From Squaresville to Triangle Town: Geometries for public transport network planning

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Abstract: Research into public transport network planning has previously identified the benefits of the "network effect" obtained by cities using a square network structure as a base for their public transport routes (Mees 2000; Nielsen et al. 2005; Dodson et al. 2011). This network effect allows cities to invest in public transport services in a way that generates far greater patronage than would otherwise have been expected by focusing on individual routes (Mees 2010). Although the ability for the network effect to occur in non-grid based networks had previously been identified (Nielsen et al. 2005), alternate network geometries used by medium to large cities have not been explored. As part of a larger study of transport planning in cities with high-quality public transport, public transport planners in Zurich were interviewed about the approach to network design in their region, which revealed the use of a triangular based geometry to provide the backbone of their network design. This paper describes the key principles and methods used in a triangular network design, and explores its potential for use in Australian cities. It concludes that the radial nature and centrality of public transport networks in Australian cities may be more easily transitioned to a triangular rather than square geometry.

Network design and the creation of Squaresville

The environmental, social and economical benefits to cities of a well-used public transport system are widely recognised (Balcombe et al 2004; Currie, Stanley & Stanley 2011; Banister & Thurstain-Goodwin 2011). Accordingly, much research has sought to understand the elements of a good public transport system, and to identify the factors contributing to usage of such systems (Balcombe et al. 2004; Ortuzar & Willumsen 2011). Transport researchers in Australia and elsewhere began focusing on the role of network design in public transport provision following the use of the Squaresville concept by Paul Mees (Mees 2000). Partially inspired by the grid-based Toronto transit network, Mees developed Squaresville from its earlier use by VicRoads to demonstrate the benefit of introducing additional services to create a grid-like network over simply increasing services on parallel routes (VicRoads 1994; Mees 2000). References to Squaresville in this paper should be assumed to be the Mees iteration of Squaresville rather than the earlier VicRoads version.

Squaresville was based on the premise that a hypothetical town initially had 10 parallel public transport routes (see Figure 1).

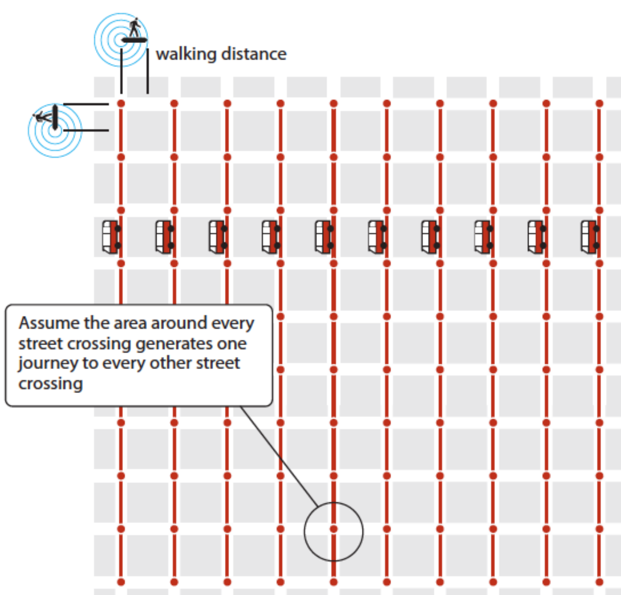

Figure 1: Squaresville initial routes (Nielsen et al. 2005, adapted from Mees 2000)

In Squaresville, there was an assumption that there was an even demand to travel from each stop to every other stop on the grid. Using this assumption of equal trip generation and distribution across the area, two approaches for doubling services were considered. The first was to double frequencies on the existing routes (see Figure 2).

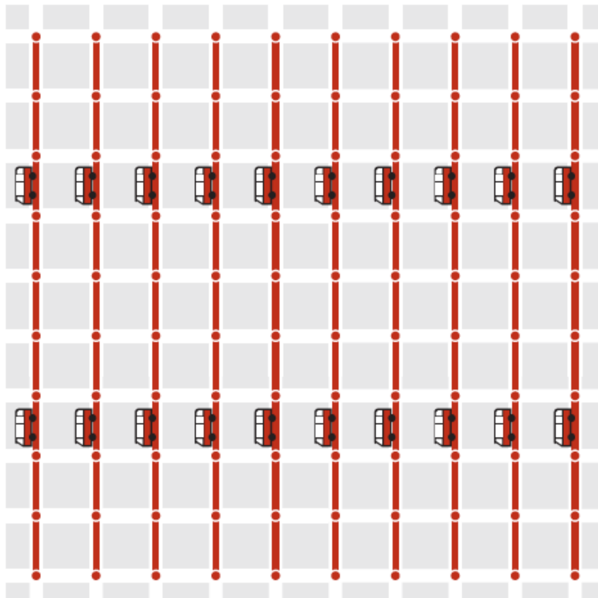

Figure 2: Squaresville doubled frequency (Nielsen et al. 2005, adapted from Mees 2000)

The second option was to keep the service levels constant on the original routes, and to add new routes to form a network based on a square grid (see Figure 3). This new network assumes that transfers can be made at each point that the perpendicular routes intersect.

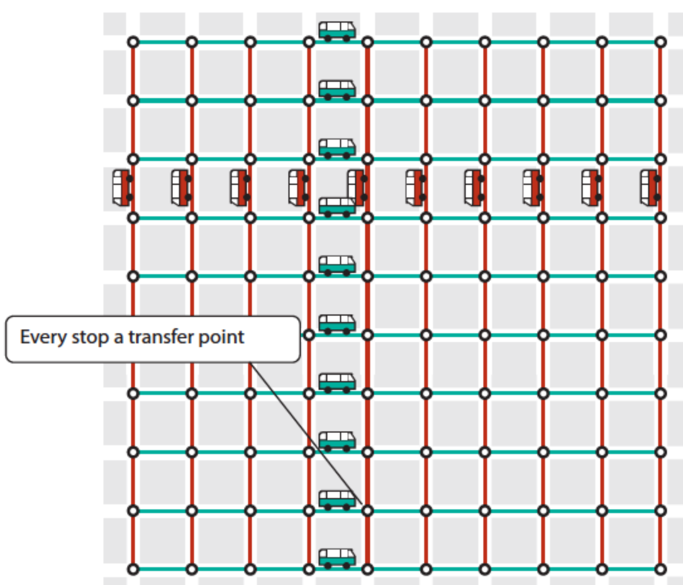

Figure 3: Squaresville ultimate network (Nielsen et al. 2005, adapted from Mees 2000)

Mees (2000) argued that this second option produced a significantly better outcome that the first option in terms of the potential number of trips that the public transport network could service, and that these different levels may be responsible for some of the wide variation in increased public transport demand seen after the introduction of additional public transport services. Nielsen et al. (2005) supported this proposition, agreeing with Mees (2000) that the second option could theoretically generate a 550 per cent increase in ridership increase for each per cent of service increase, whereas the first option would only generate a 50 per cent increase in ridership with the same level of investment required. This increase in benefit has been termed the “network effect” (Mees 2000; Nielsen et al. 2005; Mees 2010). Dodson, Mees, Stone and Burke (2011) have further explored this concept, arguing that the following are key principles for creating a public transport network effect:

- Use simple and direct network structures;
- Plan a hierarchy of lines into a network;
- Plan for speed, consistency and reliability;
- Coordinate convenient transfers; and
- Provide clear, ubiquitous and consistent information and marketing.

Nielsen et al. (2005) identified the ability for the network effect to exist in cities using simpler network designs than Squaresville, but to date alternate network geometries used by medium to large cities exhibiting a network effect have not been explored.

Network planning in successful cities

This paper aimed to explore how the principles of network design and network effect, had (or had not) been used in practice outside the cities that originally inspired the model. As part of a broader study of the priorities of transport planners in cities with high-quality public transport, 15 public transport planners across 5 cities were interviewed about their perspectives and practices as transport planners in their cities. The cities of Zurich, Munich, Vienna, London and Vancouver were chosen using a range of inclusionary and exclusionary criteria that aimed to identify places where public transport was attracting significant ridership despite residents having access to forms of private mobility such as cars. Public transport planners in each city were purposely sampled to provide perspectives across the relevant government and private organisations involved in public transport planning in each city. These interviews were supplemented by documentary analysis of key transport plans and policies for the cities.

Analysis was undertaken of the interview data using methods developed from constructivist grounded theory (Charmaz, 2014). Grounded theory was used as it focuses on developing new theories from the interview data rather than testing existing hypotheses, facilitating identification of new possibilities. The constructivist methodology was used to acknowledge that this type of data does not reflect an objective reality, but is co-created by the interviewer and interviewee (Charmaz, 2014). Where necessary, documents were purposively sampled to supplement the interview data and to saturate the properties of the emerging categories. Although a broad range of transport planning issues were explored in the interviews, this paper will focus on comparing the network planning approach in Zurich with the Squaresville model developed by Mees (2000).

Triangles in space

Interviews with the Swiss transport planners revealed they used an alternate geometry for public transport network planning. Rather than basing their network on squares like the Toronto network that inspired Squaresville, the Swiss network was based on triangles.

Participants emphasised the use of overlapping triangles at different levels of planning – for example on both the national level and the regional level.

> *Now the triangle principle is the basis of all Swiss network. There are different hierarchy levels, levels of triangles. (Z1)*

These nested triangles allow links and nodes to perform multiple roles in a hierarchy.

At a national level, triangles were formed between cities. Several examples of these triangles are illustrated in Figure 4.

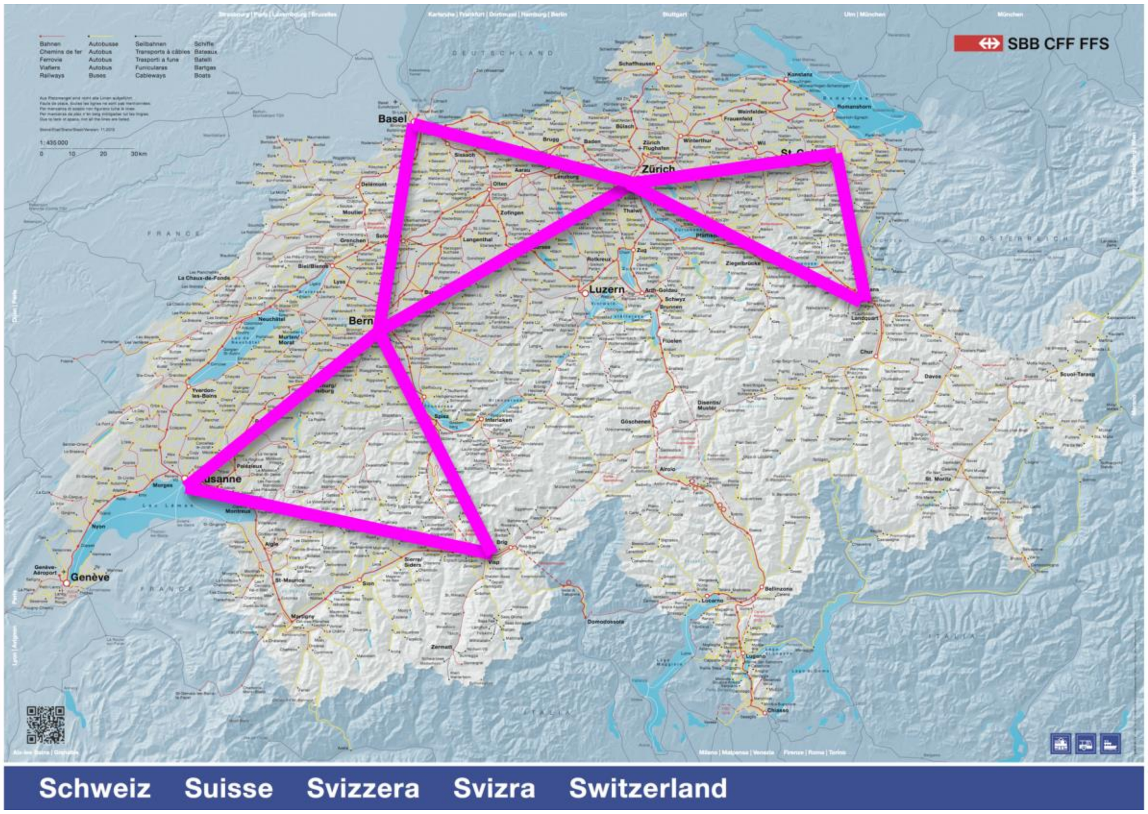

Figure 4: Selected national triangles. Base map from Swiss Federal Railways (2014).

At this level the main train station forms each of the nodes in the network (points of the triangle) and the services form the links (sides of the triangle). It is useful at this point to distinguish between the physical routes, or infrastructure, and the service provided on the route. The Swiss system aims to have direct services provided along the side of a triangle, so a passenger can travel between nodes without interchanging, regardless of the number of intermediate stops in the service. However, the route itself does not necessarily need to be direct – it can deviate from a straight line to take account of geography or utilise existing infrastructure.

At a regional level, the triangle has also been used as the geometry for the Canton of Zurich. The main train station, which is a node in the national level network, is also a node in the regional level, allowing for ease of passenger movement between the national and regional levels. There are currently 22 nodes designated within the Canton. Not all nodes are currently connected to neighbouring nodes by triangles, however additional services continue to be added that work towards this planning concept. Figure 5 shows examples of several triangles currently existing in the network.

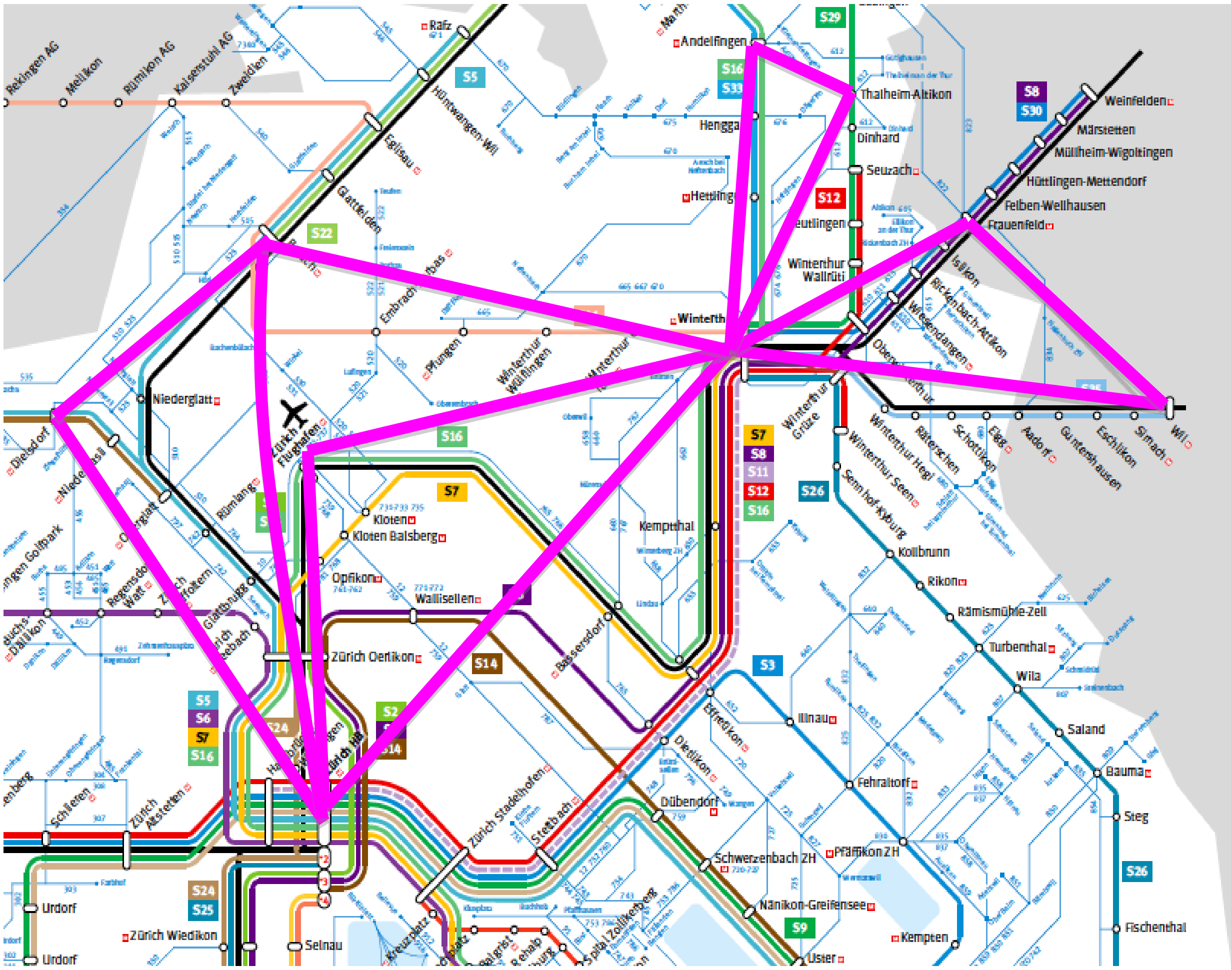

Figure 5: Selected triangles in the Canton of Zurich. Base map from Zürcher Verkehrsverbund (2014).

Triangles in time

Swiss transport planners emphasised the role of time as well as space in their triangular network. Planners aimed to achieve equal travel times on all three sides of a triangle. This goal of equal times, or isochronicity, influenced both the initial selection of the nodes, and also the speed at which services were run along a link. Altering speed of the services allows for non-equilateral triangles to be used whilst maintaining isochronicity - decreases in distance are compensated for by decreases in speed. As such, services are not always run at the maximum speed possible to minimise travel times on that link, as suggested by much conventional transport planning (Beirão & Cabral 2007). Rather, they are run to maximise temporal interconnectivity and interchange at the nodes. This means that a journey only using a single public transport service may have a longer travel time than may be possible if services were run at maximum speed, however, a journey which requires one or more interchanges between services is likely to be quicker overall due to the optimised connections at nodes. This benefit is increased in places where service frequencies are lower, as the wait time for a random connection becomes greater.

The goal of isochronicity also influenced investment in infrastructure improvements – where an improvement in run-time was required to allow isochronic travel around a potential triangle, this was prioritised over infrastructure improvements that could potentially reduce travel time on one of the faster sides of the triangle. This was the case even where there was higher travel demand on the shorter side's service. This might seem surprising from an Australian point of view, where historically infrastructure improvements would be generally targeted towards minimising travel time on corridors with a large number of services, high patronage or long delays.

Creating Triangle Town's public transport network

Although originally used by Mees (1997) to question conventional public transport elasticities, the Squaresville model has subsequently been used to illustrate the ability of grid-based public transport networks to offer an alternative to a radially structure public transport network (Dodson et al. 2011; Dodson & Sipe 2008). Similar to the way in which Squaresville is an abstraction of a grid-based network such as inner Toronto (Mees, 2000), an abstract Triangle Town network can also be created for a hypothetical city based on the Zurich experience. Although Triangle Town is necessarily simplified from the many constraints imposed on real-world networks, it nonetheless provides a useful illustration of the key principles embodied in a triangular network structure.

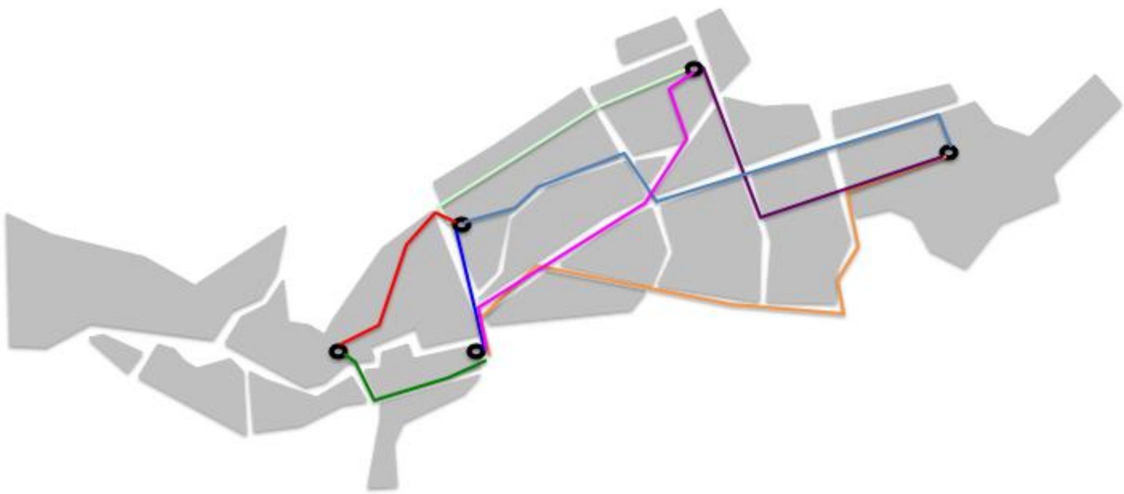

Figure 6: Triangle Town – Primary public transport network geographic layout

Figure 6 above shows the primary public transport network for Triangle Town linking the key nodes that have been identified from their land use characteristics. Using identical colours, Figure 7 below shows the same network using a schematic rather than a scale map, making the triangular design more apparent.

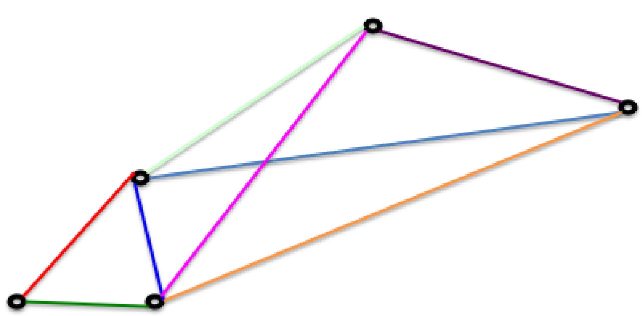

Figure 7: Triangle Town – Primary public transport network schematic

Direct public transport journeys are enabled between nearby nodes, effectively resulting in service triangles that form the backbone of the public transport network. Although each of these journey segments are shown in different colours in Figures 6 and 7, Triangle Town network planners may combine these segments into longer routes. For example the dark green and pink lines above could be combined as a single route servicing three nodes. This route would be part of several triangles in the network. Additional services (not shown above for simplicity) are added to ensure walkable coverage to all areas of town at a nominated minimum service level.

The abstract Triangle Town shown above can be complemented by the experience of network planners in Zurich in designing their triangular-based networks. Interviewees described the process of network design at a regional level as follows:

1. Select nodes

Nodes are selected for both their land use and transport characteristics (Figure 8). Strong nodes generally have higher levels of potential trip generation, whether due to the land use types or the density of activity in proximity to the node. Transport characteristics considered are generally existing infrastructure (such as fixed rail) and the ability of the node to support isochronic services.

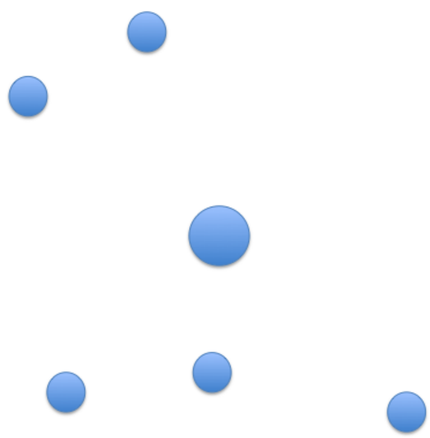

Figure 8: Select nodes

2. Connect key nodes by using diametric lines through a central node

Nodes are initially connected by diametric lines to a central node (Figure 9). For a smaller city the central node is likely to be a central bus or train station. These lines support radial movement to and from the central node, and are usually provided by higher capacity vehicles. If diametric services are unable to be used due to the city shape and geography, radial or L-shaped services may also be considered. At this stage these lines can be considered partial draft routes. Complete route design occurs in a later stage of the planning process.

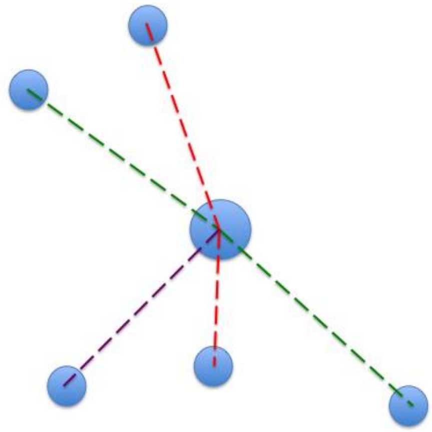

Figure 9: Diametric connections

3. Connect key nodes using tangential links

The third side of the triangle is provided using a tangential link. Node selection should be re-evaluated based on the potential for infrastructure or service improvements that would support isochronic services. Additional nodes may be required to enable this to occur (Figure 10). At this stage these tangential links are partial routes, and may later be combined with other links to become complete routes.

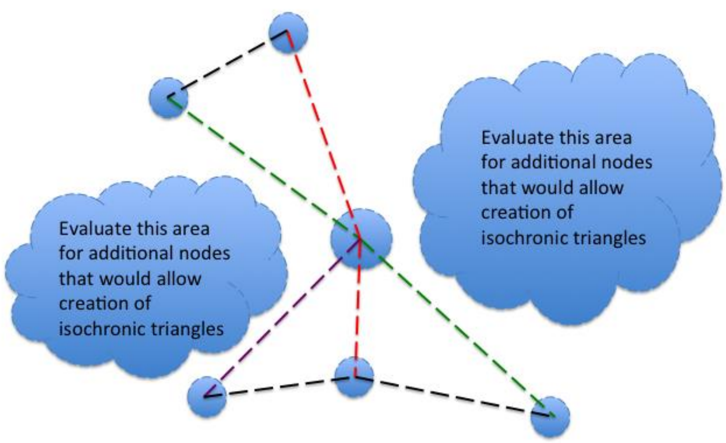

Figure 10: Tangential links

4. Connect additional nodes to the network

Additional nodes can be connected to the triangular network with either direct links to the central node or to another existing node (Figure 11). The triangular network structure allows network density and complexity to be increased by providing additional triangular links between nodes. Again, these links can be considered partial routes, with complete routes being designed in the following stage.

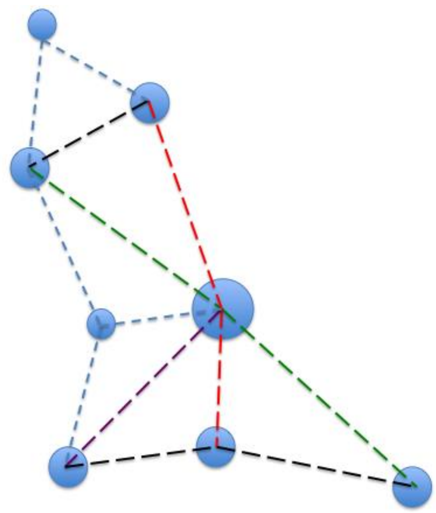

Figure 11: Connect additional nodes

5. Design routes to service the triangular backbone

Routes may run along one or two sides of a triangle. Routes can extend past the sides of a triangle, and a single route may provide links for more than one triangle. Selection of routes will be influenced by the predicted demand along the links so that vehicle capacity required remains as consistent as possible along a route. Routes will also be influenced by existing fixed infrastructure such as rail. Where possible the diametric lines drafted in step 2 should be retained. Figure 12 shows one of many hypothetical route structures for the given nodes.

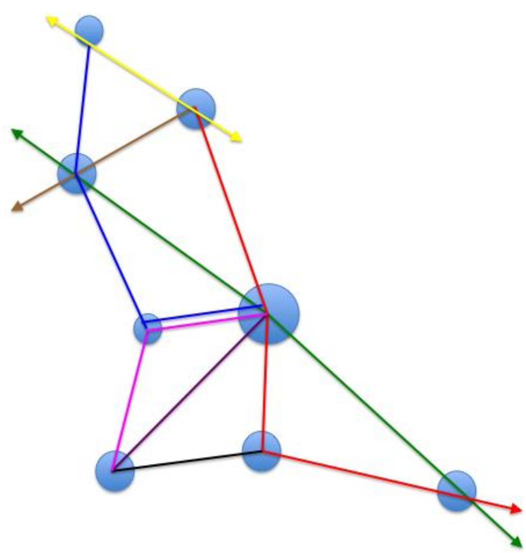

Figure 12: Design routes

It is unlikely that the entire public transport would be formed based on this pattern of network design, as depending on the number of nodes chosen, it will most likely not provide the level of coverage required for all residents to have walking distance access to public transport services. Rather, it provides the key backbone of the network onto which additional coverage services can be added. Whilst these additional services may be lower in frequency or smaller in capacity than those running on the backbone network, they are essential to ensuring accessibility across an urban area. Coverage services can be added in several ways, such as: (a) designing routes so that they provide both triangular links and extend beyond nodes to provide additional coverage links; (b) providing coverage only routes that link to the key nodes; or (c) providing coverage routes that link to other stops on the network (Figure 13).

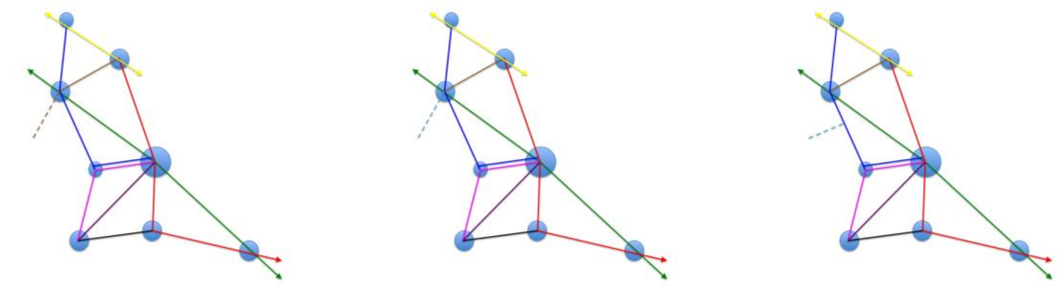

Figure 13: Coverage route options

Where possible option (b) is preferred to (c) as it provides both access to the land use functions that exist at the key node as well as connections to a greater number of transport routes using a single interchange. The choice between (a) or (b) – either extending the existing brown route or providing a new route from the same node – will depend on the difference between the minimum service standard frequencies for the city and the service frequencies being used for the triangular routes and the transport infrastructure available (road and rail). Where possible, services should be designed to meet the previous principles identified by Dodson et al. (2011) at the same time as providing coverage to an urban area.

Application to Australian cities

Australian capital cities generally have strongly radial public transport networks, although some additional orbital routes have been introduced in recent years (Mees & Dodson 2011). Like these Australian cities, Zurich also initially had a strongly radial public transport system. It transitioned to its current system through the gradual adding of tangential routes beginning more than 50 years after the radial services were first provided.

Interviewees stated that the key to successfully transforming the network was to provide sufficient service levels and reliability on the tangential link. In order to shift entrenched radial travel behaviour, using the tangential link needed to be as easy as using the radial links. This sounds obvious, but too often these tangential or orbital services are introduced into Australian cities at a lower frequency than the radial links, meaning that it can be faster to make a radial in-out trip than to wait for the tangential service. Rather than reducing service frequency due to lower demand on the tangential links than the radial links, lower capacity vehicles were used in Zurich. For example, trains might provide the radial links while a smaller bus may initially provide the tangential service. As the demand for the service increased, higher capacity vehicles could be used. Segregation of these tangential services from general traffic was also seen as important to ensure their reliability.

The strength of this network planning approach for Australian cities is that, compared to the Squaresville concept, it does not require a radical fundamental restructure of the transport network. Many key land-use based nodes within Australian cities would already have strong radial links to a central node that could be used as the first step in forming a triangular network. The challenge for most Australian cities would be creating tangential links that are equal with the radial links in terms of both journey time and frequency. This level of service input and priority would generally exceed the resources currently allocated to these lower-demand links.

The Swiss approach differs significantly from the Squaresville concept in its applicability to areas of lower public transport demand. Due to the grid structure with its numerous interchange points, the Squaresville concept relies on service levels to be high enough to support untimed interchanges, as it would be challenging to coordinate the timing of interchanges at each of the possible interchange points. The triangular network structure allows for interchanges to be timed as it creates a hierarchy of nodes (interchange points) that can be used to prioritise temporal connections. This makes the triangular network a more flexible geometry for lower density locations within cities and for regional or inter-city networks.

An additional benefit for Australian cities in transitioning to a triangular network is that one of the initial assumptions of the Squaresville concept is dispersed trip demand (Mees 2000; Nielsen et al. 2005), and maximum benefits from this network design are experienced when this is the case. Australian cities, partially because of their existing public transport networks, are quite centralised with relatively few strong corridors. The triangular network approach recognises that some corridors are likely to continue to experience higher levels of demand than others, and caters for this by reducing the capacity of the vehicles servicing these links.

A comparison of the key differences between Squaresville and an abstracted Triangle Town are summarised in Table 1.

	Squaresville	Triangle Town
Number of transfers	Maximum one transfer between any two places in network. Most journeys require a transfer.	More nearby nodes reachable without transfer, but greater than one transfer to further away destinations.
Frequency	High frequency required to support untimed transfers.	Applicable at high and low frequencies.
Timing of transfers	Untimed	Timed
Travel speed	Vehicles do not need to wait for timed transfers. Travel speed can be maximised for each route.	Travel times not maximised for each route. Reduces vehicle efficiency but may create shorter overall journey times, particularly for lower frequency networks.
Variations in demand	Assumes demand is consistent across network.	Vehicle size/capacity adjusted to reflect demand in corridors.
Running time between nodes	No specific requirements.	Isochronicity to enable timed transfers. Requires careful control over reliability and travel time.
Coverage efficiency	All locations within coverage of two routes.	Areas near nodes likely to be in coverage of two or more routes. These are likely to be areas of higher demand.
Road networks	Suitable for square grid road networks.	Suitable for a range of road network typologies.
Urban application	Yes	Yes
Rural application	No	Yes

Table 1: Comparing Squaresville and Triangle Town

Despite the identified benefits for using a triangular network structure for Australian cities, we should not assume the transition would be simple. In the words of a Swiss transport planner:

> *When something grows historically as much as we did, it becomes always a little heterogeneous and more complex, and getting it back to a simple thing, it's really hard because when you have to change something there are always some losers. It's really hard. (Z3)*

However, the success of the Swiss system suggests that network simplicity with a focus on high quality multi-directional links between key nodes is a model that could be used to enhance the public transport networks of Australian cities.

Whilst a detailed, route-level application of the triangular network structure to Australian cities is outside the scope of this paper, consideration has been given to how the high-level principles could be applied. Taking Melbourne as an example, the Metropolitan Activity Centres, National Employment Clusters and Central City identified in *Plan Melbourne* (State of Victoria 2014) could be evaluated as key nodes. These are shown in Figure 14 below. A detailed examination of public transport travel times between nodes would need to be undertaken to evaluate the potential of these nodes to support isochronic services. Using the CBD as the central node, many of these places could be easily linked with diametric lines, however other configurations may need to be chosen for lines from the north due to Port Phillip Bay. Additional nodes for the network could be selected from the Activity Centres, Health Precincts and Education precincts also identified in *Plan Melbourne* and shown in Figure 12. Whilst there are currently some public transport services providing the tangential links between these nodes, in particular the orbital Smartbus routes introduced between 2002-2010, route design would need to be reviewed to match service frequencies with radial links and to aim for isochronicity where possible. Due to the lower levels of segregation from general traffic on these tangential links compared with the radial train lines, it is likely that a program of infrastructure upgrades would be identified to enable higher levels of public transport priority along these links. The staged implementation of these upgrades and route redesigns could be used to incrementally transform Melbourne’s public transport network into a triangular structure.

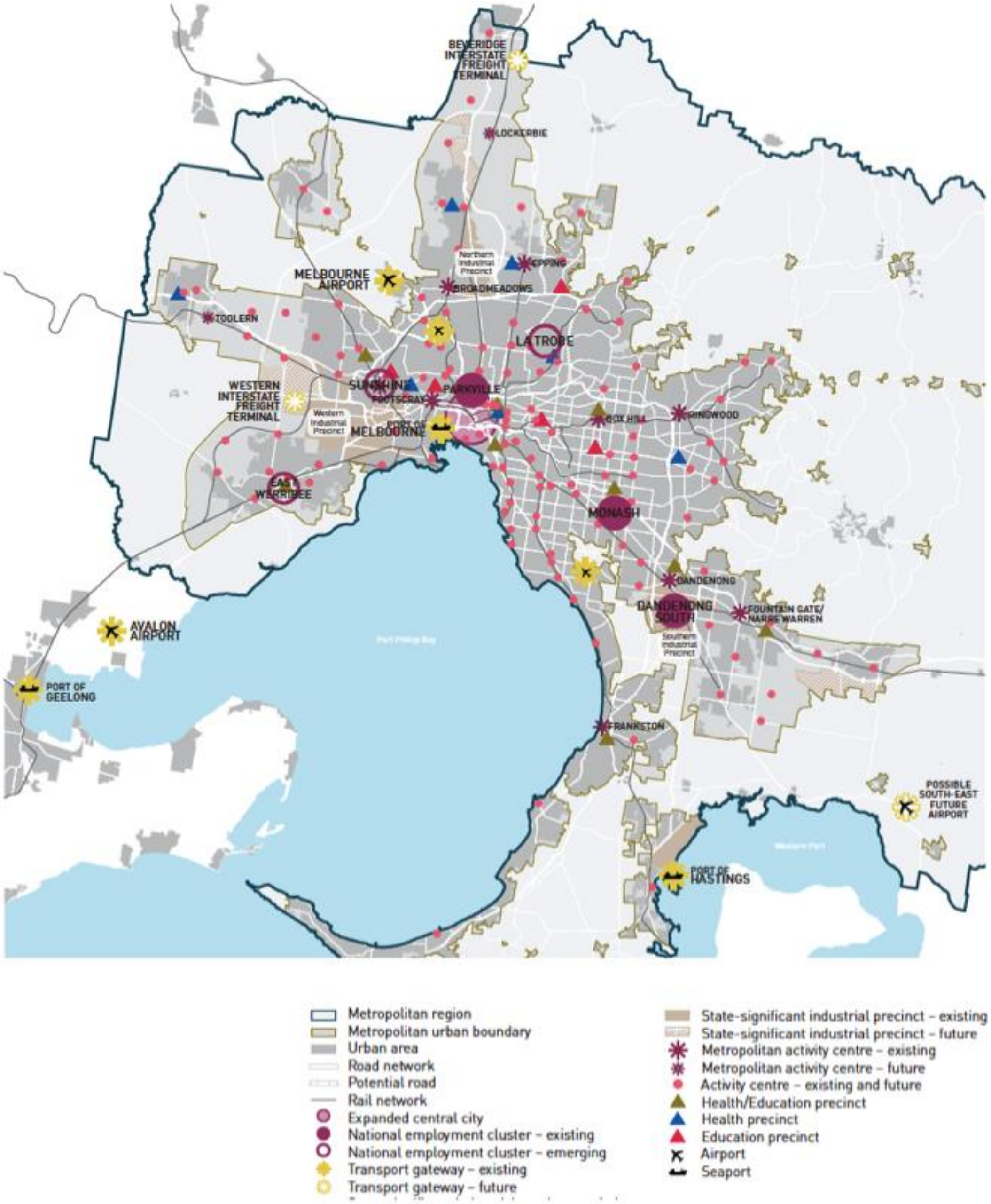

Figure 14: Possible nodes for Melbourne. Image from State of Victoria (2014).

Conclusion

The triangular network structure offers an alternative to Squaresville that may also be useful to cities seeking the “network effect” from their public transport systems. It is particularly useful for cities that do not have the grid-based street layout required by Squaresville, as the links required by the triangles can be provided on any street layout that exists between the two nodes. The design is appropriate in cities where trips are not evenly dispersed across the metropolitan area. It effectively provides a compromise between a network that tries to avoid interchange for any trips, and one that requires interchange for nearly all trips. The temporal qualities of the triangular approach mean that it is suitable for use in networks with either high or low frequency services. It is this combination of qualities that make the triangular network design concept particularly applicable to Australian cities. Further research should investigate the relative benefits of the spatial triangular structure and the temporal elements to determine whether they are interdependent or could be applied independently to a network, and evaluate in detail the application of the triangular network structure to Australian cities.

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