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Dense, mixed-use, walkable urban precinct to support sustainable transport or vice versa? A model for consideration from Perth, Western Australia

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ABSTRACT
Within the majority of the literature on sustainable transport, it is accepted as ideal to arrange new urban growth in close proximity to major public transit services. While the literature on this subject of transit-oriented developments (TOD) is positive and optimistic, for the most part such assertions are conjectural. This article will attempt to fill this gap by revealing a modeling process undertaken for a local area's reurbanization project to understand the potential and limitations of several modes of transport to support the increased activity density in the precincts. Several of the most standardized policy levers were employed, such as parking ratios and mix of use and building height, and contrasted with the trip generation and transit mode's hourly capacity to reveal potential real-estate yields. The outcomes indicate not only the immediate yields but also the capacity for urban transformation due to each level of sustainable transport investments. The model is unique in that the capacity, parking ratios, and assumptions are highly transparent.

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KEYWORDS
Transit oriented development; urban land and transportation modelling

1. Introduction

This article describes a model employing several policy levers to reveal potential outcomes, indicating the capacity for urban transformation due to sustainable transport investments. While in the literature on sustainable transport it is accepted as ideal to arrange new urban growth in close proximity to major public transit services (Calthorpe, 1993; Dittmar & Ohland, 2004; Ewing & Cervero, 2001; Kenworthy & Laube, 1999; Newman & Kenworthy, 2006; Newman, Beatley, & Boyer, 2009; America, 2014; Renne, 2008; Renne & Ewing, 2013; Vuchic, 2005), it is still inconclusive as to how this growth is to happen. Ideally an increase in the supply side of transit service is meant to induce people into a more walkable and transit-based lifestyle. On the demand side, the urban villages surrounding the transit become the most attractive places to live and in so doing consolidate the urban fabric. The walk-on transit passengers reduce CO_2 and act to allay the need for more roads and parking, both of which are expensive to build and maintain as well as inducements to travel by automobile. While the literature is positive and optimistic about individual transit-oriented developments (TODs), there is little evidence about the wider regional spread of TODs and the regional transit systems that are needed to support them. This may be due to a lack of clarity over what urban and suburban centers are meant to become and which modes of transport will support their strategic ambitions. This article posits that there is a transparent method to understand the impact of transport as a strategic investment to help trigger the real-estate market to deliver the volume of new homes necessary in a low-carbon future and the overall floor space required to help pay down the expense of the investment in a value capture setting (McIntosh, Trubka, & Newman, 2014).

Though most other aligned professions have standardized manuals describing and even predicting their work, urban design and sustainable transport planning still rely on experience and art to reinforce a qualitative base of their science. For example, which type of human settlement supports which transport mode and conversely which type of transport mode best supports which type of human settlement are still widely debated (Cox & Utt, 2004; Mees, 2010; Mees & Groenhart, 2012; Messenger & Ewing, 1996; Newman, Glazebrook, & Kenworthy, 2013; Suzuki, Cervero, & Iuchi, 2013; Troy, 2004). Though there are policy levers to be pulled, such as parking ratios and urban densities, and demographic thresholds to be crossed—such as population growth in a specified time frames—it is still not clear at which point one mode of transport (cycling, walking, automobile, regular bus, Bus Rapid Transit (BRT), Light Rail Transit (LRT), metro) is preferable to another. Even with a clear design vision it is rarely evident how a city or region may achieve the target settings such as lowered CO_2 or lowered vehicle kilometer travelled, let alone significant modal shift. When the academic and professional literature is spatialized and the ideals of land use and transport integration are examined, we see there remains a large gap between the stated promise and the revealed potential for urban density and high-capacity public transport to mix.

This model will demonstrate the relationship between potential real-estate yields and the underpinning transport infrastructure with an easy to replicate and adjust set of

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/ujst.

assumptions. The approximate real-estate yields are important as they represent a strong cycle of short-term construction activity, long-term ongoing tax returns, a promise of overall economic confidence, and a mass of population oriented to mass transit (Cervero, 2002, 2007, 1998) as a sustainable mode of transport, further reinforcing walking and cycling. The yields also reveal a consolidation of urban form[1] with a wide variety of benefits to personal, municipal, and higher tiers of government, including reduced requirements for new underground utilities, new public services such as schools, parks, and police stations (Marohn, 2012); increased productivity (Fogarty, Eaton, Belzer, & Ohland, 2008; Trubka, 2011; Trubka, Newman, & Bilsborough, 2010) and health (Frank & Pivo, 1994; Frank, Greenwald, Kavage, & Devlin, 2011); and less green-field expansion, which maintains or even increases ecological services (Mostafavi & Doherty, 2010; Wackernagel & Rees, 2013).

To understand the levers and make explicit the capacities of both land and transport infrastructure, this model was developed to predict the real-estate yields for a large urban precinct that has a long-range desire to be a densely in-filled, 24-h activity and transit-oriented node (see Figure 3) within the urban fabric of the Perth Metropolitan Region in Western Australia. The real-estate projections are based on the capacity of the transport network to provide both a rationale for the urban intensification and as desirable amenity to drive the overall redevelopment forward. This is important as once a city and region approach a certain size without a corresponding growth of road, rail, or other high-capacity transport infrastructure and/or consolidating changes to the land uses in the middle and outer ring of development, the issue begins to accrue political priority. An excellent example of this is what has started to happen in Perth, Western Australia, a highly car-dependent city.

The Perth metropolitan region sits on the Indian Ocean's edge in southwestern Australia and comprises varied topography. It is not perfectly flat, as on close inspection there are ancient sand dunes and low-lying wetlands fringed by a modest escarpment known as the Darling Scarp. This area is known as the Swan Coastal Plain (Seddon, 2004). Along the Indian Ocean coast there are significant exposed limestone reefs guarding the shore from big swells and boats without excellent charts. It is an extremely easy place to manipulate landforms into a desired (flat) shape for infrastructure such as roads and sewerage as the local sand is formed to will. The only limiting factor is the availability of fill material to create sufficient level and dry surfaces for the extensive green-field developments planned for on land-banked farms and forest (SEWPaC, 2013).

The conurbation has been growing at an unprecedented rate—a projected doubling of the current population by 2040—and is now projected to be Australia's third largest urban area after Sydney and Melbourne by 2061.

Most of Western Australia's growth is projected to occur in Perth, where the population increases continuously from 1.9 million at 30 June 2012 to between 4.4 million and 6.6 million in 2061 (Figure 1; ABS, 2013).

[1]Urban consolidation has many guises, and whether called smart growth, transit-oriented development, subcentering, new urbanism, or otherwise, they all call for a limit to green-field urban expansion and a reorientation to walkable, transit-served communities.

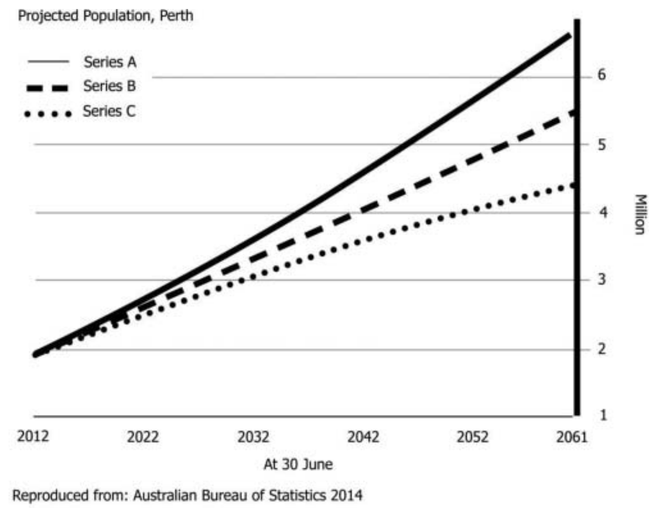


Figure 1. Projected population, Perth (ABS, 2013).

Though there has been investment in the commuter rail lines of Perth, they have not kept pace with the outward march of single-use, automobile-dependent housing developments, which remain poorly served by a frequent high-capacity alternative to the automobile (Weller, 2009). Bicycling and walking are negated as an option for most as the distances to services and jobs are lengthy and the active transportation infrastructure of questionable safety, especially at intersections where the different modes require sharing space. Nevertheless, along with the expansion of the Perth regional commuter lines there has been a reorientation of the bus network to work as a feeder system and maintain the integrated ticketing of the transit network (McIntosh, Newman, & Glazebrook, 2013), a rarity in Australia (Mees, 2010). Coupled with the increase in parking rates in the central business district (CBD) and increasing congestion on the few limited-access highways present, there has been a strong inducement to travel by bus and train, in excess of modeled projections (CfP, 2011; Newman et al., 2013; PTA WA, 2012b, 2012c). This growth in passenger numbers has been significant as the level of accessibility along the radiating corridors to and from the CBD has increased (Scheurer, 2012; Scheurer & Curtis, 2008).

To confront the growing demand in the real-estate market and financial means for accessibility, there has been a Western Australian State Government policy directed to infill housing and subcenter jobs (Western Australia Department of Planning, 2012c, 2011, 2012a). This has been united with a market response to vehicle congestion prioritizing public transit access with medium-density redevelopment. Yet, within the promise and ambitions of the state policies there remains much which is uncertain and unknown: if a high-density precinct is planned for, how dense is enough to warrant a higher-order transit service? Conversely, which transport mode will support the ambitions for dense urban fabric most appropriately: car, bus, BRT, LRT, or commuter rail?

2. Model

To help answer these questions regarding public transit and urban transformation, a clear and transparent model was

Land Use and Transport Integration Index

Parcel Information					Land Efficiency				
KEY	Change in Row	Change in Cell	Check	Answers					
Parcel ID as per Hassell 2012	Area is the Sq.M. inside the boundary of each parcel	Efficiency is total area minus parking coverage + POS	Area in Hectares	Max Height as per Hassell 2012	Gross Lettable Area is Efficiency X Max Height	Mixed Use Type	Input reflects % of Dwellings	Dwelling Gross Floor Area	Dwelling Sizes in Sq.M.
Parcel ID	Area Sq.M.	Efficiency	Area H	Max. Height	Total GLA	Named Type of Urbanism Note 2	% Mix	Dwelling GLA	Dwelling Size
Inputs		0.6							
	Sum			Average					Average
TOTAL	2,116,915	1,270,149	127.01	6	7,864,484	TOD	0.30	2,359,345	96
Stage 1 Gov	70,400	42,240	4.22	11	453,376	Mixed	0.30	136,013	80
Stage 1 Private	174,215	104,529	10.45	10	1,045,290	Mixed	0.30	313,587	80
Southern	287,835	172,701	17.27	7	1,272,870	Mixed	0.30	381,861	80
1A1 (wf)	32,255	19,353	1.94	10	193,530	Mixed	0.30	58,059	80
1A2 (a/care)	9,390	5,634	0.56	10	56,340	Mixed	0.30	16,902	80
1A3 (group)	1,610	966	0.10	10	9,660	Mixed	0.30	2,898	80
1A4 (houses)	9,420	5,652	0.57	10	56,520	Mixed	0.30	16,956	80
1B1	2,470	1,482	0.15	12	17,784	Mixed	0.30	5,335	80
1B2	2,695	1,617	0.16	12	19,404	Mixed	0.30	5,821	80
1C1 & 1C2	4,990	2,994	0.30	12	35,928	Mixed	0.30	10,778	80

Figure 2. First portion of the model. This is merely to show the look of the model and how yellow and green cells may be changed. Horizontal cells are coded green and yellow for so-called assumption change cells, and red cells work as a check on numbers later in spreadsheet. Vertical color coding on the left refers to ownership of, and thereby direct development control for, a block of land within a precinct. See the appendix for further information on operations of the model.

specified with transportation mode options and the ultimate outcomes in land use. This model (see Figure 2, snapshot of first segment) was elaborated as it remains unclear what role a change in public transport access has, or has not, on built form. This article attempts to untangle the variables that are the responsibility of policy makers and designers to set. The variables that are available to be set are the following:

- Land availability
- Mix of use on each parcel
- Height limitations
- Dwelling size in square meters
- Parking ratios
- Automobile access
- Level of public transit service

What is not under the control of planners or designers, and therefore not included in this model, are the following:

- Capital markets in the macroeconomy
- Region wide economic slowdowns
- State and local politics
- Fuel prices
- Awareness about the health benefits of locating home closer to work
- Shifts in the preferences of home-buying demographics over the coming decades

All of these other variables will invariably shift the focus or aspirations of a redevelopment program over the coming years as society changes. While these may be beyond the control of any government, getting the policies set right regarding the former variables is not only possible but very desirable. This model will demonstrate the interplay of the variables and the pay-offs and trade-offs that may be necessary to achieve 21st-century planning goals of access, walkability, diversity, lowered carbon emissions, value capture to pay down the infrastructure, and higher productivity. Though not expanded into projected walking and cycling mode splits, it is predicted these mode numbers would increase as a place became denser and more mixed use, thereby having an impact on the model's outcomes (Handy, Boarnet, Ewing, & Killingsworth, 2002).

2.1 *Description*

The algorithm anticipates the interaction of height of buildings, mix of land uses, reservations for public open space (POS), and setbacks and the influence that surface or structured parking might have on the ability for a precinct to be both walkable and transit serviceable. This algorithm essentially adds quantitative

Figure 3. Total area of the reurbanizing project and precincts shaded by height. Three-dimensional (3D) model by author showing building heights coded light green (two- to three-story townhouses) to blue (towers adjacent to rail station) by ascending height, 2013.

Table 1. Quick guide to Road and Traffic Authority of New South Wales's *Guide to Traffic Generating Developments* (RTA, 2002).

Residential parking	Residential trip generation	Commercial parking	Commercial trip generation	Retail parking	Retail trip generation
1 per apartment unit	5 per unit	2.50 per 100 m^2	10 per 100 m^2	5.10 per 100 m^2	50 per 100 m^2

rigor to the theory of land use and transport integration (LUTI) through urban design and the development process.

2.2 *Land efficiency*

Essentially, using Excel as a primary means of executing the algorithm, the basic units of squared meters (denoted as m^2 or sq. m.) for residential, retail, and commercial office space are then multiplied by a percentage of urban form to be devoted to each land use and multiplied again across the numbers of floors predicted for each precinct of urban fabric. This reveals the *aspirational* net lettable area for each land use type, block by block and precinct by precinct, across the whole of the reurbanizing precinct.

3. Transport and parking factors

What then remains to be solved for is the impact of various transit modes on the capacity of the built form to actually absorb the *aspirations* of the land efficiency. This solves for what has been named the transport and parking factor. The different transport modes are listed here:

- Base case (no public transit, fully reliant on the New South Wales' *Guide to Traffic Generating Developments*)
- Road (with a regular bus service)
- Bus rapid transit (on a separate right-of-way or with lane priority)
- Light rail transit (on a separate right-of-way or with lane priority)

Department of Planning Western Australia (DoP WA) directs us to use the New South Wales' Road and Transport Authority's (RTA) guide as a basis for decisions on traffic generation and parking ratios (see Table 1). With this established, we are able understand the day-time and night-time populations as well as predict the traffic generation and parking requirements according to the RTA.

The capacity of each mode (see Table 2) to accommodate the aspired daily trips stemming from the stated desired land use was calculated from the land use, spread across 12 h of the majority of mobility hours in a mixed use precinct, and was contrasted with the capacity per mode per hour (Parsons Brinckerhoff Australia, 2010) under most circumstances. For example, we can see in the charts that 1 million trips across 12 h of each day could be accommodated by the various modes at the rate of 7% by bus, 21% by BRT, and 31% by LRT.

Table 2. Mode capacity chart.

Mode	Capacity (h) [a]	Hours	Daily trips [b]	Capacity (%)
		12	**1,145,508**	
Bus	6,000			6.9
BRT	20,000			21
LRT	30,000			31.4

[a]Notes from Parsons Brinckerhoff Australia (2010): Bus, peak hour capacity of up to 6,600 passengers per direction, 4000 typical (p.10); BRT, 4,000–20,000 passenger per hour (p. 19); LRT, 9,000–32,000 per hour typical (pp. 4, 24, 25).
[b]Note from RTA: RTA trips are 5 per residence, 10 per commercial 100 sq. m. and 50 per retail 100 sq. m.

These numbers were then used to reduce the parking ratios required for each lot of land. The parking reduction rate is the inverse of the transit mode's ability to carry 12 h of heavy transit requirements. This reversing of the numbers maintains a transparent balance for this reason: If a trip can be made by a transit mode, then this can be deducted from the car base.

This reveals the real-estate yield of floor space that might be developable based on the transit modes planned and provided to the reurbanizing project agency. This, of course, has huge implications in understanding the volume and dimensions of physical services to be provided by the city and state to accommodate these residents and workers. It also has magnitudes of importance in understanding the potential value capture possible in these areas where money into public transit is being invested.

4. Results

The results demonstrate that there is sufficient capacity in the land base and with the suggested urban fabric volume (building floors) as aspired. However, in the land efficiency columns it is evident that with each level of service in public transport *and the concomitant reduction in parking ratios* there is an increase in the transport and parking factor. It is notable that in the area with the greater floor area ratio (FAR) and the greatest mix of uses among residential, office, and retail there is the greatest gains in efficiency of urban consolidation, so long as higher order public transit service is inserted as a condition, along with parking ratio reductions.

The total will be used as an example of the model's results for the reurbanized area. It will be exhaustive to demonstrate, in charts, all the results of all the blocks and all the precincts, though the way the model was developed this is possible to view. With the example of the overall total there will be an expanded discussion on the role and function of the model. These following sections will demonstrate the ability of this model to untangle the roles a select group of levers may have in any reurbanizing project to become a high-capacity transit and high real-estate yield subcenter.

Figures 4–9 are intended to convey results in the most efficient manner possible.

Figure 4 represents the meters squared of the entire project site. This is a compilation of all the blocks size from each precinct, lot by lot, expressed as area. Efficiency is the deduction

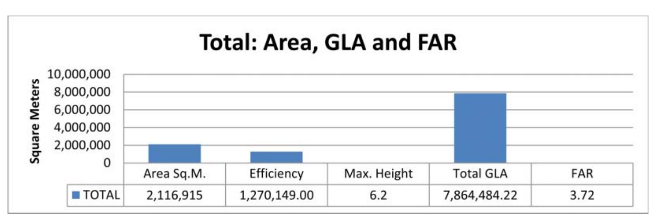


Figure 4. Area, GLA, and FAR.

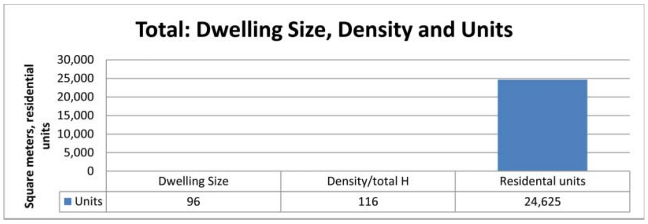


Figure 5. Dwelling size, density, and units.

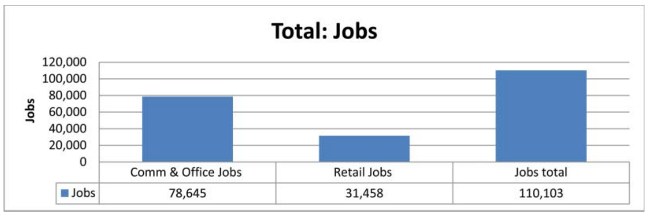


Figure 6. Jobs.

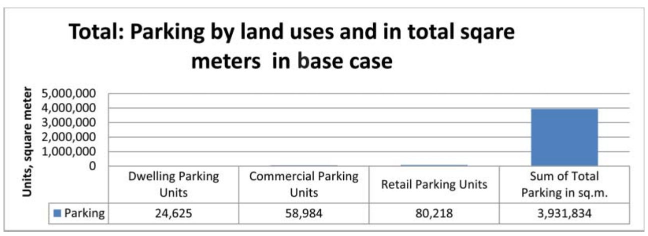


Figure 7. Parking.

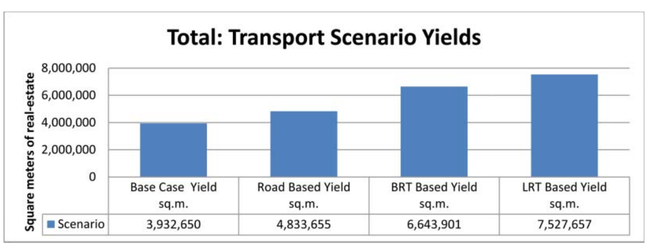


Figure 8. Transport scenario yields.

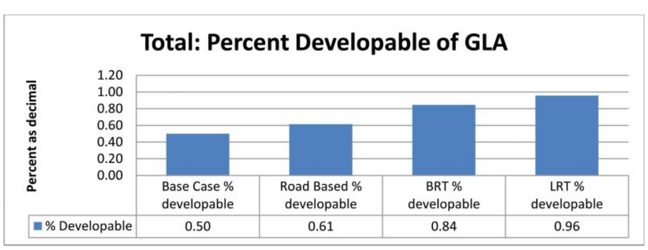


Figure 9. Percent developable of GLA.

taken from that base area for public or private open space, internal roads and drives, setbacks, utility reserves and other. Maximum height relays the *average* maximum height across the entire project area. Total GLA is the gross lettable area once the land is extruded upwards by the allowable maximum. As gross, not net, it is effectively the envelope of the building including stairs, corridors, lobbies, walls, and other such areas that will eventuate in a reduced net figure. FAR is the floor area ratio, which is the total gross lettable area divided by the area square meters. In this instance is it 7.8 million / 2.1 million m^2, which results in a figure of 3.72. This figure, in global terms, is very modest for an urban area but certainly urban in feel. It represents approximately 3.7 times the lot coverage, or roughly the same as a four-floor building with a very modest setback and a minor courtyard.

The *average* dwelling size (as prescribed by the client) across the project area is shown to be almost 96 m^2 with an average density of 116 dwellings per hectare (Figure 5), equalling 24,625 dwelling units. This is derived from residential land use only being given a 30% value of the total square meters of yield. If this were raised, as it most undoubtedly will in detailed modeling, there would become a much higher number of residential units. Likewise, if the land efficiency were changed or the height limits altered (this report uses the 2011 consultant's report to establish heights), then again these numbers will rise or fall immediately. At this stage in the modeling these results only represents *aspirational* yields, untempered by transport limitations.

Commercial and office property yields (Figure 6) could generate over 78,600 jobs and retail could produce 31,400, given 30% and 20% land use mixes, respectively. This demonstrates *aspirational* yields in one scenario. However, this will be most likely reduced in detailed modeling as in some locations the project area will have a much higher proportion of commercial and/or retail land use near transit corridors, while in other residential areas it may be seen as appropriate to have as high a rate of residential properties.

Figure 7 shows, in the first three columns, the numbers of parking spaces for each dominant land use according to the NSW RTA's guide (RTA, 2002). The column in the right-most side shows the ramifications of this quantum in square meters. It is a dramatic number, at almost 4 million m^2, especially when the total aspired to gross lettable area is only 7.8 million. The effects of this parking ratio application will be shown in Figure 8.

Once the aspirational yields are crossed with portion of the daily trips generated (RTA, 2002) with the transit mode capacity (Figure 1), we see that there is a sharp diminution of the possible yields due to this very obtuse reality: If a portion of a buildings fabric and or capital is to go towards parking there is an equal reduction in lettable area, or yield.

We see clearly that LRT, or at least some transit mode of similar hourly capacity, can provide enough mobility to be able to reduce the parking requirements enough to support the expected aspirational real-estate yields.

With a high-capacity, high-frequency transit service, the yields can be expected to rise as the transport impact assessments can be expected permit higher density and day-time activity in the precincts.

Figure 9 reflects the percent, as decimals, in development yields the reurbanization project may expect if parking ratios are reduced and transit is provided. A light rail type of service will be able to provide the urban fabric with a transport solution suitable for 96% of the aspirational yields in this scenario.

5. Conclusion

The aspirational development, as outlined, was taken to be one scenario. A more detailed modeling will change the results as presented in this article. As enabling detailed modeling was the main objective of this exercise, the results are intended to demonstrate the ability of the model, not the final result.

The first pass with the model demonstrates the strong relationship between built form and transit provisions. It reveals in stark simple number how if single occupancy vehicles are planned for, as in the base case, what will eventuate as a built form is low-slung, large-format shopping complexes, which already dominate the reurbanizing area. However, on the other hand, if a high-intensity activity center is planned, then there are a series of specific policy settings and design issues that must be expressly decided to reach the aspiration of the redevelopment project. The maxim of "minimum densities and maximum parking" is supported by this modeling (Kenworthy, 2006; Kenworthy & Laube, 1999; Shoup, 2009; 1999).

Ultimately, this model demonstrates how growth of activity intensity in an area helps determine the transportation system required to fuel that same growth. This is not so-called predict and provide modeling, which has deliberately predicted and indeed provided space for automobile-oriented sprawl over the past half century. Rather, this is a relational model demonstrating the pay-offs and trade-offs for each decision made regarding transit provision, parking ratios, density and height, mix of use, and public open space reserves. Though it is well known that there are many obstacles to implementing strategic precinct-scale projects (such as transit-oriented development) there are equally many options for policy makers, planners, and designers to help shape the city. The relationship has rarely been understood in a model, and this one attempts to provide clarity and transparency.

The results of this model demonstrate the very physical effect of policy levers, such as parking ratios, transit supply, mixed use, residential density, which must be pulled in unison to achieve not only precinct and project scaled changes but also conurbation-scaled transformations based in sustainable transportation. Significant regional reorientation to active walking and cycling as well as public transport is reliant on rational decisions being made for the best outcomes consistently and thoroughly in all projects, large or small. It is a daunting task to maintain every decision, as millimeters add up to meters and meters to hectares, as being but small steps towards a preferred physical urban outcome across the city and region. With such a model the decisions may be made clearer with policies and outcomes weighed against each other to unfold the ideals of land use and transport integration. In such a way, the large gaps between the promise and the potential for appropriate urban density and high-capacity public transport may begin to close.

6. Formulas

1. Efficiency: Area of block × Efficiency factor (removes land area for parking, internal lanes, setbacks, and public open space) = a reduction of land available to be developed. This can be raised or lowered according to a perceived ability to overcome these land-rich obligations.
2. Area: Area of block / 10,000 = Hectares. Useful for deriving a density figure later.
3. Total GLA: Efficiency × Floors of development allowed / suggested / aspired to = Total gross floor area of this block
4. Gross floor area by land use: % Mix (what percent ought this block have of each type of land use) × Total GLA
5. Density: (Dwelling GLA / Dwelling size) / (Area sq. m / 10,000)
6. Commerce and retail jobs: Commercial GLA × 30 (representing 30 m^2 per worker) or Retail GLA × 50 (representing 50 m^2 per worker) to find how many workers could work in these spaces
7. Land efficiency factor: Sum of weighted land uses / Efficiency = a measure of how efficiently the land is being used. Height and mix of use are rolled into these values to give an overall value dependent on the area of the efficiency
8. Residential units: Dwelling GLA / Dwelling size = Number of residential units
9. Jobs total: Retail jobs ± Commercial jobs = Number of jobs expected to be in the area (many of these will be taken up by residents)
10. FAR: Gross land use (same as Total GLA) / Area sq. m = Floor area ratio or a way to understand volume of building on a piece of land
11. Dwelling parking ratio: Residential units (see above) × 1 = Number of parking stalls for residents as per RTA of NSW
12. Commercial parking ratio: Commercial GLA / 100 × 2.5 = Number of parking stalls for commercial uses
13. Retail parking ratio: Retail GLA / 100 × 5.1 = Number of parking stalls for retail uses
14. Total parking in sq. m: Total stalls (from above three uses) × 25 (meters required for one stall plus drive aisle) = Number of sq. m. These square meters must be reduced from the possible redevelopment as a limitation unless it is all to be underground, which is difficult in Perth because of a high water table. Even without this limitation, underground parking is very cost prohibitive (25 m/stall is a conservative measure, as it often comes out to much more once ramps and turning radii are counted in structured parking).
15. Base case: Full RTA parking: Gross land use (GLU) − Total parking in sq. m = Remainder uncovers what area remains after parking is reduced.
16. Parking reduction: Total parking sq. m × Reduction factor = New volume of parking. This can be thought of as either actual volume of space in square meters or as liberated capital to be expended elsewhere in the project, as part of a cash-in-lieu program towards precinct-level parking structures, or contributions toward value capture. Though this is perhaps not as clear where exactly the square meters or capital may end up, for this model it assumes it goes toward added real-estate yield.

17. Yields: Parking reduction × Mode-based yields (due to reduced parking) = New volume of real estate
18. Percentage (%) developable: Mode-based yield / Gross land use = Percentage of possible development yields
19. Composite index: % Developable × Land efficiency factor / Distance to transit service = Value to demonstrate the relationship between land efficiency (mix of use, height and land area) along with transport capacity (by mode split) and parking reduction

7. Equation

See Table 3 for list of variables.

Expressed as equations, the model may be expressed thus:

$$GLA = E \times H^{123} M^{123456}$$

$$U = \frac{Dwelling\ GLA}{S^{123}}$$

$$LE = \frac{GLA_{W^{12345}}}{\mathrm{E}}$$

$$FAR = \frac{GLA^{12345}}{\mathrm{A}}$$

$$\mathrm{Y} = Pk^{1232} \times Mode^{1234} \times \mathrm{Mode}_{\mathrm{a}^{1234}}$$

$$D^{1234} = \frac{Y}{GLA^{12345}}$$

$$\mathrm{CI} = \frac{D^{1234} \times LE}{Di}$$

This model uncovers yield as the amplification of capacity with modifications for reduced parking due to increased transit provisions multiplied by the increased floor area this creates. It is equal to parking scenario 1, 2, or 3 multiplied by the public transport mode (M) capacity 1, 2, or 3, which signifies how much the parking may be reduced from the base case. This is multiplied again by the allowable increase in built form due to the decrease in parking:

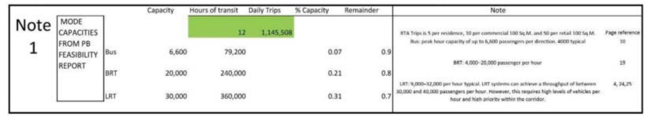
$$Y = Pk^{1232} \times Mode^{1234} \times \mathrm{Mode}_{\mathrm{a}^{1234}}$$

It must be noted that though a parking area for a particular parcel of land is reduced it does ensure the land will become residential, commercial, retail, or other public use land. However, if it is parking—because of minimum parking ratios based on automobile dependence—then it cannot be those other land uses complementary to lower carbon lifestyles in compact, walkable, transit-served neighbourhoods spoken for in the literature or designed with the best intentions (Figure 11).

Likewise, simply rationalizing an argument for higher density and mixed use alongside transit does not guarantee a social

Table 3. Equation variables.

Y^{123}	Yield of real estate	LE	Land efficiency
A	Area	U	Residential units
E	Efficiency being area minus POS; setbacks; right-of-ways for utilities, internal roads and surface parking	FAR	Floor area ratio
H^{123}	Maximum allowable height on an area due to precinct size (small precincts have lower heights allowed)	Tr	Trips expected from GLA^{12345}
M^{123456}	Mix of dwellings, commercial, retail, community, and entertainment land uses	Di	Distance to transit service
GLA	Gross lettable area	Pk^{123}	m^3 parking expected from units
GLA_w^{12345}	GLA weighted	Pr^{1234}	Parking ratio based on mode scenarios
S^{123}	Size of residential, commercial, or retail space per person	MY^{1234}	M^3 yields based on mode scenarios
R	Resident	D^{1234}	Percentage (%) developable based on mode scenarios
J	Jobs in commercial and retail	$Mode^{1234}$	Mode capacity to move person per hour
Tr	Trips expected from GLA	$Mode_a^{1234}$	Allowed increase in development due to reduction of parking
C	Capacity	CI	Composite index



Note 1	MODE CAPACITIES FROM PB FEASIBILITY REPORT		Capacity	Hours of transit	Daily Trips	% Capacity	Remainder	Note	Page reference
				12	1,145,508			RTA Trips is 5 per residence, 10 per commercial 100 Sq.M. and 50 per retail 100 Sq.M. Bus: peak hour capacity of up to 6,600 passengers per direction. 4000 typical	10
		Bus	6,600	79,200		0.07	0.9		
		BRT	20,000	240,000		0.21	0.8	BRT: 4,000–20,000 passenger per hour	19
		LRT	30,000	360,000		0.31	0.7	LRT: 9,000–32,000 per hour typical. LRT systems can achieve a throughput of between 30,000 and 40,000 passengers per hour. However, this requires high levels of vehicles per hour and high priority within the corridor.	4, 24,25

Figure 10. Mode capacity chart from the model.

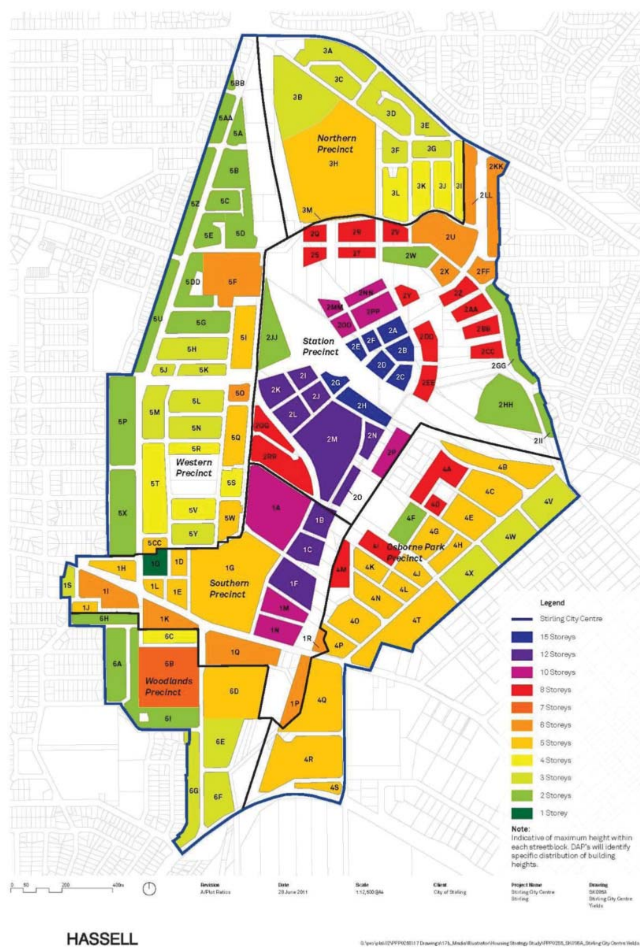


Figure 11. Total SCC area and precincts. *Source*: Hassell Consulting.

shift toward walking and cycling. However, the literature leads us to understand that without increased destinations, such as jobs, shopping, recreation, or education mixed into the urban fabric, walking and cycling are unlikely to be viable modes. Without the appropriate mixes and densities there will not be an appreciable change in travel patterns toward walking as automobile access will prevail in the local area surrounding the transit station precinct.

The capacity of each mode (see Figure 10) to accommodate the aspired daily trips stemming from the land use was used to reduce the parking ratios required for each lot of land. The parking reduction rate is the inverse of the transit mode's ability to carry 12 h of heavy transit requirements. Inversing the numbers maintains a transparent balance.

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Appendix: How to use the model

The parameters and assumptions are flexible.

In the rows of each block under the yellow columns, change the following:

- Block-specific ID
- Area
- Max height
- % mix of each land use (which must equal 1 in the red cell)
- Dwelling size

In green boxed cells are the primary assumptions such as the following:

- % land efficiencies (due to car parking, internal lanes, setbacks, and POS)
- Weight (value) each land use (residential, commercial, retail, community, entertainment) has towards achieving the overall vision
- Size of each unit of work space for commercial and retail
- Parking ratios of dwellings (residences), commercial, and retail land uses
- Parking reduction rates by public transit mode
- Yield increase rates by mode
- One can also change the
  - §Hours of transit service
  - §Formula of trips by land use (default is RTA of NSW guide to trip generation as residential = 5 trips per day, commercial = 10 trips per day per 100 m^2, and retail = 50 trips per day per 100 m^2)

As everything in the model is hyperlinked, the results will be tabulated throughout the spreadsheet.

With each decrease in parking ratio possible due to a different public transit capacity[2] being able to sufficiently accommodate the needs for mobility in a car reduced scenario, the yield of real-estate increases as real-estate space takes the place of parking area.

[2]For example, an actual LRT line does not hold many people per day if it only runs once an hour and for only a few hours, while a bus network might be very effective as a capacity creator if it runs every 4 min. However, this capacity from buses is only theoretical, as *bus bunching* (overtaking and congestion of busses) will occur, there is a great expense of owning that many buses (likely more than a fleet of LRT carriages), and with that many drivers the labor costs will be very prohibitive.