensure

Table 1. Vehicle specifications for 3-module trackless tram. Source: CRRC Corporation.

Length	31.6 m
Width	2.65 m
Weight (loaded)	51 tonne (average 9 tonne per axle)
Capacity	250 - 300 people
Max speed	70 km/hr
Gradient	13%
Turning Radius	15 m
Design Life	Over 30 years

Figure 2. Taipei metro line 1—Wenhu line. Source: Bombardier.

Figure 3. Trackless tram system station. Source: Marie Verschuer.

a smooth arrival at stations it may be appropriate to construct concrete pads, however the CRRC claim that its light construction means that it can be implemented very rapidly into most urban road systems without change and that after three years of trials there is no sign of road damage.

Implementation is therefore possible to do in a weekend (after all approvals have been gained of course) with modular stations that come as part of the cost of the Trackless Tram System. These contain the desired ticketing and gateway systems as well as recharging facilities for rapid (30 seconds) recharging at stations or longer recharging at the terminus of a route. Implementation can also be simply integrated into a Bus Depot for overnight storage and deep recharge and can use a normal main roads Control Centre to ensure it is running well. The guidance system software and technology to create the exact route can be installed well before the system needs to be running. The best way to enable a mass transit system in a street is to create a free-flowing space and this will require detailed planning but no more or less than with a BRT and probably less than an LRT.

The big difference in implementation of TTS compared with conventional light rail is that a TTS avoids excavation of or interference with buried services such as water mains, electricity cables, telecommunications lines, storm water and waste water systems that add substantially to the cost if disturbed. According to the manufacturer a Trackless Tram vehicle has a loaded weight of 9000 kg per axle, which is similar to a conventional bus or heavy vehicle but has significantly less pavement impact due to its double axle bogeys, special tyres and the IMU system which manages the sway which causes pavement rutting. Hence pavement construction should not need to be any different for Trackless Trams. There are reasons why the autonomous driving character will minimise road damage as it is not subject to the heavy momentum swings associated with sudden driver interventions. No rutting has been found in the first three years of operation of the Trackless Tram in China (**Figure 4**).

2.2. Self-Guiding along "Virtual Rails"

The Trackless Tram combines a number of autonomous vehicle guidance technologies to follow "virtual rails" along its corridor. The main elements of the guidance system are imaging recognition for optical guidance, satellite navigation, radar point scanning and inertia management. These systems are likely to be used for many autonomous vehicles, especially transit systems that operate in traffic as will be the case in most cities. The lines marked on the road provide optical guidance while also clearly identifying the path of the vehicle for pedestrians and other motorists. Additionally, a differential global positioning system (DGPS) uses fixed positions along the path of the vehicle to constantly update the relative location signals sent and received from satellites—increasing the location accuracy to the order of 10 - 15 cms from what can be up to 15 m with traditional GPS. Radar and light point scanning (Lidar) enhances the vehicle's ability to recognize route signs, network characteristics and dynamic interferences

Figure 4. Construction of the Edinburgh tram project. Source: The Independent.

that may occur, fitting this data to the information sourced from the other guidance technologies to create an overall sense of the surrounding environment.

The high precision achieved through the combination of these technologies adds to the appeal of the Trackless Tram by significantly increasing ride quality, improving the safety of the network, and reducing the damage caused to the road surface [10] [11]. In particular, an on-board Inertia Management Unit (IMU) measures the TT's pitch, yaw and roll, adjusting orientation and speed to stabilise the vehicle and create a ride quality characteristic of a rail-based tram or train. Connection to the broader traffic control system through an on-board intelligent transport system (ITS) can control intersection timings and provide real-time feedback to the traffic control centre, driver and passengers. Although it is possible to be driverless the Trackless Tram will have drivers due to its use in mixed traffic where unexpected events can occur and to assist with navigation and assist passengers where needed. Drivers can over-ride the programmed track for the vehicle if there is an accident or blockage.

2.3. Electrification and Energy Storage

The Trackless Tram is electric and is powered by on-board lithium ion phosphate batteries (with a 25-year lifespan) that are supplemented by regenerative braking. The form of battery used by CRRC can recharge faster than many other lithium ion batteries and perform better in cold conditions. The 600 kW-Hr on-board batteries can quick-charge at 10 kV platform-style overhead charging stations during normal operation, and do 10 minute recharging at the end of a line as well as a deep recharge overnight in a Bus Depot. The CRRC Corporation estimates that for their 3rd generation vehicle a 10-minute charge can provide enough energy for between 15 and 25 km of travel depending on the loading and the level of air-condition required; with the fourth generation Trackless Tram the battery is anticipated to extend this to 50 - 60 km. Given the imperative to shift away from fossil fuels, especially diesel causing health impacts in cities, the electrification of transit systems provides a way to harness renewable energy generation, especially during daylight hours when solar energy is generated. Along with these improvements an electric drive system offers better ride quality through smoother acceleration/deceleration and less vibrations compared with an internal combustion engine vehicle.

2.4. Cost Efficiency

The cost of Trackless Trams can be substantially lower than that of light rail. For instance, in a report commissioned by the City of Parramatta in Sydney, Bodhi Alliance and EDAB Consulting [12] estimated that a Trackless Tram option would have capital costs three times less than a light rail option. The biggest uncertainty in these figures is around construction costs in the road and tracks as well as the needs of particular design requirements around stations [13]. The presence of buried wires and pipes can severely complicate light rail construction. It is highly undesirable to build a light rail line on top of this critical infrastructure, as accessing them may require digging up the line, at huge expense. Such services are generally relocated when a light rail line is built, increasing the capital cost of installing the line. Such costs were found in the recent Sydney Light Rail which has taken nearly four years to complete a 20 km track through the old part of Sydney at the cost of nearly USD$130 million per km which is around ten times the cost of a Trackless Tram.

Compounding this problem, records are often not able to pinpoint the exact location of services, and in some cases the record of their very existence may have been lost. This creates a major uncertainty in the cost of the infrastructure provision for urban rail-based systems. This uncertainty is a particular problem in older cities, where infrastructure may have been laid down many years ago. While light rail projects typically take years to build, the Trackless Tram can be installed much more quickly (assuming suitable quality roadways and stations being prefabricated for rapid onsite erection). This will reduce the level of disruption to businesses, residents or traffic flows associated with light rail construction, though space must still be found in the roadway.

2.5. Modal Interoperability: Does the System Allow for First and Last Mile Services?

The Oxford Dictionary defines "interoperability" in the context of computer systems as a characteristic of a system where the various components are able to work with one another and exchange information despite being of different form, and use the example "*interoperability between devices made by different manufacturers*" [14]. In a similar way, we use "Modal Interoperability" in the context of transportation systems to describe a system where corridor mass transit and last mile services/modes seamlessly integrate. Given the race to deliver to market a functional and safe driverless vehicle by the world's automakers the technology in this area has seen significant recent research and development.

Despite it being applied primarily to private vehicles it also stands to assist public transport as Trackless Trams and other rail systems across a city still need first mile/last mile linkages at stations. If these can be electric autonomous shuttles then they need to be serviced at stations and this requires interoperability between the electric recharge systems. The CRRC have designed the Trackless Tram station recharge system to have such interoperability. This approach can see a fleet of 8 - 12 person driverless shuttles used as feeder and distributer services around stations (See **Figure 5**).

The following examples illustrate the fleet size and transit service possible from such a system:

1) Trackless Tram Corridors: Much like light rail systems, Trackless Tram Systems are well suited to corridors of 8 - 20 km that serve the inner areas of large cities with stations spaced in the order of 600 - 1200 m apart, serving 1.5 km around each station. For instance, a 20 km line with 25 stations and three autonomous shuttles per station (carrying up to 12 passengers) that provides a service every 20 minutes would be able to feed around 120 people per hour into the station and service up to 3,000 people per hour along the entire corridor.

2) Low Density Heavy Rail Corridors: Modern heavy rail lines are fast and have high capacity, carrying people along long corridors with stations around 3 to 4 km apart. A Heavy Rail transit line from the CBD extending out 30 km with 8 stops would need each station to be serviced by a larger fleet of autonomous shuttles than a Trackless Tram System. To provide a service every 5 minutes each station would have around 6 shuttle loops with 4 shuttles per loop to service a 2.5 km radius around the station (creating an urban corridor of 150 km^2). This would require in the order of 192 shuttles for the entire line that would have the potential to deliver nearly 7000 people per hour to the system, in addition to those that walk or cycle, or use a conventional bus to reach their local station. Such lines could also be linked radially around cities by Trackless Tram corridors.

3) Medium Density Heavy Rail Corridors: For higher density corridors like traditional transit fabric from the early 20th century, stations would generally be closer together (traditionally 1.6 km apart) and would have higher capacity of around 20,000 - 40,000 passengers per track per hour. With stations spaced every 1.5 - 2 km, smaller catchments per station would allow higher frequency autonomous shuttles (providing a service every 3 minutes), with the capacity to deliver nearly 12,000 passengers per hour to the system. Again, such lines could also be linked radially around cities by Trackless Tram corridors.

4) City Wide Application: Considering a city in the order of 2 million people, and assuming a corridor transit network of 15 heavy rail lines and 20 trackless Tram (TTS) lines this would involve 200 heavy rail stations (each with an average of 20 shuttles) and 500 TTS stops (each with an average of 3 shuttles)—so a fleet of 5500 shuttles would be required to service the entire city. Assuming each shuttle delivers 20 passengers per hour to a station the system could deliver as

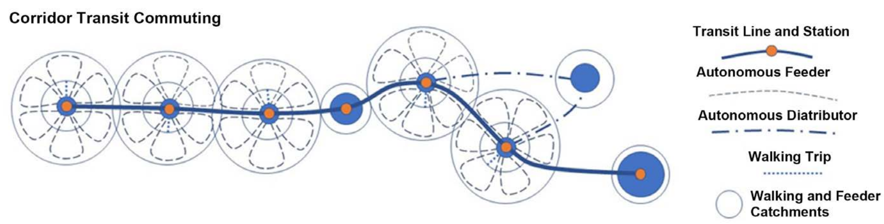

Figure 5. Potential for First and Last mile provision using self-driving shuttles for feeder and distributor services. Source: Amended from Glazebrook and Newman [15].

many as 110,000 passengers per hour on average, or 200,000 during the morning peak period. This would translate to around 1 million extra heavy rail and Trackless Tram trips per day (500,000 in each direction).

According to Metro Report International there are a number of early movers in this autonomous shuttle space such as a trial on the Nanyang Technological University campus in Singapore using a system with "magnetic pellets on the road for navigation and a maximum speed of 40 km/h", as shown in **Figure 6** [16].

Other examples include the City of Arlington, Texas, beginning trials on 2017 of the use of self-driving shuttles to provide services between the car parking area and the city's entertainment district during large events. According to the Community Development and Planning Director for the City, John Dugan, "*The pilot project will allow us to see how this driverless vehicle system really works and to look at the overall picture of how these vehicles could enhance the city's transportation options*." Two self-driving shuttles provided by EasyMile will carry up to 12 passengers at a speed of 30 km/hr [17]. Similar trials are underway in the Greenwich Peninsula in southeast London [18], the Seestadt District of Wien in Austria (including the development of legal guidelines) [19], between the stations of Austerlitz and Lyon in Paris using a dedicated road lane [20], Mixed traffic trials are also underway on the CEA Paris-Saclay Research Campus in France [21], the Brussels Airport in Belgium [22], and the city of Neuhausen am Rheinfall in Switzerland [23]. A similar shuttle is being trialled on Curtin University campus and it will be the subject of a future research paper, particularly how it can be integrated into a Trackless Tram corridor.

2.6. Conclusions of the Trackless Tram Transport Niche

These factors all suggest that a Trackless Tram System (TTS) is likely to replace Light Rail and Bus Rapid Transit systems due to its ability to mimic all the best qualities of these systems while harnessing technology from High Speed Rail. The Trackless Tram can run rapidly in the road system but not cause the pollution and noise of BRT or the disruption and high construction cost of the LRT. The corridor system can be complimented by an electric shuttle service providing last mile/first mile interoperability as outlined. The significant cost reduction makes it highly attractive to fill the niche currently occupied by BRT and LRT with a TTS. Such a system is likely to provide a major reduction in car and bus

Figure 6. Trial Autonomous Shuttle on Nanyang Technological University campus in Singapore. Source: Metro Report International.

dependence while offering greater accessibility. However, there is one more major attraction of the Trackless Tram System that stands to provide a powerful drive for urban renewal and development. This is the city-shaping potential which is illustrated through two case studies in the following part.

3. Considering the City Shaping Potential of a Trackless Tram System in Economic, Environmental and Social Terms

The city shaping potential of a light rail or heavy rail has been well documented [3] and has many economic, social and environmental advantages. The assessment of how a Trackless Tram can help with city shaping is set out below by applying the assessment criteria to two different cities, one a developed city, Perth in Australia and the other Thimphu in Bhutan.

3.1. Sprawl Relief: Does the System Contribute to Slowing Urban Sprawl?

Effective and efficient corridor transit allows for a slowing of urban sprawl by facilitating greater urban density. This is demonstrated in the two cities. Firstly, a developed city, Perth, the capital city of Western Australia with a population of 2 million people that has sprawled over 150 km along the coastline and where various strategies have been proposed to increase redevelopment rather than greenfield sprawl, without success. Secondly a developing city, Thimphu, the capital city of The Kingdom of Bhutan with a population of 100,000 with aspirations to grow to 400,000 in a valley with very limited development space and hence where sprawl management is critical.

Perth has a history of automobile dependence since its strong urban growth period from the 1950's onwards [24]. Like many developed cities it had tramways from the 1900's to the 1950's but then shifted favour to the car, sprawling 150 kms along the Indian Ocean coastline and creating numerous urban issues. Perth had a rail revival from the late 1980's that has seen its heavy rail system grow from 7 million passengers a year to 70 million [24]. However, the heavy rail system has been implemented in limited corridors and mostly provides services to people in the outer suburbs with destinations towards the city centre. Several attempts have been made to create a light rail system that can service corridors that are currently served only by buses and are dominated by cars, but a feasible model for funding the system has yet to be adopted. Detailed planning led to a system that would cost $80 m per km and would have led to 2 - 3 years of disruption to inner city streets; the system was abandoned in 2016 with a commitment by the State Government to examine potential new ways of doing light rail. Meanwhile a $6b heavy rail system was committed to along new outer area corridors after a proposed unpopular freeway was cancelled and the funding recycled into the rail package. This is likely to make urban sprawl easier and yet the State's plan is to enable more than half of urban development to be focussed back into the inner and middle suburbs. This plan now needs a transit solution that can unlock such re-development potential [25].

Thimphu has seen a rapid rise in automobile use and the subsequent consumption of petroleum fuels with both fully imported into Bhutan. According to the Asian Development Bank [26] it is anticipated that the number of vehicles in Bhutan will rise from 75,000 in 2015 to over 350,000 in 2040. As of August 2018, the latest statistics by the Road Safety and Transport Authority of Bhutan indicated that 52% of the total vehicles in the country are in the Thimphu region. According to Hargroves and Newman [27] this is likely to cause issues such as increases in road fatalities, air pollution, greenhouse gas emissions, fuel imports, and congestion and will disrupt many of the nation's plans for simultaneously improvements in carbon neutrality, Gross National Happiness and economic growth [28]. Fuel imports place a significant economic toll on Bhutan being nearly equivalent to the entire hydroelectricity revenue generated by the Kingdom. In 2015 Prime Minister Tobgay stated that, "*My target for Bhutan is a 70 percent reduction in fossil fuel imports by* 2020". Such a goal can only be achieved through greater electrification of transport, with significant hydropower reserves available considering that in 2011 the Asian Development Bank [26] estimated that just 6 percent of the estimated 30,000 MW of hydropower potential in the country was being harnessed.

Considering the potential for slowing urban sprawl in Perth a proposal [29] to develop a new 25 km transit corridor with 12 stations stands to reduce the need for development on the fringes from 100 km^2 to 65.7 km^2 of urban re-development—see **Table 2**. Hendrigan and Newman [30] estimate that some 30 years of urban growth could be accommodated in and around new and revived transit stations if a program of light rail was introduced to complement the new heavy rail and was associated with such station precinct-focussed urban regeneration.

Table 2. Estimates of land space savings from adoption of corridor transit systems in Perth, Australia and Thimphu, Bhutan.

Parameter	*Perth*	*Thimphu*	*Units*
Predicted Additional Population	120,000	300,000	People (Ppl)
Population Density (Fringe)	12	40	Ppl/Hectare
Population Density (Corridor Stations)	35	80	Ppl/Hectare
Additional Area Required (Fringe)	100	75	km^2
Additional Area Required (Corridor Stations)	34.3	37.5	km^2
Area saved by corridor transit approach	**65.7**	**37.5**	**km^2**

Similarly, Thimphu, a city of 26 km^2, plans to accommodate population growth from 100,000 to 400,000 people calling for the city to quadruple in size. Given the steep topography of the valley that the city is located in it is not an option to spread this out much beyond the footprint of the present city. It will be crucial for Thimphu to increase urban density in order to accommodate this population increase through urban re-development. As **Table 2** shows a proposal by Hargroves and Gaudremeau [31] to develop a new 8.5 Km transit corridor with 12 stations stands to reduce the need for land from 75 km^2 on the fringes to 37.5 km^2 of urban re-development.

3.2. Congestion Relief: Does the System Contribute to Alleviating Congestion?

Traffic congestion is an ongoing issue facing transport planners and network managers with levels of congestion growing to unworkable levels in many of the world's cities, calling for alternative strategies rather than simply seeking to accommodate more automobiles. In 2015 alone Australia's capital cities were estimated to have a combined congestion cost of $16 billion, expected to increase to $37 billion by 2030 [32]. Perth's congestion costs are expected to increase the most based on anticipated growth from the mid 2010's, almost tripling from $2 billion in 2015 to $5.7 billion in 2030 [32]. In the US, the cost of congestion in 2012 was estimated to be in the order of $121 billion, the equivalent of $818 per commuter per year, and some additional 25 million tonnes of CO_2 per year [33]. Together with lost time alleviating congestion leads to reduced vehicle wait times in traffic jams which reduces vehicle exhaust, thus reducing carbon emissions and air pollution. In the US alone, 25 million tonnes of CO_2 per year was emitted from vehicles delayed on congested roads [34]. In addition, inhaling vehicle exhaust for extended periods has also been linked to human health problems such as brain-cell damage [39].

Newman and Kenworthy [3] show that most cities are now building urban rail instead of accommodating more automobiles as the speed of such transit systems has been increasing in all cities relative to the speed of traffic and bus speeds are simply not competitive even with the declining private vehicle speeds as buses are usually stuck in the traffic. The rail option will deliver more lasting congestion relief and is likely to enable emerging cities to break out of their traffic spiral [35]. This is evident when considering that one lane of roadway can carry an average of 2500 people per hour per km with cars compared to dedicated corridor transit options such as a Trackless Tram System which can carry as much as 20,000 people per hour per km, as shown in **Table 3**. Where feasible, heavy rail has even greater patronage potential of up to 50,000 people per hour per km. The new Hong Kong East Rail Line is achieving a capacity of 86,000 people per hour per direction during the morning peak; thisis much higher than the average as it is operating 12 rail cars (3750 people per train) running every 2.5 minutes due to the use of new autonomous technology such as outlined above in the rail system [36].

Given the issues related to congestion, air pollution, and greenhouse gas emissions it makes sense to take advantage of higher capacity options, especially heavy rail, however connections down corridors using transit such as light rail or Trackless Trams would also be a much better transport option rather than accommodating more automobiles.

3.3. Reclaim Car Parking: Does the System Allow the Reduction of Car Parking Requirements?

As outlined above there is a large land requirement associated with urban fringe development and lesser but still significant requirement for land to accommodate urban re-development. If a transport option can be enabled such as the system outlined in section 2.5 above, then there is a large reduction in the need for parking which can save up to a third of the land that then can be available for more productive urban uses. Considering the potential to reclaim car parking space in cities, the International Energy Agency [37] suggests that by 2050 India was on track to require between 10,000 - 20,000 square kilometres of surface parking area, equating to 35 times the size of Mumbai. According to Newman and Kenworthy [38] automobile dependent cities around the world can typically have between 5 and 8 car parking spaces for every car in the city. In Perth for instance there is on average 4 parking spaces per person in inner-city areas, and as much as 10 in outer suburb areas [39]. This means that a significant amount of the land in cities is being allocated to parking vehicles which could be used for higher return development options. Much of this land could be unlocked by integrating a new Trackless Tram line with a series of land developments associated with station locations along the corridor, coupled with quality walking and cycling options, which can enable parking to be reduced to less than one per household. As outlined in section 2.5 the model of the Trackless Tram augmented with local autonomous shuttles can remove any need for station precinct parking.

To put this into context, in the proposed corridor transit project in Perth each of the 12 proposed stations would serve an estimated 10,000 residents who

Table 3. Estimations of average patronage capacity for various transport modes. Source: Compiled from Newman and Kenworthy [3] [39].

Transport Mode	Average Passengers per hour per lane per km	Multiples of car capacity in a suburban street
Car in suburban street	1000	1
Car in freeway lane	2500	2.5
Bus in traffic	5000	5
Bus in freeway lane (BRT)	10,000	10
Trackless Tram (or Light Rail)	20,000	20
Heavy Rail	50,000	50

would require at the very most four parking spaces in the urban area they use rather than ten if they were on the fringe, saving a total of 9.3 km^2 (based on minimum parking size requirements of 5.4 m × 2.4 m). In Thimphu rather than a 4 inner-city and 10 outer suburb parking allocations as is the case of Perth, it is assumed that there would be a reduced need of 2 inner city and 4 outer suburb car parks per person, with the proposed corridor transit system saving as much as 7.7 km^2 of parking space, as shown in **Table 4**.

3.4. Job Creation: Does the System Contribute to Job Creation from Greater Urban Density?

A clear relationship exists between the density of employment and the proportion of new knowledge economy jobs [40]. For over a century urban productivity has been shown to be directly correlated to both the knowledge sharing effects induced by density and human capital cultivated in cities [41] [42] [43] [44]. The proximity of businesses and activity centres within dense urban areas allows for the face-to-face interaction of knowledge-based economy workers and thus enables the flow of knowledge and innovation in any 21st century city. A study by Haughwout [45] suggested that doubling of a country-level density index increases state-level productivity by 6 percent but this is much higher if urban densities are considered. When highly-skilled workers are involved, density also plays an important role in urban innovation [46], with studies showing that the doubling of spatial employment density can increase the intensity of patent creation by 20 percent [47].

According to Kane & Whitehead [48] agglomeration enables access to a large pool of skilled labour and markets and has the "economies of scale" advantage of bringing the supply of resources, goods and services within easier access. Rawnsley [40] suggests that for firms in higher density areas, they become more competitive as they have access to cheaper and more complementary suppliers, so they can become more specialised and make use of the skilled labour that is much more accessible in denser areas. Even if competing firms are present there may still be benefits such as attracting more suppliers which can compete, and collectively they may attract more customers which can form markets that

Table 4. Estimates of parking space savings from adoption of corridor transit systems in Perth, Australia and Thimphu, Bhutan.

Parameter	*Perth*	*Thimphu*	*Units*
Predicted Additional Population	120,000	300,000	People
Car Park Supply (Urban Fringe)	10	4	Ppl/Hectare
Car Park Supply (Corridor Transit)	4	2	Bays/Hectare
Additional Parking Area Required (Fringe)	15.6	15.4	km^2
Additional Parking Area Required (Corridor)	6.2	7.7	km^2
Area saved in a corridor transit approach	**9.3**	**7.7**	**km^2**

could not have been generated with one firm alone. For individuals, they have access to the opportunities that this rich cluster of productivity and innovation enables.

Newman and Kenworthy [3] point out that corridor transit stations integrated into land development create the conditions of walk ability in densely occupied areas surrounding stations that enable the face-to-face creative discussions for the jobs of the new economy to flourish in other areas of the city as well as central business districts. As densities continue to increase, automobile dependence cannot facilitate the necessary movement of large amounts of people into central areas or into sub centres in the suburbs, hence mass transit is required such as the Trackless Tram System. Graham [49] suggests that workers need to be able to move efficiently between homes and workplaces, and reduced travel times and costs enable greater agglomeration benefits to be realised. As agglomeration is shown to provide increasing returns for cities, investment in transport thus induces positive productivity returns by enabling the development of economic mass [49] [50]. For workers, new opportunities emerge through new innovations, changed ways of working and operating for firms, and new businesses and collaborations emerge within areas of rich networking and interaction. A study by Rawnsley [40] suggests that increasing effective job density by 50 percent can increase labour productivity by as much as 175 percent due to the creation of knowledge economy jobs. A Trackless Tram Systems is thus not just smart technology it is enabling powerful economic development to be unlocked.

3.5. Environmental Benefits: Does the System Provide Environmental Benefits?

In addition to car-related environmental impacts, greenfield expansion on the urban fringes is also commonly cited as the cause for loss of farmland, open space, forest and habitat [51]. **Figure 7** shows the correlation between urban density and per capita energy use for transport. It is clear that as urban density increases, there is a drastic reduction in energy consumptions per person for passenger transport, resulting in less air pollution and greenhouse gas emissions.

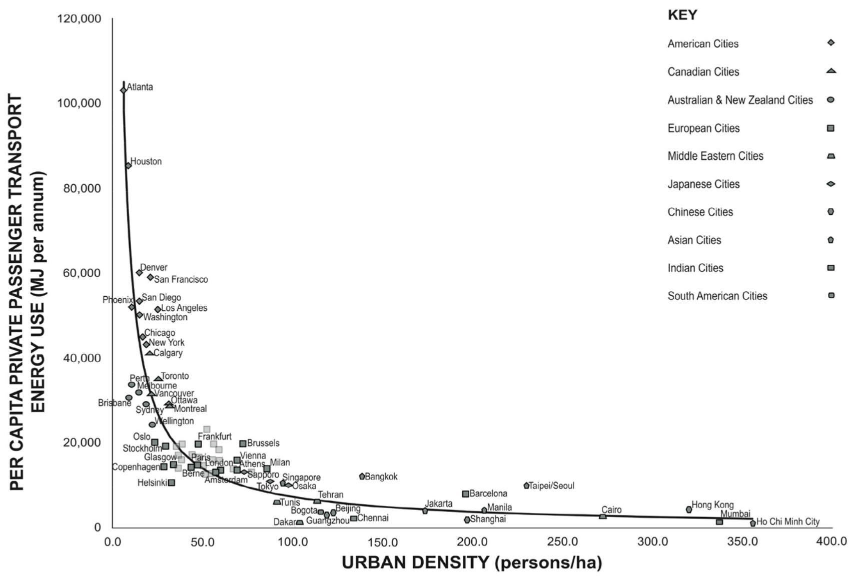

Figure 7. The relationship between urban density and per capita private passenger transport energy use. Source: Newman and Kenworthy [3].

The advent of the Trackless Tram System now makes urban re-development and higher densities to be far more achievable and affordable for cities around the world, especially in the developing world.

With transport constituting approximately 23 percent of global energy-related greenhouse gas emissions [52], viable transport solutions need to reduce fossil fuel consumption, such as systems based on high-density urban areas with effective electric corridor transit solutions, such as the Trackless Tram System. Hence transit systems that provide commuters with effective corridor transit powered by electric vehicles that charge at grid-connected stations which are powered by renewable sources stand to significantly reduce transport-related fossil fuel consumption and associated greenhouse gas emissions. This will be even more effective if local shared mobility autonomous electric shuttles are also part of the Trackless Tram System. Trubka *et al.* [53] estimate that a rail transit system can reduce daily per capita greenhouse gas emissions for commuters from the fringe of cities by between 8 - 10 kg and those in urban areas by as much as 4 kg. This would be reduced to zero by a Trackless Tram System, assuming that it also uses solar energy as its power source for recharging the vehicles. According to the London Department of Transport even if the electricity for the system is sourced from fossil fuels there are still environmental benefits compared to automobile dependent cities using fossil fuels [54].

3.6. Social Benefits: Does the System Provide Social Benefits?

The World Health Organisation (WHO) released data in 2016 showing that an estimated 4 in 5 people living in monitored urban areas are exposed to air quality pollution that exceeds recommended levels [55]. The data also showed that in low-and-middle income cities above 100,000 inhabitants, 98 percent do not meet the air quality guidelines. In Thimphu for instance, data from the National Environment Commission showed the level of particulate matter (PM10) was 40.5 μg/m^3, just over double the WHO Guideline Level of 20 μg/m for the annual average [31] [56]). Diesel and two-stroke engines are one of the most significant contributors to air pollution in urban areas in Asian countries [57]. According to Hargroves and Newman [27], given that some 45 percent of the Bhutanese population are under the age of twenty years old, shifting to a modern clean transit system to provide mobility in the capital city will have long lasting health benefits. These benefits are in addition to the increases to fitness and health of citizens from increased walking and cycling around station precincts, which has been shown to greatly improve the health of populations and can even outweigh the benefits of air pollution reduction [58].

In addition to air pollution benefits a shift to corridor transit will reduce vehicle collisions and road fatalities. According to the WHO more than 1.3 million people die annually on the road in the world and another 20 - 50 million are injured. A study by the WHO and the Asian Development Bank found that Bhutan is second only to Nepal in the number of road deaths per 10,000 vehicles. To compound this social challenge, neighbourhoods of lower-socio-economic status generally tend to have the highest motor vehicle collision rates [59], and can often be more dependent on non-motorised modes to travel longer distances, which can increase the complexity of the system and increase risk for vulnerable road users [60]. On the other hand, studies have shown that public transport is up to ten times safer per mile than private vehicle travel, and that transit-oriented communities are twice as safe [61]. The Trackless Tram has the ability to create such benefits for communities.

The need for cities to engage their citizens and provide equitable solutions for their future has been a major thrust of the New Urban Agenda [62]. This is not just needing social policies by central and local governments that focus on all their communities, but it does have a spatial and urban form dimension. There is now an awareness that pushing affordable housing to the urban fringe does not enable equitable and sustainable living but that a policy of including affordable housing in any new urban re-development is more likely to create the inclusive outcomes sought by the New Urban Agenda [62] [63]. These environmental and social issues have tended to be put aside in the need for cities to achieve competitive economic development, however the Trackless Tram System may indeed be able to solve these at the same time as enabling better economic outcomes.

3.7. Conclusions of City Shaping Potential of Trackless Tram Systems

As this paper has shown there are multiple benefits that can be achieved by implementing a Trackless Tram System as the basis of city shaping. The Trackless Tram System is likely to contribute to most of the SDG's especially the need for an "*inclusive*, *safe*, *resilient and sustainable city*" not just because of its technology but because it enables city shaping. The need for urban regeneration to create new centres of urban activity is now a high priority for most cities. The Trackless Tram has all the qualities to enable such densities and mixed urban activity to be attracted to station precincts. These Transit Oriented Developments are not new in concept but are hard to deliver unless made into a whole corridor of urban regeneration. According to Newman *et al.* [6] this is feasible if a Trackless Tram System is delivered using an entrepreneurial approach that brings private investment into the partnership from the beginning. The approach, together with the very low capital cost of a TTS, means that significant capital burden can be removed from governments who usually are seeking public private partnerships to deliver infrastructure for development but in the past have had to take the major cost for transport, especially transit. The TTS may enable a breakthrough in facilitating partnerships that attract private investment because they enable urban re-development where they can seek a stable return on their investment. This approach is outlined further in other publications [6] [8].

4. Comparison Summary

The best way to draw together the character and potential of a Trackless Tram System is to compare it to Light Rail and Bus Rapid Transit systems. **Table 5** sets out how BRT, LRT and TTS compare based on six criteria.

Others looking at the characteristics in **Table 5** may rate some characteristics higher or lower however it is the conclusion of the authors after extensive investigations, analysed and set out above, that the Trackless Tram System is the preferable option over the BRT or LRT in the corridor connection niche of transport as well as the city shaping niche of urban planning. The TTS in our assessment is better than a BRT due to its ride quality and land development potential (as is LRT), but it is better than LRT because of its much lower cost, its lack of construction disruption and its much better implementation time. It also has a technology "wow factor" that has been lacking in bus-based public transport options. It therefore is likely to replace LRT in cities and provide far more opportunities for creating the much-anticipated transition to more urban regeneration and less car dependence as well as their associated multiple economic, social and environmental benefits.

5. Conclusion

The Trackless Tram System is a new kind of transit system that has been generated by crossover innovations from High Speed Rail being applied to a bus. It is neither a Tram nor a Bus though it has the speed/capacity, ride quality and land development potential of a Tram and the cost, lack of disruption and rapid implementation of a Bus. It is therefore a new kind of transit technology that offers radical and transformative opportunities for cities needing connection across suburbs and electric accessibility that unlocks urban regeneration. The Trackless

Table 5. Indicative comparison of characteristics of corridor based urban rapid transit systems.

Characteristic	Bus Rapid Transit (BRT)	Light Rail Transit (LRT)	Trackless Tram System (TTS)
Speed and Capacity	✓	✓✓	✓✓
Ride Quality	×	✓✓	✓✓
Land Development Potential	×	✓✓	✓✓
Cost	✓	×	✓
Disruption during construction period	✓	×	✓✓
Implementation Time	✓	×	✓
Overall	✓	✓✓	✓✓✓

Tram System presents a tangible and affordable opportunity for cities around the world to combat automobile dependence while providing an obvious economic opportunity for harnessing new land development potential. By harnessing technologies applied in various other forms of autonomous and high technology transport, the Trackless Tram System presents a new and unique transit option that can not only incorporate cutting edge technology but deliver significant economic, social and environmental benefits to the worlds' growing cities.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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urban science

Article

From TOD to TAC: Why and How Transport and Urban Policy Needs to Shift to Regenerating Main Road Corridors with New Transit Systems

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Abstract: The need for transit oriented development (TOD) around railway stations has been well accepted and continues to be needed in cities looking to regenerate both transit and urban development. Large parts of suburban areas remain without quality transit down main roads that are usually filled with traffic resulting in reduced urban value. The need to regenerate both the mobility and land development along such roads will likely be the next big agenda in transport and urban policy. This paper learns from century-old experiences in public–private approaches to railway-based urban development from around the world, along with innovative insights from the novel integration of historical perspectives, entrepreneurship theory and urban planning to create the notion of a "Transit Activated Corridor" (TAC). TACs prioritize fast transit and a string of station precincts along urban main roads. The core policy processes for a TAC are outlined with some early case studies. Five design principles for delivering a TAC are presented in this paper, three principles from entrepreneurship theory and two from urban planning. The potential for new mid-tier transit like trackless trams to enable TACs is used to illustrate how these design processes can be an effective approach for designing, financing and delivering a "Transit Activated Corridor".

Keywords: transit; entrepreneurship; rail; effectuation; entrepreneur rail model; finance; PPP; transit-activated corridor; corridor transit; urban planning

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1. Introduction

Transit oriented development (TOD) [1,2] and transit adjacent development (TAD) [2,3] are current terminology in transport and land use planning with TAD being called "TOD gone bad" by Reconnecting America [4]. Others have suggested transit and joint development (TJD) as a concept needed to bring together the necessary public and private sector development opportunities [5]. All of this literature and practice is based on single entity developments around individual stations. This paper introduces the concept of a "Transit Activated Corridor" (TAC), which emphasizes the role of transit in enabling denser development along a whole corridor with a series of station precincts, or TODs. It seeks to help define how the concept of a TAC can be done through a novel integration of three theoretical approaches: from historical analysis of how transport creates land value; how entrepreneurship theory can enable the approaches to tapping that value; and how urban planning tools can enable it to be designed, financed and delivered providing both effective corridor transit and high-quality station precincts.

2. Theoretical Basis 1: Historical Analysis of Transport and Land Value

Effective and efficient corridor transit infrastructure is a key part of a growing city, with numerous cities across the world rediscovering transit's economic value after decades of automobile dependence [6]. The effects of the COVID-19 pandemic on transport intensity, and, therefore, emissions and traffic fatalities, has reinforced the potential of moving away from automobile-dominated transport planning. This new market is being driven by the fact that transit is becoming faster than traffic in most cities and thus providing cities with the option to deliver transit services that are less welfare oriented [7]. In many cases this is a return to the past when railway projects around the world were used to unlock new development opportunities, such as the privately-operated trams and trains of the 19th and early 20th century that were used by most major cities to create real estate opportunities [8]. These were typically entrepreneurial projects funded by the private sector and this approach can be traced as far back as the horse-drawn carriages that ran from the 17th century, through to the tram era and omnibus projects in New York city in the 1820s [9].

Britain's railway expansion in the 19th century and early 20th century was almost entirely led by private entrepreneurs, which resulted in an extensive rail network. Both rail and tram corridors were built primarily as private real estate ventures based on the land value unlocked by the new transit technology. This approach was replicated in many cities around the world as the basis for expanding mobility and settlements for the next 100 years. Some countries took a more public-led approach that lagged behind the British success, such as the French who relied on state-led planning of routes and facilities before engaging the private sector [10].

In many cities the legacy of the entrepreneurial rail era is a medium density urban fabric that follows corridors out from the traditional walking fabric town center; despite many of the railway lines since being taken up these corridors are still quite distinct and given the levels of accessibility that were created often represent higher than average real estate prices with a substantial proportion of the city's knowledge economy jobs [11]. The benefits of transit and walking urban fabric are now one of the driving forces as to why cities are seeking to build more transit down corridors and are wanting more TODs instead of outer area urban sprawl. Hence there is a growing demand for Transit Activated Corridors that deliver both effective transit and cost-effective dense urbanism.

The problem in the recent decades of building railway infrastructure is that it has been built much like freeways, as transport engineering projects only. This is understandable as transport engineering from the 1940s was built around the notion of freeing up congestion by building extra road capacity for automobiles. The new era of cars and buses saw cities spread outwards from the old tram and train lines which were either closed or made part of a welfare-oriented "public" transport system [7]. Thus, the previous approach to transport as being transit integrated with private land development was largely abandoned in favor of government funded freeways and then government funded rail projects. Their value was measured mostly in time savings.

The freeway approach has dominated urban growth until more recent times when sprawling outer suburbs could no longer be effectively serviced by roads and automobiles as congestion levels and average trip times were rising to a level that called for an alternative solution [7]. Whilst many planners like Calthorpe (1993) [1], Newman and Kenworthy [7], Dittmar and Ohland [12], with the Congress of New Urbanism, called for transit oriented developments (TODs) as a solution to this problem, there was little that could happen until rail transit began to be refurbished and new lines installed. Building new rail lines, both heavy rail and light rail, accelerated in the early part of the 21st century, especially in China and India, along with virtually all major developed cities; this has become known as the "Second Rail Revolution" [7].

However, delivery of contemporary transit did not always involve TODs as the mind set and institutional setting of these transport projects was often focused on only the transit solution to time savings and not on land use outcomes, similar to the way of building a freeway. Planning and delivery of TODs was often seen as an optional extra and usually only associated with one or two station precincts while the rest was TAD or park and ride [13]. Thus, urban sprawl was not always reduced as dense urban regeneration around new rail stations often remained marginalized in favor of parking. Thus, the goal of achieving more urban fabric in transit corridors and more walkable urban fabric in TODs has not been as successful as hoped when the rail revival happened. It is possible to make a case for such "freeway-like" rail projects for fast trains servicing outer suburbs without proper transit options [14], but there remain real challenges in stimulating urban regeneration in inner and middle suburbs.

Such transit adjacent development, or isolated TODs, is inevitable if funded entirely by governments as they are typically not able to leverage the land development being implemented around stations as a primary funding source. This suggests a re-invention of the historic approach to building transit as a partnership with the private sector through land development.

With a growing market for fast, high quality transit the idea of bringing in private funding has become more obvious for cities that are growing rapidly [15]. The obvious mechanism is through land development rather than just fare box returns which often do not cover the cost of operation. In Chinese cities, land value capture to fund transit is commonplace [16].

Integrating TODs, or station precincts, into a transit system from the start to enable funding of the transit, as well as urban regeneration along a corridor is therefore of growing interest. This approach we have called the Entrepreneur Rail Model [13] and the core principles are outlined below. Hong Kong and Japan use this approach and more recently interest in using private investment has grown with new mid-tier transit technologies like the trackless tram showing the potential for a low-cost urban regeneration catalyst [17]. The success of the Brightline private rail project in Florida has shown that the approach can work in more car dependent cities and regions; this is funded and financed through land development and fare box returns and has begun an extension, and a new, unconnected line, with plans to extend into 20 other cities. Although not an urban TAC but a regional rail corridor the same approach has been used to generate funding and financing from the associated land value around stations.

This paper seeks to show how the Entrepreneur Rail Model approach could be mainstreamed and extended into planning systems to design, finance and deliver Transit Activated Corridors (TACs). The paper suggests how insights can be gained from entrepreneurship practice-based theory and urban planning tools that favor the combination of transit that is designed to deliver reasonable speed along the corridor and walkable station precincts.

In the current approach to building transit (Figure 1) government transport agencies forecast transit numbers based on current and forecast development in the corridor, then set the route and station locations based on the least resistance and least costs, and then finally seek funding from government. In this approach, under-developed land in the corridor can be over-looked as these areas do not currently generate transit demand and the potential to merge the transit and land development interest can be largely lost. If funding is achieved using this approach, new land use opportunities are considered last when the value of the land has already increased following the construction of the transit infrastructure and there is less profit margin for land developers, and no incentive to invest in the transit infrastructure.

Instead, an ERM-based approach (Figure 2) would suggest that rather than beginning with a pre-determined route and station configuration, governments could harness available means by drawing on the private sector to develop a number of proposals for transit service configurations within a broader corridor based on the uplift potential of available land and development sites—or a private proponent could make an unsolicited bid to government to harness such potential. This way partnerships can be formed that include local governments that can often foresee development opportunities and with private developers who make their living out of recognizing good value urban development opportunities. The goal is to harness the available means, both the expertise of the municipality and the private sector and the physical assets themselves in the corridor, to propose transit configurations that create sufficient development opportunities to allow investment in transit infrastructure, while also satisfying the corridor's transport needs. This process can also make use of under-developed public land. Hence in this approach the first step is to identify uplift potential from transit services along the corridor, to then leverage this to secure financing, finally followed by design of the most appropriate transit configuration.

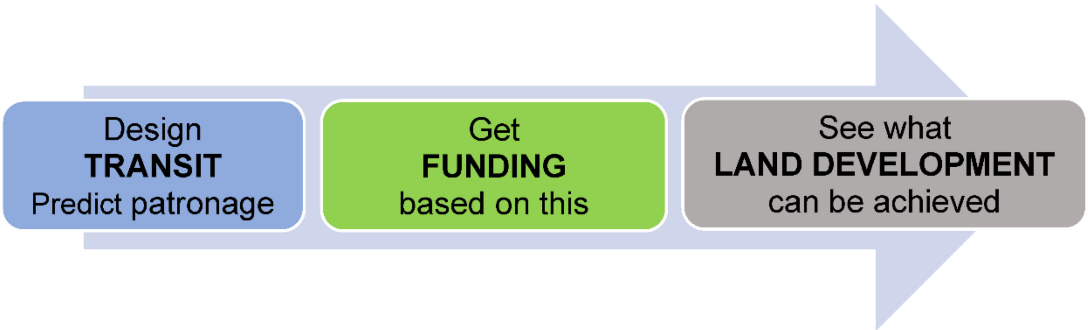

Figure 1. A schematic representation of a typical corridor transit planning process. Source: [13].

Figure 2. A schematic representation of an entrepreneurial approach to the corridor transit planning process. Source: adapted from [13].

The synergy created through such an entrepreneurial approach where the new land development is made viable because the new transit station makes it accessible, is one which aggregates both commuters and customers. In turn new developments attract more people to use the transit system, a mutually reinforcing relationship that sees more people opt for shared transit rather than private vehicles—forming a strong business case for greater development (rather than land-based charges that make it more expensive to be located near a station whether it delivers value or not). When developers are given the opportunity to co-locate stations with office complexes or choose land parcels in areas with greater need for more office space, there are compounding benefits across many financial and livability measures when compared to development "added" after transit is provided [18]. This approach to building transit down a whole corridor of TODs used to fund and finance it, is the approach adopted by Hong Kong in its MTR, and by Japan in projects such as the new Tsukuba Express Line and more recently in China.

3. Theoretical Basis 2: Entrepreneurship Theory for Transit Activated Corridor Development

The historical analysis shows that the transit-oriented, dense urbanism developed from the mid-19th to mid-20th century was created by entrepreneurs along corridors. Thus, it would appear sensible if this urban fabric is again on the agenda for 21st century cities to understand the role of entrepreneurs in creating TACs.

The study of entrepreneurship is a growing discipline, mostly focused on individual start-up approaches for new businesses, with a lack of consensus on the definition and practice of the knowledge in the field [19,20]. There is general agreement however that a core feature of the practice of entrepreneurship is creating value, often under conditions of uncertainty, and typically to obtain private wealth [19] though not without seeing its public benefits. Thinking of entrepreneurship as a process of value creation has led to its broadening beyond just start-up individuals, and towards the traits and approaches sometimes displayed by government and civil society, termed "Entrepreneurial Governance" [21–23]. Similarly, Harvey [24] presented "urban entrepreneurialism" as urban governance that increasingly focuses on "new ways in which to foster and encourage local development and employment growth".

Rather than thinking of "entrepreneurial approaches" as purely strategies that are applied by individuals or start-ups seeking to grow profitable companies, these approaches can also be used to create value in the form of jobs and wealth, improved use of public space, reduced environmental pollution, alleviating congestion, and delivering cleaner and more efficient cities [25]. In the same way, this paper refers to principles of entrepreneurship to outline the process of entrepreneurially activating corridors using new transit lines—given the entrepreneurial legacy of this process throughout history.

The entrepreneurship literature that seems to provide the greatest guidance on how to achieve the entrepreneurial approaches required for TACs and to provide the most potential to further enhance its application, is called "Effectuation" [26]. According to Sarasvathy, effectuation is a logic used by entrepreneurs during new venture creation under conditions of uncertainty and involves a number of key principles with three particularly relevant to TACs and the Entrepreneur Rail Model: create partnerships from the start; value creation rather than prediction; and begin with available means rather than pre-determined ends [26].

3.1. Principle 1: Create Partnerships from the Start

The first principle drawn from effectuation is to build a group of partners and stakeholders from the beginning, reducing uncertainty and risk as a co-created vision is developed between all parties and is realized through collaboration [26]. Just as expert entrepreneurs build partnerships from the start, an ERM or TAC project would begin with a partnership between land interests, communities, local authorities and financiers, and then reaches agreement with government. Effectuation suggests that "self-selecting stakeholders" tend to have more commitment to the project; and in the case of private funding and financing of urban rail projects, self-selecting stakeholders are often able to reach agreements around the distribution of benefits and costs more easily [27].

These partnership-first approaches have been growing rapidly around the world in recent years, taking the place of siloed professional practice [28]. For cities and infrastructure, this partnership approach has sometimes been called a "City Deal", and enables a more bottom-up approach to infrastructure planning and provision. These new approaches will be important for involving private funding to help fund the capital costs involved in quality transit projects [13]. The Australian Federal Government has followed the success of the UK City Deal policy and has created a program based on this concept to encourage urban renewal, that includes a focus on urban rail [29]. The program offers financial risk guarantees rather than contributing direct funding, reducing the risk for private sector involvement. The City Deal program includes requirements to enable [30]:

- An agreement between the three tiers of government, setting out a plan for the City Deal,
- Greater community involvement and support for any projects, and

- Involvement of the private sector, including innovative financing that integrates transit and land development, and with supporting funds from local and state government, with the federal government providing a risk guarantee.

The United Kingdom's City Deal approach began as part of an agenda to devolve power from the national government to city governments, with the aim of boosting economic growth. This began with a first wave of the eight largest city economies in England, outside of London. The Manchester City Deal was notable for its "earn back" feature, which allowed the local authority to retain part of additional tax revenue gained from investments connected with the City Deal [31]. This is akin to tax increment financing, combined with central government funding, and does not involve the entrepreneurial approaches as outlined in this paper. Since then, the City Deals have become more entrepreneurial.

The approach to the City Deal program in Australia was analyzed by Clark and Moonen [32] and involves an integration of policies related to providing infrastructure and urban planning with private sector land development in order to create "great cities". It requires governments at all levels to set up partnerships with private financing, especially superannuation companies looking for long term investments, developers who understand markets and innovation in urban development, as well as communities who know what they prefer in their precincts and neighborhoods for the long term [28,30]. The partnerships enable the best economic value creation by facilitating social capital, financial capital and political capital as explained in Newman and Kenworthy [7]—see Figure 3.

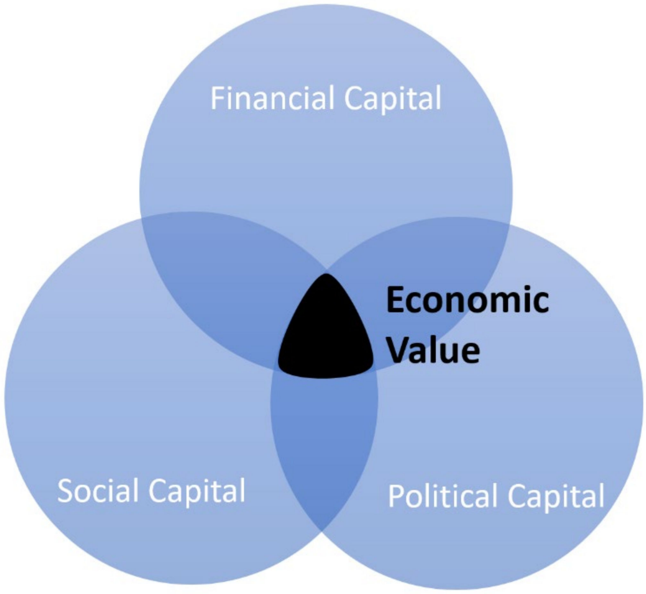

Figure 3. Economic value creation through integration of financial, social and political capital—the intention of a "City Deal". Source: [7].

Another key feature of the City Deal approach is it provides an effective mechanism to align the policy intent of the different tiers of government. This provides greater clarity to the private partner, reducing risk, and facilitates co-ordination with other government programs, see Figure 4.

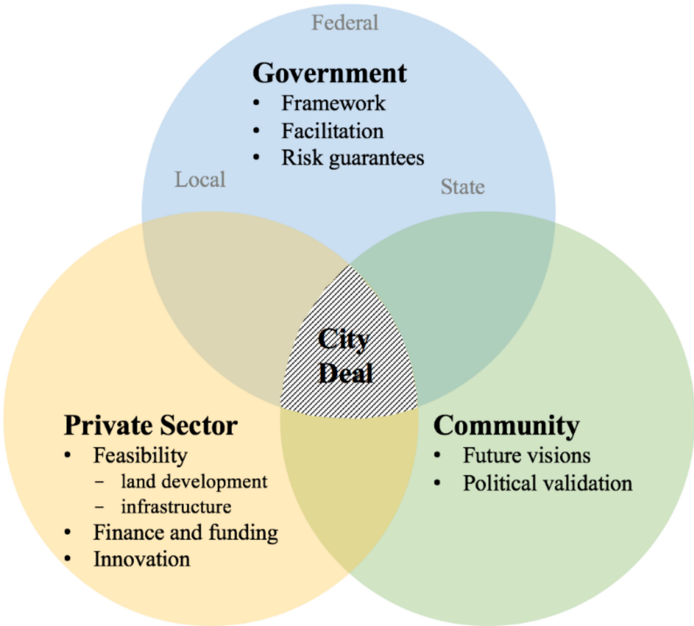

Figure 4. The City Deal partnership model. Source: [7].

This key feature of a City Deal, the alignment of multiple tiers of government, community and the private sector, can be seen to various degrees in existing rail projects around the world, including:

- The Tsukuba Express project in Japan, which came about as a result of long-term government strategic planning. It was delivered on commercial terms by a specially constituted company with ownership shared between city, prefectural and metropolitan governments along the route, and the private sector. The central government provided concessional financing to support the project, but it was delivered by a private company [8].
- The Indian Government's Metro Rail Policy, which sets as a requirement of central government support of a project that it includes private participation, and also must consider the potential for private funding contributions and transit-oriented development. The implementing agencies are also encouraged to maximize project revenue from commercial real estate development at the stations and other non-fare box revenue. Metro rail is seen as a means to achieving sustainable development and a more compact urban form and the mechanism for delivery includes the Urban Mass Transit Company which is a 50:50 government and private agency that has flexibility in raising finance as well as enabling assessments of Metros [33].
- London Crossrail—a project jointly funded by private interests, the Greater London Authority and the national Department for Transport with partnerships developed through the Infrastructure and Projects Authority which is a national government advisory group establishing PPP to enable the funding and financing of infrastructure [8].

City Deals are well-suited to facilitating Transit Activated Corridors, as they can provide increased regulatory certainty or guidance along the corridor, by aligning the objectives of the different tiers of government and can enable the private sector to obtain their finance. In Australia this involves an Infrastructure and Projects Finance Authority that operates in parallel to the assessment process through Infrastructure Australia. At state and local level where detailed planning is done, this would include environmental approvals, land use planning changes, reduced parking requirements and appropriate regulatory approvals in transport, including rail safety regulation. Agreements can also be reached with multiple levels of government to provide associated public infrastructure work such as recharge services for stations where electric battery recharging is needed.

3.2. Principle 2: Value Creation Rather Than Prediction

The second principle drawn from effectuation is to focus on what can be controlled to "create value" rather than to act based upon "predicted outcomes". In practice, according to Sarasvathy [26], this means expert entrepreneurs focus on the controllable aspects of an unpredictable future rather than acting based on predictions of an uncertain future. Some of the mechanisms for capturing value created by the transit system are set out in Newman et al. [7], including the highest value-producing mechanism of a fully private entrepreneurial approach through to the lowest value-producing fully public approach with various levels in between.

Currently, transit corridors are assessed based on predicting the number of people who would potentially use a new mass transit system based on present land use and travel patterns and seek to finance this through public funds or additional rents and land-based charges imposed on surrounding landowners. Traditional government funded value capture approaches rely on a "predicted return", whether this be a predicted number of passengers, a predicted reduction in congestion, or a predicted amount of development and thus value capture can be managed; however, most of the value leaks as soon as a route and set of station locations with density zoning is made public by government, unless partnerships with entrepreneurs are made at the planning stage. There is also an issue with prediction. Transport planners have struggled with prediction, particularly for road networks, due to the principle of induced demand which causes unexpected behavior from commuters when new travel options become available [34]. A prime example of this is that despite providing additional vehicle lanes to relieve congestion, the new lanes are unable to provide lasting congestion relief, due to travelers shifting travel times, routes and modes when networks are changed, even slightly. This is referred to by Downs [35] as the theory of triple convergence and it leads to ineffective prediction-based interventions. This effect can also occur when forecast-based transit interventions deployed in isolation of land development are undertaken and can result in less-than-expected reduction in traffic congestion [36]. Means of overcoming this in Europe are set out in Principle 4 using Sustainable Urban Mobility Plans.

The Entrepreneur Rail Model however creates Transit Activated Corridors through a focus on creating complimentary opportunities for both new land use investment and increased transit ridership, resulting in greater urban densification and less urban sprawl—which is not possible through current transit planning. This is made viable through integration of private land development with transit services to create station precincts which creates two increased sources of value: one is due to the land value increases of between 20% and 50% usually associated with transit (summarized in [13] which enables higher density development, and second, a reduced need for expensive car parking infrastructure of around 20% which enables better urbanism [7]. The result of greater value increase is that it can also mean investment to construct the transit infrastructure, so the value is created. It is in this way that the entrepreneurial approach "creates new markets" that government planners cannot achieve on their own. This value increase can only be achieved in partnership with governments that manage the common good outcomes necessary but are freed from the need to raise all the funds.

This entrepreneurial approach was used by Hong Kong in its metro and in the development of the private suburban railways in Japan, primarily in the first half of the Twentieth Century. Railway companies augmented their transport revenue through real estate development and management, but also proactively managed land uses around their stations to influence passenger demand. Land was provided to institutional users such as hospitals or universities at concessional rates at the outer terminal stations, creating demand for travel in the reverse direction from central business district commuting patterns [37]. The private railways had to diversify in this way to survive, as the Japanese Government had partially nationalized the industry to create the Japan National Railway. Private companies were forbidden from building railways which interfered with the national railway's operations and were mostly restricted to areas with low population. This forced them to build their own catchment population around their railways [38], making the best use of the assets at their disposal. This is a good example of a TAC that was privately created but had significant benefits to the wider community. Similar results, albeit with less striking development histories, have taken place in Hong Kong, and more recently, has begun to take place in mainland China.

Thus, value creation can be applied to the TAC model using value uplift in land development to create value for the transit funding, rather than the value capture or value leakage that occurs under the present approach to "predict and provide" transit, leading to limited interest in transit projects.

In cities that do not have such attractive land development potential as does Hong Kong and Japan, this approach can be taken a step further to attract private investment in transit infrastructure. Rather than just buying pre-rail land and selling it at post-rail prices, the partnerships with landowners and developers can be expanded to capture even greater value around stations. This can be done by incorporating developer preferences for the location of the transit line and associated stations to allow for fully private transit lines to be constructed and operated in unison with new developments [8]. Coupled with this, there are technological innovations occurring in the transport technology sector that are providing rail-like solutions at a much cheaper cost, discussed below.

Such an approach stands to provide cities and nations with a way to break out of the gridlock of automobile dependence and under-financed transit by harnessing private investment to deliver integrated transit and land development along corridors. This way enables value creation from the transit that can be used to contribute to the costs associated with delivering the transit without driving away investors and developers.

3.3. Principle 3: Begin with Available Means Rather Than Pre-Determined Ends

The third key principle drawn from effectuation is to "begin with a set of available means, rather than pre-determined ends" [26]. This requires thinking differently about what constitutes a cornerstone for action, innovation and finance. During new venture creation, expert entrepreneurs tend not to decide upon a "final product" and then seek to assemble the required resources, but instead begin with what is available, giving preference to actions which harness available resources or networks and which appear to help with their perceived journey.

Unlike the current approach to transit which seeks to predict and build transit infrastructure based on current conditions and reliant on government funding, this principle suggests that instead of using a pre-determined route and trying to "add on" land value creation at the end, the "available means" or available land opportunities are in fact the basis for the viability of the entire project and need to be considered right from the start.

Despite entrepreneurs often being considered "risk takers", expert entrepreneurs seek to minimize risk by "controlling the downside scenarios and finding ways to reach the market with a minimum expenditure of such resources as time, effort and money" [26]. This means entrepreneurs seek to creatively leverage underutilized or "slack" resources, such as land development sites that can be made viable through transit accessibility. Such development opportunities can then provide a powerful dynamic in the process to design and deliver transit infrastructure. Hence, rather than having a fixed route and set of station locations in mind, the process can begin with a configuration that best leverages investment in the early stages. As station precincts then begin to be built and create more value, the investment in the transit can continue to grow to provide greater services and station precinct locations. Organic growth of a TAC project can be based on stages that depend on what the land development market can achieve.

Examples of this organic process of beginning with what is available can be seen in the United States in the development of new corridor rail lines based on a series of TODs built-in stages. Organic stepwise approaches to US transit and land development are usually based on entrepreneurial land developers linked in partnership through mechanisms like Tax Increment Financing or Business Improvement Districts. TIF projects raise bonds based on estimated future tax revenue developed from successful urban development. Business Improvement Districts (BIDs) are more directly involving contributions from business and have mostly been used to regenerate urban areas though they are now being extended along a corridor. While BIDs do involve new levies, they are either initiated by, or negotiated with, local businesses who will benefit from the infrastructure.

Four examples of such organic TAC-like delivery are outlined.

3.3.1. San Francisco

A BID in the Bay Area established a local committee of the district's residents, business owners, tenants, schools and developers, creating a strong base in social capital. The committee prepared a local development proposal including a financial plan and sought approval from local government authorities thus generating the political capital. In this case however, the district residents were charged with elevated property taxes to fund the infrastructure to help regenerate their area. This consensual charge generated the financial capital, rather than leveraging land value uplift to attract new investment [39].

3.3.2. Pearl District Streetcar

The Portland MAX Light Rail, or Metropolitan Area Express, was a fully government funded project from the 1980′s and was so successful that various other communities wanted to have a similar urban renewal process in their area. The Pearl District of Portland was an old industrial area—creating "available means" for urban regeneration, with businesses and residents wanting a modern transit service to link them to the city center. An organic process was begun in the 1990′s to generate a variety of funding sources including a Tax Increment Financing (TIF) set up through the local council (providing 13% of funding) and a BID-style "Local Improvement District Levy" on local business (providing 17% of funding) in partnership with state and federal funds. The first two stages of the Portland Streetcar opened in 2001. One further stage was extended in 2007 using 21% TIF funding and 31% BID funding as the success of the first two stages had raised land values.

When the Pearl District was legally formed in 1998 the value of property was estimated at $446 million and in 2014 at $2.2 billion. The tram system for the Pearl District is owned by the City of Portland and managed by Portland Streetcar Incorporated, a non-profit public benefit corporation whose board of directors report to the city's Bureau of Transportation. The Pearl District corridor that is serviced by this light rail is an outstanding success story of urban regeneration with multiple sustainability out-comes [40–43].

3.3.3. South Lake Union Streetcar, Seattle

The South Lake Union Streetcar project was initiated by community and business interests working together over several years. The prospect of urban renewal opportunities being generated by a light rail service was embraced by a range of businesses and residents who lobbied for the return of the historic tram car service. The South Lake Union Streetcar project was able to attract the interest of local, state and federal governments who worked out how to fund the project with the local business community. A fee from 760 land parcels was estimated to provide 52 percent of the total project cost. The City of Seattle issued government bonds to raise capital and linked them with the private funds. The city assessed a fee in 2004 and landowners in the precinct approved it in 2005. The street car project became operational in 2007. The assessed fee was based on estimated land value uplift for various land uses. The land owners were provided an option to pay a fee up front or in 18 years at a 4.4% interest rate. In this case the project was considered a low-risk as it was applied in an established urban area with a strong real estate market [44]. Only 12 of the affected property owners formally objected to the proposed Local Improvement District tax. The South Lake Union Streetcar is owned by the City of Seattle and operated and maintained by a transit agency with representation from the local community.

The last two examples show how a range of procurement and financing models can be organically leveraged through partnerships, based on what is available, to support projects focused on urban regeneration using transit infrastructure—and to further expand as the area grows. By starting with available means, further entrepreneurial opportunities are created as the initial segments succeed. From the perspective of the private sector, the benefits from the urban regeneration opportunities are greatest when they are in-volved early, which makes early partnerships and inclusive planning crucial.

3.3.4. Brightline

A larger development known as Brightline, Florida has been set up as a purely private rail project using a TAC approach. The project began by leveraging funding from a New York hedge fund based on private sector opportunities around new stations as well as potential fare box returns.

The first stage of the Brightline was developed in partnership with the local and county governments and the local community [7,45]. It opened in late 2017, initially running from Miami to Fort Lauderdale, but with an extension to Orlando International Airport under construction, and further extensions to Disney World and Tampa in planning [46]. There are also plans to build a new line from Los Angeles to Las Vegas.

The latter project includes purchasing 38 acres of land adjacent to the Las Vegas strip for the station and a mixed-use development. It came about via the acquisition of XpressWest, which had secured federal approvals for the rail corridor [47]. The company plans to expand further and describes its business model as "a scalable model for twenty-first century passenger travel in North America" and identifies eight new potential corridors within the United States and Canada [48]. Thus, by taking an organic approach the corridor was eventually completed and the model is now being replicated.

In practice Transit Activated Corridors raise investment for transit through partnerships that grow organically as the land development opportunities are realized and expanded. This minimizes risk for participating private parties and increasingly shifts towards private funding to complete projects. Hence this can reduce government's role especially in terms of having to raise the full capital (often difficult and compared with the ERM/TAC model less value creating) allowing a focus on roles more aligned to the purview of government such as being critical in the delivery partnerships. Government needs to provide creative leadership on zoning, planning integration, and facilitating connections to the wider transit network. Government can also assist with land assembly and risk management in procurement [7], easing the process for private parties to participate and creating new value. Similarly, for the public sector, project-based implementation risk is reduced through sharing with the private sector in this organic stepwise process.

The application of these three principles of effectuation will be a key determinant of the success of the application of the ERM model to deliver Transit Activated Corridors. There are also a range of government tools in urban planning that can be delivered in partnership with developers and investors, and which can help create Transit Activated Corridors.

4. Theoretical Basis 3: Urban Planning Tools for Fast Transit Corridors and Walkable Station Precincts

Urban development and infrastructure are best developed when they are part of both a strategic and a statutory framework. The majority of these planning systems, especially in Australia and America, still enable urban sprawl and associated car-based communities and have a lesser focus on enabling transit and urban regeneration. There is however a growing movement to find new ways that urban planning can produce effective corridor transit and TODs. These approaches will be examined in terms of tools for corridor design that facilitate transit and dense urbanism as in a TAC, as well as tools for walkable urban design in the associated TODs. Thus, two more principles have been selected from urban planning tools to help design, finance and deliver Transit Activated Corridors.

4.1. Principle 4: Define Transit Activated Corridors

The first planning tool for creating a high-quality transit system down a corridor is to declare it or zone it in strategic and statutory plans as primarily for transit and dense urbanism. A series of such plans are being developed around the world since Transport for London declared their policy called "Street Families" [49] which sets out the streets that give priority to transit and where density will be given special encouragement. In Melbourne the Victorian Government has a policy called the "Movement and Place" framework which recognizes that streets are not only about moving people from A to B, but in many contexts also act as places for people and public life. Similar policies have been developed for Auckland, New Zealand, and Western Australia. The movement and place framework enables the "place" prioritization of streets to create walkable, livable centers. In Perth the approach has been proposed to create a "Green Route" in the Metropolitan Region Scheme that requires transit priority and density to be the joint focus along the road. Such routes could be specified as potential Transit Activated Corridors with associated zoning along the corridor.

This approach is increasingly being used in the UK and Europe more generally as part of Sustainable Urban Mobility Plans [50]. The approach is outlined in Table 1 below.

Table 1. Summary of guidelines for sustainable urban mobility plans compared to traditional planning. Source [50].

Traditional Transport Planning	**>**	**Sustainable Urban Mobility Planning**
Focus on traffic	>	Focus on people
Primary objectives: Traffic flow capacity and speed	>	Primary objectives: Accessibility and quality of life, as well as sustainability, economic viability, social equity, health and environmental quality
Modal-focussed	>	Balanced development of all relevant transport modes and shift towards cleaner and more sustainable transport modes
Infrastructure focus	>	Integrated set of actions to achieve cost-effective solutions
Sectorial planning document	>	Sectorial planning document that is consistent and complementary to related policy areas (such as land use and spatial planning; social services; health; enforcement and policing; etc.)
Short- and medium-term delivery plan	>	Short- and medium-term delivery plan embedded in a long-term vision and strategy
Related to an administrative area	>	Related to a functioning area based on travel-to-work patterns
Domain of traffic engineers	>	Interdisciplinary planning teams
Planning by experts	>	Planning with the involvement of stakeholders using a transparent and participatory approach
Limited impact assessment	>	Regular monitoring and evaluation of impacts to inform a structured learning and improvement process

A core part of designing TACs would be a set of detailed design options for how a mid-tier transit service like light rail or a trackless tram (see below) could travel at speed down a clearway where road space is available, and then slow down when it enters a station precinct where the design and place focus would be to facilitate walkability and pedestrian activity. The latter part of the road works could be the responsibility of the private sector partners. This would send the signal that dense urban development would be favored as it would have a high-quality transit system linking it to the rest of the city and would have a highly attractive urban design quality for attracting people-based activities in and around the stations.

The responsibility to enable TACs would be given to an agency, or cross-agency group, that has both responsibility for delivering transit and delivering urban regeneration. Thus, roads chosen for this category would shift their priority for providing mobility services for through traffic, to a focus on how they could enable quality transit and urban design along the corridor that delivers value to both developers and the community. This would mean more of a focus on accessibility, sustainability and equity as set out in Table 1. Compared with car only lanes such routes could carry the equivalent of six lanes of traffic [51], easing congestion issues while increasing activity along the corridor through transit and urbanism.

4.2. Walkable and Sustainable Station Precinct Design

Station precincts must be allowed to be dense and mixed use in the strategic and statutory zoning systems used to enable TACs. There are a large number of design tools created to make station precincts or TODs into "inclusive, safe, resilient and sustainable" places including walkable urban design, solar design, water sensitive design, biophilic design, affordable housing design and most of all integrated design. For instance, there are a number of detailed manuals from the Congress of New Urbanism that set out best practice in these areas [52–55]. Such guidance now needs to be reflected in statutory requirements for station precinct developments along transit corridors. Such requirements also need to consider how new technologies for smart and sustainable systems can enhance various design outcomes. This may include how driverless electric shuttle buses can carry people to the station precincts (providing first and last kilometer solutions) without ruining the walkability qualities of the area [30]. Evidence is showing that Uber (and potentially driverless vehicles) are increasing the vehicle kilometers travelled (VKT) rather than decreasing it as many had anticipated, causing greater congestion and accessibility issues [56]. To counter this trend will require a different approach to mobility and TACs are likely to be part of this.

5. Applying Transit Activated Corridor Development with Mid-Tier Transit

A research project as part of the Sustainable Built Environment National Research Centre (SBEnrc) has been developed with a series of partners seeking to deliver a mid-tier transit-based TAC using the ERM approach. It was given a significant boost when a new transit technology was discovered that we have called a "Trackless Tram". The trackless tram systems (TTS) have taken six innovations from high-speed rail, put them in a carriage bus—or tram like vehicle—with stabilization through bogeys and optical guidance systems, that not only mean it is largely autonomous (though not completely driverless), but it is also enabled to move at speed down a road with the ride quality of a light rail. Being electric through batteries and with no need for steel tracks, it is significantly cheaper and easier to implement than a light rail and significantly better than BRT at creating urban land value uplift. Research was conducted on assessing this technology [51] and the conclusions are presented in Table 2.

Table 2. Indicative comparison of characteristics of corridor based urban rapid transit systems.

Characteristic	Bus Rapid Transit (BRT)	Light Rail Transit (LRT)	Trackless Tram System (TTS)
Speed and Capacity	✓	✓✓	✓✓
Ride Quality	✗	✓✓	✓✓
Land Development Potential	✗	✓✓	✓✓
Cost	✓	✗	✓
Disruption during construction period	✓	✗	✓✓
Implementation Time	✓	✗	✓
Overall	✓	✓✓	✓✓✓

The assessment provided above highlights that TTS has the potential to stimulate urban redevelopment potential just as well as good light rail and hence can enable the delivery of TACs. This will require assessment in different cities, but an approach is suggested using the five principles developed from the three entrepreneurial principles and the two urban planning tools. This enables a high-level approach to assess the potential to deliver very efficient and effective Transit Activated Corridors using a mid-tier transit as the catalyst. The core requirements from the five principles for TAC are applied to the three options of BRT, LRT and TTS and are set out in Table 3. This enables us to see how well the new technology of TTS promises to facilitate a TAC.

Table 3. Comparison of TAC characteristics for corridor based urban rapid transit systems of BRT, LRT and TTS.

Characteristic 1: Ability to facilitate partnership-driven planning		
BRT	BRT is able to achieve partnership driven planning, however partnerships are generally transport-centric given the lesser urban regeneration ability achieved by traditional bus-based schemes.	✓
LRT	LRT is able to bring transit, land development and community interests to the table and this has been demonstrated around the world, including in the case studies above.	✓✓
TTS	TTS are able to bring the same interests together as LRT to plan a transit project financed by urban regeneration, however TTS can enable the inclusion of far more parties than under the recent welfare finance model of most light rail. Projects do not need to be “Tokyo” in scale to get started, and have less risk. An inclusive, bottom-up, community-engaged planning approach can be achieved with the less expensive trackless trams, rather than only being considered by the top-down stakeholders.	✓✓✓
Characteristic 2: Ability for value creation through urban regeneration		
BRT	Bus-based systems have had less urban regeneration success in most cases.	✗
LRT	Light rail has been successful in attracting investment and urban regeneration around its lines, especially given its fixed nature, however urban regeneration is best achieved if land development is used as the cornerstone of transit finance such as proposed here.	✓✓
TTS	Ability to be used like light rail, particularly through an entrepreneurial financing process to ensure urban regeneration is undertaken, but at lower cost to the entrepreneurs and thus is more likely.	✓✓
Characteristic 3: Ability for organic resourcing through staged financing		
BRT	The lack of strong urban regeneration attraction created by BRT systems creates a lack of investor incentive for the finance of new lines.	✗
LRT	Has been achieved in a number of cities, highlighted in case studies above.	✓✓
TTS	Organic resourcing through staged financing would be similar to the LRT as in the case studies outlined above. At each stage of financing the two parts of the TAC, the trackless tram and the chain of TODs could be financed with steps assessed for land value uplift, patronage and other benefits and costs, before proceeding to the next stages.	✓✓

Table 3. *Cont.*

Characteristic 4: Ability to service strategic plans (TAC route)		
BRT	If strategic plans are developed mode agnostically, BRT is competitive on infrastructure cost and speed if given priority. However, it will not achieve urban regeneration outcomes.	✓
LRT	If strategic plans are developed mode agnostically, LRT is competitive on capacity per vehicle, speed and ability to attract regenerative investment.	✓
TTS	If strategic plans are developed mode agnostically, TTS can enable the capacity and speed of LRT but cost much less. This is likely to open up the potential for many more strategic routes and help create an overall network with far greater overall benefits.	✓✓
Characteristic 5: Ability for integrated application of TOD design tools		
BRT	The same TOD principles can be applied but without private investment they rarely happen.	✗
LRT	Able to utilize best-practice integrated TOD design from light rail projects to achieve walkable, people-centric transit precincts.	✓
TTS	Design tools for TODs would be just as effective in station precincts around trackless trams as around LRT except the cost of the infrastructure is much less (no overhead catenary and no steel tracks).	✓✓

The high-level assessment would suggest there is a very high capability of a trackless tram system and a light rail to enable a TAC to be created with a quality transit corridor and a chain of high-quality station precincts linked to it. These results are summarized in Table 4.

Table 4. Indicative comparison of characteristics of corridor based urban rapid transit systems in terms of entrepreneurship and urban planning factors supporting a Transit Activated Corridor.

Characteristics in Terms of Ability to Use	**Bus Rapid Transit (BRT)**	**Light Rail Transit (LRT)**	**Trackless Tram System (TTS)**
Partnerships	✓	✓✓	✓✓✓
Value Creation in Urban Regeneration Potential	✗	✓✓	✓✓
Organic Resourcing through Staged Financing	✗	✓✓	✓✓
Strategic TAC Route	✓	✓	✓✓
Design Tools for TODs	✗	✓	✓✓
Overall	✓	✓✓	✓✓✓

6. Conclusions

Growing cities around the world are looking for new ways to deliver transit and urban redevelopment. This paper suggests a new option called a Transit Activated Corridor (TAC) and sets out how best to achieve them using five principles drawn from entrepreneurship theory and urban planning:

1. *Create partnerships from the start*, that suggests for TAC the need for partnerships between government, community and the private sector which can leverage such entrepreneurial approaches similar to the historic role of entrepreneurs in creating train and tram corridors, and the emerging models for involving the private sector in rail developments, especially involving City Deals;
2. *Value creation rather than prediction*, which suggests for TAC taking value creation opportunities through involvement of private sector financing of land development rather than predicting transit outcomes as in current transit planning;
3. *Begin with available means rather than pre-determined ends*, suggesting that TAC could use available resourcing from land development in organic steps to stage the financing;

4. *Define Transit Activated Corridors*, that suggests a high-level strategic plan to develop Transit Activated Corridors (like the European Sustainable Urban Mobility Plans) with statutory mechanisms that require the delivery of transit priority as well as dense, urban regeneration, and providing a delivery agency focussed on this task; and
5. *Walkable and sustainable station precinct design*, that would mean a series of statutory design requirements for the station precincts to be high quality designed TODs for walkability, affordability and sustainability.

All these require the private sector to be actively involved from the beginning of the planning process, providing the opportunity to collaboratively shape and capture benefits from transit activation along the corridor, creating the basis for the private sector to contribute financing given the attractive development opportunities that exist.

When the five principles were applied to a high-level assessment of new mid-tier transit technology, it showed that these lower cost new technology options are likely to help with the design, financing and delivery of a Transit Activated Corridor down urban streets.

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Trackless Trams and Australian Urban Fabric

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Abstract

There is growing interest in the concept of Trackless Trams as part of the suite of transport technologies available to help shape more urban outcomes. However, there is much more for decision-makers to consider than the vehicle itself. This paper discusses both the city shaping possibilities of these systems and the challenges and opportunities inherent in integrating new technologies into existing city systems.

Informed by studies, field trips and current trialling of the technology this paper documents the history of the trackless tram from rail to optically guided bus with level 4 autonomy. It describes the potential role of integrated transit systems anchored by Trackless Trams in transforming our cities from car-dominated roadways to green interconnected living streets or activated transit corridors with new urban centres.

The paper then applies the technology to Australian cities using the theory of urban fabrics and how it can assist urban regeneration in all three fabrics: walking, transit and automobile urban fabric. A framework of seven design approaches is used to see how the Trackless Tram could be integrated into the urban regeneration process. It uses work done in Townsville, Sydney, Melbourne and Perth as case studies to illustrate how Trackless Trams could help transform Australian cities in various urban fabrics across their cities. New governance systems and changes to planning rules will be needed to deliver this.

Key words: Trackless Tram technology, urban regeneration, theory of urban fabrics, transit activated corridors

1. Introduction

Trackless Trams are providing a new approach to urban transit through delivering a potentially much more 'light rail-like' transit system at around the price of buses. This is done through an optical guidance system developed for high speed rail that means it does not need steel wheels on steel tracks, as well as using new technology batteries that mean it is electric without needing an overhead catenary. The system can carry the patronage of a light rail with similar ride quality and therefore has potential to compete with cars. Being electric its impact locally on noise and air quality is significantly better. It therefore appeals to developers and local/state planners looking to increase urban regeneration around transit routes and especially stations where buses have so far failed. This paper therefore examines the technology in terms of its potential to achieve common good planning outcomes so that a city can simultaneously improve transit and housing/jobs outcomes in different parts of the city. It uses Australian cities as case studies based on a research project involving four Australian cities for the Sustainable Built Environment National Research Centre (Newman, Mouritz, et al., 2018; Newman et al., 2018).

The paper uses the Theory of Urban Fabrics (Newman, Kosonen, & Kenworthy, 2016) to enable a better understanding of how land development mechanisms are inherently linked to transport technologies and what this means for creating urban revitalisation and regeneration. The paper uses a Framework developed in 2019 for the SBEnrc comprising seven design principles and associated practices to inform the qualities needed in creating urban regeneration projects based on transit systems like Trackless Trams.

The Framework is then conceptually applied to four case study urban fabrics from the four Australian cities, showing how solutions should differ in emphasis but still have important shared approaches.

2. Trackless Trams

In a previous research project that has been developed with a series of partners seeking to deliver a light rail-based urban regeneration approach we have created a model for how transit and land development can be integrated with private finance to enable urban regeneration (Newman, Davies-Slate, & Jones, 2018). The project was given a significant boost when the new transit technology of Trackless Trams was discovered. The Trackless Tram Systems (TTS) have taken six innovations from High Speed Rail, put them in a carriage bus – or tram like vehicle, with stabilization through bogeys and optical guidance systems, that not only mean it is largely autonomous (though not driverless) but it is also enabled to move at speed down a road with the ride quality of a light rail. Being electric through batteries and with no need for steel tracks, it is significantly cheaper and easier to implement than a light rail. Research was conducted on assessing this technology (Newman, Hargroves, et al., 2018) and the conclusions are presented in Table 1. The crosses indicate major problems, the ticks give the level to which these are solved.

Table 1. Indicative comparison of characteristics of corridor based urban rapid transit systems

Characteristic	**Bus Rapid Transit (BRT)**	**Light Rail Transit (LRT)**	**Trackless Tram System (TTS)**
Speed and Capacity	✓	✓✓	✓✓
Ride Quality	✗	✓✓	✓✓
Land Development Potential	✗	✓✓	✓✓
Cost	✓	✗	✓
Disruption during construction period	✓	✗	✓✓
Implementation Time	✓	✗	✓
Overall	✓	✓✓	✓✓✓

Source: (Newman, Hargroves, et al., 2018)

This Trackless Tram Systems assessed here lean towards the one created by CRRC in China as it has the most developed optical guidance system that controls ride quality. However, there are other Trackless Tram Systems that are developing in Europe that could also be used to create better people-friendly and place-based urban spaces that are not affected by excessive traffic. Table 2 summarises the evolution of these systems and summarises the qualities that seem to characterise their progress (Newman, Mouritz, et al., 2018).

In 2001, the Guided Light Tram (GLT) rubber tyred vehicle was manufactured by Bombardier guided by a single central rail. But due to the system costs, limited reliability and maintenance issues this GLT became unsuccessful. In 2007, Translohr was built within a modular design which addressed the conditions of coming off the guide rail and pavement rutting. However, its weakness was lack of interoperability and high costs. Then in 2011 Van Hool developed the ExquiCity which was suitable for corridor transit. It has the ability to travel up to 100km on a full charge. This tram was operating across Italy, Switzerland, Germany, UK, Spain, France and also entered the Australian market through a relationship with the Transit Australia Group TAG. Later in 2017, Iriza was launched with a stylish appearance featuring more glass and chrome edge around the body and was able to run 200km range on a charge. In 2018 the ART Autonomous rapid rail transit vehicle started its operations in China with fully autonomous commands from both a control centre and guidance from on board sensors as well as GPS, Lidar systems and cameras enabling it to fully a painted line on the road with millimetre accuracy (Bodhi Alliance, 2018; Newman, Mouritz, et al., 2018).

These Trackless Tram systems are considerably cheaper than light rail with the Chinese ART estimated at $3-4m per km plus whatever road works are needed to enable a separated lane; this compares with a minimum $50m per km for light rail and up to $175m per km for the Sydney LRT.

Table 2: Examples of the evolution of trackless trams

Year	Type and link	Manufacturer	Countries of operations	Key features commentary	Indicative Image
2001	Guided light rail tram	Bombardier Transportation	France	▪ Rail guided by a single central rail ▪ System costs, reliability and maintenance issues. ▪ Too fewer vehicles to serve the demand.	
2007	Tramways on tyres	Translohr	France, Columbia, China, Italy	▪ Modular design with between 2 and 7 carriages. ▪ Narrow vehicle permanently fixed to guide rails ▪ Cannot divert, similar to traditional steel-wheeled rail vehicles. ▪ Lack of interoperability, and expensive to build and maintain.	
2011	Bus Rapid Transit	Van Hool	Italy, Switzerland, Germany, UK, Spain, France, Luxemburg, Sweden, Norway, French Antilles and Austria	▪ Similar to light rail regarding comfort, smoothness, and stylishness though without a full optical guidance system. ▪ A range of propulsion systems: fully electric trolley, on-board systems, hybrid gas electric, gas and hydrogen fuel cell technology.	
2017	ie Tram	Irizar	Spain	▪ More glass for the carriages ▪ Chrome edge around the body for a stylised appearance. ▪ 200km range on a single charge	
2018	Autonomous Rail Rapid Transit (ART)	CRRC Zhuzhou Institute Co Ltd	China	▪ Resembles a rubber-tyred tram, but with flexibility to move around like a normal articulated bus. ▪ Autonomous rapid rail transit vehicle fully autonomous and bi-directional. ▪ Composed of individual, fixed sections joined together by articulated gangways ▪ Well developed optical guidance system	

Source: (Caldera et al., 2019)

In advancing the Trackless Tram journey it is critical to meet the interoperability requirements in any urban system and to ensure that implementation would not be limited to any one supplier. With increasing attention on local shared mobility systems that can broaden catchment areas and limit parking spaces, TTS is a potential game changer for creating better urban regeneration through integrated transit, finance and land development. The question then is where a Trackless Tram System is best able to be deployed and how best to approach urban regeneration within that corridor as the station precincts become critical to how such a TTS system can be funded and how effective it is at getting people out of cars as well as providing high quality urban outcomes in all aspects of urban development. The next section uses Urban Fabric Theory to create some perspectives on this question.

3. Urban Fabric Theory

Each urban fabric consists of a particular set of spatial relationships, typology of buildings and specific land use patterns that are based on their transport infrastructure priorities (Newman et al., 2016; Thomson & Newman, 2018). Figure 1 presents the original typologies; Figure 2 shows the overlapping nature of these three fabrics.

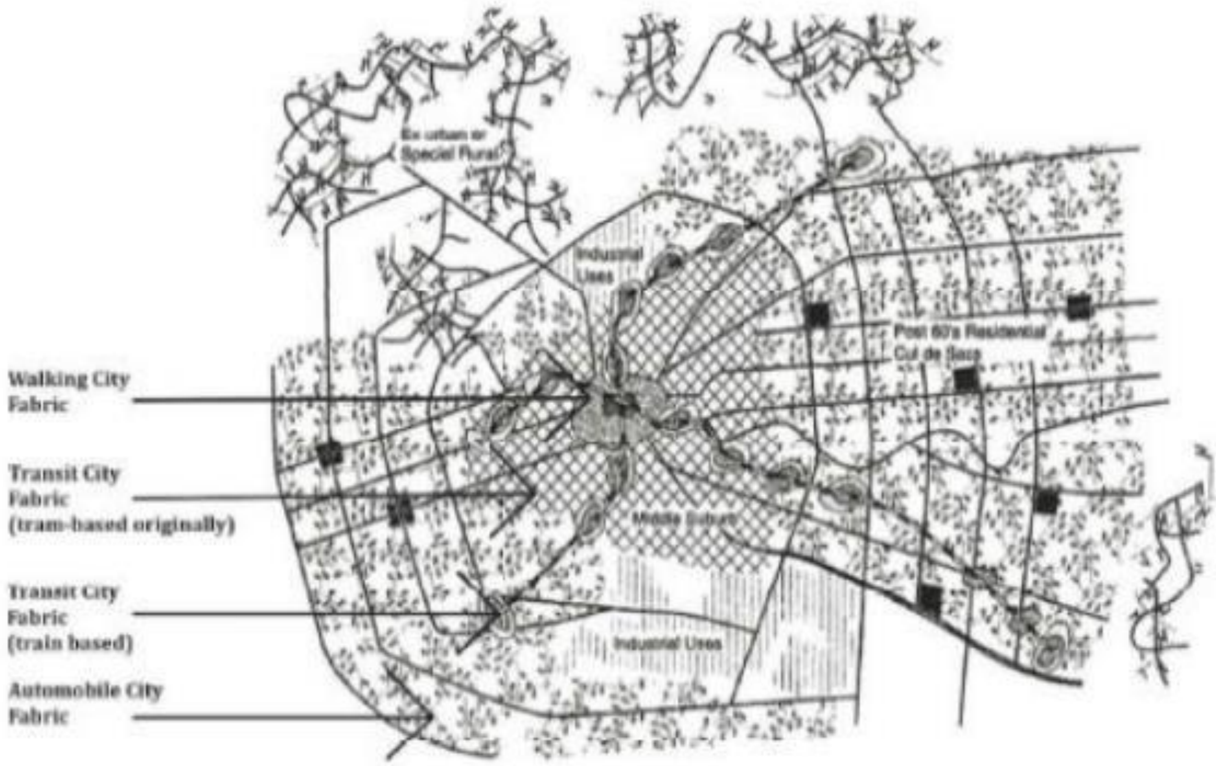

Figure 1: The urban fabric typologies
Source: (Kosonen, 2013)

Figure 2: Walking, transit and automobile city a combination of three overlapping systems
Source: (Kosonen, 2013)

The urban fabrics of any city can be visualised through maps based on historical development patterns. The fabrics can be defined and understood by the qualities of historical transport systems in the fabrics that have created the daily travel time budgets of the inhabitants as outlined below and the resulting properties of the three fabrics are presented in Tables 3 and 4.

3.1 Walking urban fabric

Walking cities have a long history as it was the only form of transport available in the majority of historical settlements to enable people to move from one place to another. Walking cities were dense (usually over 100 people per hectare), with mixed-use areas with narrow streets and this fabric remains in the old parts of cities. Most global cities attempt to retrieve the intense urban activity and fine-grained street patterns associated with walkability in their city centres but have realised that they have to adhere to the urban fabric of the walking city areas. The building of new walking urban fabric in other parts of polycentric cities is now also firmly on the planning agenda due to its economic attractions (Florida, 2010; Kenworthy & Newman, 2015; Newman & Kenworthy, 2011).

3.2 Transit urban fabric

The transit urban fabric since 1850 was originally based on trains and then trams. Both trams and trains could travel faster than walking; trams with average speeds of around 10-20 km/h and trains at around 20 – 40 km/h. This created opportunities for cities to spread out in two ways with trams forming the urban fabric of the inner transit city 10-20 kilometres across. Trams created linear development, and trains created dense nodal centres with mixed land uses along corridors (Newman et al., 2016; Thomson & Newman, 2018). Many cities are trying to enhance their transit fabric and extend it into new areas lacking transit.

3.3 Automobile urban fabric

With the emergence of roads and parking for automobiles, trams were often replaced by buses, supplementing car use and resulting in low density urban sprawl. Automobile Cities from the 1950s onward could spread to some 80 km diameter in all directions, and at low density because automobiles could average 50-80 km/h while traffic levels remained low. Ultimately such areas became the basis of automobile dependence (Newman & Kenworthy, 1989) and automobility (Urry, 2004). These are the fabrics where many urban planners, developers and communities are wanting better transit, better local services and jobs and even more affordable higher density housing options, especially in declining middle suburbs (Thomson & Newman, 2018). This requires a combination of transit and urban regeneration.

The importance of regenerating and creating more walking and transit fabric in cities is that this fabric is considerably reduced in its metabolism (less resource consumption and associated waste) as well as having greater opportunities for knowledge economy jobs (Florida, 2010; Thomson & Newman, 2018). Thus Tables 3 and 4 summarise these urban fabric qualities.

Table 3: Urban Fabric elements within a city (walking/ transit/ automotive) (Source: Newman et al., (2016))

Urban Fabric Element	Walking City	Transit City	Automotive City
1. Street Widths	Narrow	Wide enough for transit	Wide enough for cars/trucks
2. **Squares and Public spaces**	Frequent as very little private open space	Less frequent as more private open space	Infrequent as much greater private open space
3. Street furniture	High level for pedestrian activity	High level for transit activity (bus stops, shelters)	High level for car activity (signs, traffic lights)
4. Street networks	Permeable for easy access; enables good level of service for pedestrians	Permeable for pedestrians, networks to reach transit stops, corridors enable good levels of transit service	Permeability less important, enables high levels of service for cars on freeways, arterials and local roads. Bus circulation often restricted by cul-de-sac road structure.
5. Block scale	Short blocks	Medium blocks	Large blocks
6. Building Typologies	High density minimum 100/ha usually	Medium density minimum 35/ha usually	Low density <35/ha, often much less than 20/ha.
7. Building set backs	Zero set backs	Setbacks minimal, for transit noise protection and more space	Setbacks large for car noise protection and extra space
8. Building Parking	Minimal for cars, seats for pedestrians, bike racks	Minimal for cars, seats for pedestrians, often good bicycle parking	Full parking in each building type
9. Level of service for transport mode	Pedestrian services allow large flows of pedestrians	Transit services allow large flows of transit users	Car capacity allows large flows of cars

Table 4 highlights how they can be regenerated and how old walking and transit fabrics can be built into new areas now that some fundamental problems are being found with building a city-region just with automobile urban fabric (Newman et al., 2016).

Table 4: Fabric qualities across the urban fabric elements (Source: Newman et al., (2016))

Urban Fabric Element	Walking City	Transit City	Automotive City
1. Urban form qualities			
▪ Density	High	Medium	Low
▪ Mix	High	Medium	Low
2. Transport qualities			
▪ Car ownership	Low	Medium	High
▪ Level of service	High l.o.s for pedestrians	High l.o.s. for transit users	High l.o.s. for car users
▪ Transport activity	High ped activity	High transit activity	High car activity
3. Economic qualities			
▪ Infrastructure costs per capita	Low - Medium	Medium - Low	High
▪ Gross domestic product per capita	High	Medium	Low
▪ Labour intensity	High	Medium	Low
4. Social qualities			
▪ Difference between rich and poor	Low	Medium	High
▪ Ability to help car-less	High	Medium	Low
▪ Health due to walking	High	Medium	Low
▪ Social capital	High	Medium	Low
▪ Personal security	Variable	Variable	Variable
▪ Traffic fatalities	Low	Low	Medium to High
5. Environmental qualities			
▪ Greenhouse gases and oil per capita	Low	Medium	High
▪ Waste per capita (buildings, households)	Low	Medium	High
▪ Footprint per capita	Low	Medium	High

4. Emergent principles for an urban regeneration centres framework

Seven emergent principles for creating quality urban centres around a Trackless Tram have been developed from the SBEnrc project on Australian cities along with a range of urban design and infrastructure or urban development practices used to achieve these principles. These are presented below in Table 5.

Table 5: Framework for Regenerating Urban Centres with core design/planning practices [Source: (Caldera et al., 2019)]

Core Principles	Core Practices
1. Precinct safety and accessibility The development should be safe and healthy for people waiting to access transport nodes	▪ Human centred design ▪ Walkable urban design ▪ Place and movement design

2. Carbon neutral - positive approach The development should aim for carbon positive, being at least zero carbon, in both power and transport	▪ Solar passive design ▪ Solar active design ▪ Carbon neutral analysis
3. Local shared mobility The development should encourage diverse local modal services to access the transit service, with defined spaces	▪ Local mobility design ▪ Feeder transport design ▪ Mobility as a service
4. Property diversity The density and urban mix should contribute to urban regeneration	▪ Community engaged planning ▪ Agglomeration economy analysis ▪ Financial modelling
5. Property affordability The development should include diverse property options to provide affordable living as well as affordable housing	▪ Social housing analysis ▪ Life cycle assessment ▪ Sustainability operational analysis
6. Nature-loving and biodiverse spaces The development should include and connect biophilic and biodiverse greenspaces, supporting endemic species and habitat	▪ Biophilic design ▪ Water sensitive design ▪ Landscape oriented design
7. Inclusive, integrated, place-based planning Planning, design and implementation (operation, maintenance) should involve diverse stakeholders and all tiers of government to provide an integrated place-based approach.	▪ Joined up governance analysis ▪ Partnership analysis ▪ Procurement options analysis

1.

5. The Framework for Urban Regeneration of Centres and its Application to Urban Fabrics

In Table 6 below, the seven core principles are applied to four kinds of urban fabrics that are relevant to the case studies in the SBEnrc research. The routes in all four cities: Townsville (from CBD to James Cook University and Health Campus), Sydney (from Liverpool CBD to new Badgerys Creek Airport), Melbourne (City of Wyndham with need for links to heavy rail and for new urban centres), Perth (five local governments from Canning through the CBD to Stirling). All but two of the case studies go through a central area walking city, all but two go through an inner city transit fabric that has been defined by a previous tramway, all have a middle suburb with potential for transit fabric as the only redevelopment is backyard infill that is failing to provide a centre with transit, and all have an outer suburb automobile fabric area with the need for a centre and transit.

Table 6: The Framework applied to four different urban fabrics.

Core Principles/ Urban Fabric Examples	Central City Walking Fabric (current rail-based centre)	Inner City Transit Fabric (old tram line area)	Middle Suburb Transit Fabric (infill failing)	Outer Suburb Automobile Fabric (new area needing a centre)
1. Precinct safety and accessibility	Walkability the critical value	Walkability in centre and corridor access both critical	Walkability in centre and corridor access both critical	Walkability in centre and corridor access both critical
2. Carbon neutral – positive approach	Strong transport carbon reductions but harder to do solar on buildings	Easier to do solar on buildings and harder on transport carbon reductions	Easy to do solar on buildings and hard on transport carbon reductions	Very easy to do solar on buildings and much harder on transport carbon reductions

3. Local shared mobility	Essential character	Essential character	Essential character	Essential character
4. Property diversity	Essential character	Essential character	Essential character but markets harder on mixed use	Essential character but markets hard on mixed use
5. Property affordability	Important but more difficult	Important but still difficult	Important and easier to achieve	Important and easier to achieve
6. Nature oriented space	Critical with emphasis on biophilic buildings and small pocket parks	Critical with emphasis on biophilic buildings, small pocket parks and green corridor	Critical with emphasis on biophilic buildings, small pocket parks and green corridor	Critical with emphasis on small pocket parks, green corridor and landscape-oriented development
7. Inclusive, integrated, place-based planning	Essential for delivery	Essential for delivery	Essential for delivery	Essential for delivery

The main conclusions from this analysis are that Trackless Trams could provide a major design solution for each of the four urban fabrics examined. However, the differences in urban fabric are considerable and significant so they do need to be addressed separately. They will need to have specific design issues resolved for each area as summarised below:

1. Walkability for safety and accessibility is the critical value in all four fabrics. High quality corridor transit is the extra critical accessibility component in the fabrics outside of the central city. This is a global issue where a Trackless Tram may be a significant opportunity as a connector down corridors or to heavy rail lines enabling a much better transit network quality.
2. Carbon neutral or carbon positive is easier the closer to the city centre as there is much less car dependence, but the extra space associated with lower density outer area fabrics is easier for solar on buildings; this trade-off can be managed to achieve carbon neutral in all fabrics but needs different kinds of technologies and investments (Newton & Newman, 2013).
3. Local shared mobility is essential in all four fabrics to manage the need for parking, for equity reasons and for transit support (Glazebrook & Newman, 2018); managing how to enable this along with walkability is a new design challenge as new evidence is showing that Uber and autonomous vehicles are increasing VKT not decreasing it as suggested by branding (Schaller, 2018).
4. Property diversity is also an essential character in each fabric though achieving mixed land use becomes harder with distance from the central city area due to the density levels required to achieve market viability, and the prevalence of single-use residential zoning and minimum parking requirements.
5. Property affordability is important to seek in all urban development not just low density areas on the urban fringe but this becomes easier to achieve the further away from the city centre.
6. Nature-oriented space is also a critical element of all fabrics as it is an essential part of human health and planetary health, but varies in its spatial definition from intensively building-oriented biophilics in the walking city supplemented with small pocket parks, to an emphasis on how the transit corridor is greened, then more and more landscape-oriented design as the fabric has less spatial intensity (Desha et al, 2016).

7. The integration of each of the other six core principles into a final design, procurement and delivery process that has place as its core focus, is essential for each urban fabric. This will require changes to governance systems that can enable inclusive, integrated, place-based planning.

6. Conclusions

The future of urbanism in Australia and around the globe to adapt and respond to the big challenges of climate change, economic development and social inclusion, will depend on how well we do urban regeneration and create new urban centres in the suburbs. This paper has built on the need for improved urban regeneration and urban centre-building in Australian cities to be linked to the need for improved transit systems and particularly Trackless Trams. An analysis based on the Theory of Urban Fabrics and a Framework for Urban Regeneration involving seven principles, has created some approaches to how well Trackless Trams can assist with urban regeneration. The Framework has been applied to four different urban fabric types, based on the fabrics in the four case studies being studied as part of the SBEnrc project. The differences in the fabrics are considerable thus requiring significant attention to specific design policies, however the overall need for better transit and more urban regeneration is clear in all areas. In each case the urban regeneration centres will not emerge unless they have a quality transit corridor that can reduce car dependence, nodes at stations which emerge from redevelopment opportunities, and place-based design that can make the most of the amenity needed to create value along the whole corridor. In other words, the urban regeneration and the new transit system must be done together.

The approaches to integrating transit and urban regeneration will differ in different parts of the city. Each area has a different urban fabric that requires its features to be recognised and respected before designing solutions. The seven principles created to help with this design process seem to have some ability to help in this process; all have relevance to each site and some need to be very specifically oriented to accommodate the differences in urban fabric quality. Delivering such different urban design qualities along a new transit corridor or in an old main street remains a major challenge for designers, planners and engineers to work out with politicians, developers, financiers and community leaders. The planning governance systems in Australian cities will be tested for their flexibility and relevance to enable the range of private investment to be involved and will require significant levels of partnership to be developed to enable inclusive, integrated, place-based fabrics in each part of the city.

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