

A GIS Methodology for Estimating the Transport Network Impedance to Last-Mile Delivery

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Abstract: The 'last mile' delivery in cities is not merely a logistics problem, but also a significant urban planning challenge. With the rapid growth of online retail transactions, the size and scope of last mile problem will more likely to escalate. The 'atomisation' of freight, de-bundling of large container load into smaller parcels, has increased delivery lead time from a high-capacity freight hub or port to the final destination. This last leg is the most vital and often less efficient part of the supply chain.

One key factor that contributes to the severity of last mile problem in urban areas is planning controls. The relationship between last mile delivery and urban planning control measures such as parking restrictions, access to loading bays, restricted capacity of transportation infrastructure and land use, is neither being theoretically evaluated nor empirically tested. As the built environment of Australian cities continues to get more compact with roads getting narrower, more congested, and shared between different users, the last mile delivery will remain a challenge.

This paper aims to measure the transportation network impedance to last mile delivery of goods. Key urban planning deterrence to movement closer to final delivery points in urban areas are evaluated using a set of GIS based urban indicators. The levels of impedance are computed across the entire transportation within Maribyrnong City Council network to show the key hotspots of potential last mile problems.

The key findings from the study reveals that level of last mile impedance varies in different part of the study area and are also affected by Activity Centres, Shopping areas, planning zones and the transport attributes.

The mapped outputs will help urban planners and logisticians in mitigating potential delay in delivery of goods. Localised strategies can then be deployed to improve the delivery lead time to retail businesses particularly in Central Business District.

Key words: Last miles, city logistics, supply chain, retail, planning controls and land use.

1. Introduction

The 'last mile' delivery in cities is not merely a logistics problem, but also a significant city planning challenge. Last mile deliveries are expected to escalate as a result of increased online retail transactions, changes in demand for global products, and the increased complexity of logistics and supply chain networks. In addition, there are request for a greater variety of goods by consumers, with the reduction in life cycle of products, and limited capacity of warehousing sales floor. The increased demand and the reduction in warehouse capacity results into increased last mile demand frequency in business to business (B2B) last mile delivery and business to consumer (B2C) deliveries. The business to business are last mile delivery that includes retailers and distributors, suppliers of groceries, parts, and large items (furniture and electronics etc.).

Survey of the Australian Bureau of Statistics (2004) indicated that between 2000 and 2004, the volume of last mile delivery increased from 21million to 25million. In the same period of time, the total tone kilometre increase from 134 million to 157million with total tone of freight increased from 1469 million to 1696 million with the volume and the distance increasing over time. Also, Christopher (2011) estimates last mile city logistics to account for 20 to 30 per cent of all vehicles kilometres. Specifically, Casey et al. (2014) estimated that 32 and 34 per cent of light delivery/service vehicles and heavy commercial vehicles respectively entering the Melbourne CBD were city logistics last kilometre freight vehicles. These developments, together with the need for an agile, lean and just-in-time logistics have accelerated last mile delivery problems (Stratec, 2001). Overall, according to Goodman (2005), last mile delivery accounted for 28% of of all transportation within the supply chain. In addition, last mile delivery has continued to increase in terms of volume, distances and fuel consumption.

To add to last mile delivery complexity is the fact that government are seeking designs based on compact city model with the aim to contain and manage urban growth (Chhetri et al., 2013) and to increase population within the inner city and Activity Centres (Melbourne 2030). Chhetri et al. (2013), highlighted the general purpose of city compactness to include reduction in urban sprawl and support greater utilisation of existing infrastructure and services in more established areas, particularly in the inner and middle-ring suburbs. As a result of the increased densification of housing, and greater concentration of employment and retail services, roads are getting narrower; parking spaces are getting reduced, with increased congestion resulting into delays and loss of productive time and impedance to last mile delivery. Han et al. (2005), estimated that in large urban areas in the U.S, a total delay caused by illegally parked pickup/delivery vehicles to be 500 million vehicle hours annually, costing about \$10 billion in lost time. They concluded that there has been very little effort to reduce truck-related congestion in urban area, especially though redesigning the elements of built environment such as land use, transport networks, streetscape, and urban design. Hence, repeated cycling of the last miles trucks can be attributed to the lack of parking space (curb space) or insufficient off-loading facilities, (Morris 2009), or lack of manoeuvring space as a result of poor road designs and engineering. In addition it has been established that land-use policymakers considered population growth and spatial spread of city separately or in isolation from each other (Agunbiade et al 2014). By extension, last mile logistics characteristics are neglected in policy making process by policy makers. (Tschopp et al., 2004); (Angel et al., 2011).

Brown and Guiffrida (2014) states that consumers have two basic options in retail purchase. Consumers can pick up the products or get the products delivered to them, hence researchers have examine the implications of carbon footprint from conventional customer shopping and delivery of products to consumers, (Siikavirta et al. 2003; Edwards, McKinnon, and Cullinane 2010). Such studies for business to business is still not established in literature.

In this study, the transport network last mile impedance is defined as the amount of resistance required to traverse a route in a network from the point pick-up to the point of delivery. Resistance may be a measure of transport distance, travel time, transport cost or speed of travel multiplied by distance. Higher impedance scores indicate more resistance to last mile delivery, and a value of zero indicates no resistance. An optimum freight route in a transport network is the path of lowest impedance, also called the path of least resistance or least-cost path. Impedance to last mile delivery is computed as the potential hindrance or obstruction to last mile delivery as imposed by transportation and planning constraints to movement of goods on the network and not in terms of time or monetary value.

This research paper is structured in six sections. Section 2 discuss the dilemma of city logistics and last mile. Section 3 discuss last mile and the built environment. Section 4 presents the research methodology. Section 5 discussed the mapped last mile impedance index. Conclusion of the paper is presented in section 6.

This paper aims to present a methodological in the discussion of last mile delivery. Using planning and transport systems attributes. To achieve this aim, the following research questions are set out.

- i. What is the key impedance to last mile delivery in an urban setting?
- ii. How can urban and transport planning systems linked to last mile delivery?
- iii. What method can be applied to estimate and map the transport network last mile impedance to freight delivery?

2. City Logistics and Last Mile dilemma

City logistics (*CL*) plays the key role in facilitating consumers to access delivery of needed goods within a large urban setting. Several terms has been used to describe the term city logistics and last mile. These includes urban goods movement (McDermott, 1980), urban freight logistics, (Gonzalez-Feliu et al., 2012); urban freight (Tipagornwong and Figliozzi, 2014); (Allen et al., 2012); (Stathopoulos et al., 2012); (Cherrett et al., 2012); and urban logistics (Alho and de Abreu e Silva, 2015). However, Taniguchi et al. (2014); Bozzo et al. (2014); Rao et al. (2015) and Crainic et al. (2009) specifically used the terms city logistics in the context of good movements within the city. (Wolpert and Reuter, 2012) Various definitions have been provided to illustrate what city logistics is. Ballantyne et al. (2013) stated that "Hicks (1977, p. 101) presented the first formal definition of urban freight which is currently termed city logistics". *CL* is defined as "all journeys into, out of, and within a designated urban area by road vehicles specifically engaged in pick-up or delivery of goods (whether the vehicle be empty or not), with the exception of shopping trips". McDermott (1980) specifies a population threshold to define city logistics. He describes *CL* as "comprising all freight distribution within an urban area of a city with a population of more than 50,000". Other studies however have not used this threshold in their subsequent work to differentiate city logistic provisioning. Taniguchi and Thompson (2002), defined *CL* as "the process for totally optimizing the logistics and transport activities by private companies in urban areas while considering the traffic environment, its congestion, safety and energy savings within the framework of a market economy", while Barceló et al. (2005) refers to *CL* as "freight transport in urban areas and specifically the freight flows associated with the supply of goods to city centres". Also, Qiu et al. (2005) identified what *CL* included when they stated that "CL encompasses the routing and the movement of freight across all transport modes, as well as associated activities such as warehousing, exchanging information for the management of freight at each end of its journey". (Dablanc (2007) defined *CL* as "any service provision contributing to an optimized management of the movement of goods in cities". Furthermore, Crainic et al. (2009) defined *CL* as a "concept that tries to optimize urban freight transport systems by considering all stakeholders and movements in urban areas". Since then, numerous definitions have been presented, with varying levels of detail, for example by Taniguchi and Thompson (2002), Allen et al. (2012), and Dablanc (2007). The number of different definitions of urban freight transport and city logistics reflects the complexity of this field and the persistent lack of consensus on how to address the issues.

Ehimke (2012), specifically relates *CL* with the last mile. He defined *CL* as "the second leg of the logistics network and to include pickup and delivery of goods to customers in terms of last mile (*LM*) delivery. This includes the last part of the delivery process. Anderson et al. (1996) consider *LM* as an integral part of city logistics and characterise it as being the delivery of final products in low volumes and at high frequencies. To Lindner (2011), *LM* involves "a series of activities and processes that are necessary for the delivery process from the last transit point to the final drop point of the delivery chain", hence Gevaers et al. (2014), sees it as the "the last part of the supply chain". Given the need for de-bundling of large container load into smaller parcels prior to the final delivery, Morganti, & Gonzalez-Feliu (2015), see *LM* as "small scale distribution of goods in an urban environment", while Morris et al. (2003), defined *LM* as the "pick-up /drop-off point to the end customer in commercial buildings". Aized and Srail (2014), considers *LM* as the final step in business to customer logistics. Hence Aized and Srail (2014) confirmed that *LM* is one important step in supply chain in terms of business to business (*B2B*) and business-to-customer (*B2C*) paradigms and is responsible for efficient and economical final delivery of goods to customers.

While other aspect of the supply chain can be carried out via different modes of transportation including sea, air and rail, the last mile delivery is carried out mostly via the road. And last mile delivery typically has an average share of 10% in the total urban transport. (London, 2012) confirmed that 90% of last mile delivery are made by road. Thus, Ehmike, (2012) identified last mile delivery to involve transportation over short distances with smaller trucks. It should be noted that the last mile delivery via water or rail is possible in locations where the urban transport infrastructure enables it through the existence of suitable canals or urban rail terminals. Due to the interaction between last mile delivery vehicles and other road users, studies on LM generally concentrate on the its negative impact on the environment and transport networks, Anderson (1996), Casey et al. (2014), Ehmike (2012).

3. Last Mile delivery and Built Environment

The term built environment refers to those surroundings created for humans, by humans, and to be used for human activity. The built environment is extensive and it provides the context for all human endeavours. Built environment is defined and shaped by context (Habraken and Teicher, 2000).

Policies often formulated by local authorities have hindered last mile delivery by placing restrictions on city logistics (Anderson, 2000; and Dablanc, 2007). Many of these restrictions, if not all, create impedance to last mile delivery. While less efforts has been made by local council in Australia (Casey, 2013), Ballantyne, Lindholm and Whiteing (2013), noted that in Europe, a large number of policy measures have been used, and that local authorities are slowly beginning to acknowledge the need to consider freight in their overall transport planning processes. They demonstrated the requirement for greater interaction between local authorities and freight transport stakeholders with regards to last mile delivery issues. Also local authorities are getting the awareness that that last mile delivery planning can be improved by involving a wider range of stakeholders. However, the findings of Ballantyne, et al (2013) shows that the issues faced by the city logistics freight industry are still not fully understood. Their submission contradicts earlier research results that suggest differences in the ways that local authorities consider freight transport, and goes some way towards demonstrating that the problems faced by local authorities are not unique to one country or any specific category of urban area.

The concept of compact city is a planning tool that has been widely used in developed countries for cities. The use of the compactness concept often combines various principles of city planning (Jenks et al., 1998). Compactness has been seen as a mechanism for controlling and regulating urban sprawl by promoting a relatively high-density, mixed land-use city structure, supported by a more efficient public transport system and increased opportunities for walking and cycling Chhetri et al., (2013). While compactness is defined as high-density or monocentric development by Gordon and Richardson (1997), Ewing (1997) defines it as means concentration of employment and housing and a greater diversity of land uses. Galster et al. (2001), defined compactness as the degree to which development is clustered to minimise the amount of land developed per square mile.

The last mile problem is not solely dependent on the operational efficiency of supply chains and logistics infrastructure and services, they are also influenced by the elements of the built and regulatory environment. Figure 1 shows the interlocking systems within which the operational efficiency of last mile delivery is dependent. These include: metropolitan planning system and transport system. The basis of this proposed conceptualised framework to identify the bottlenecks caused by urban systems is discussed below.

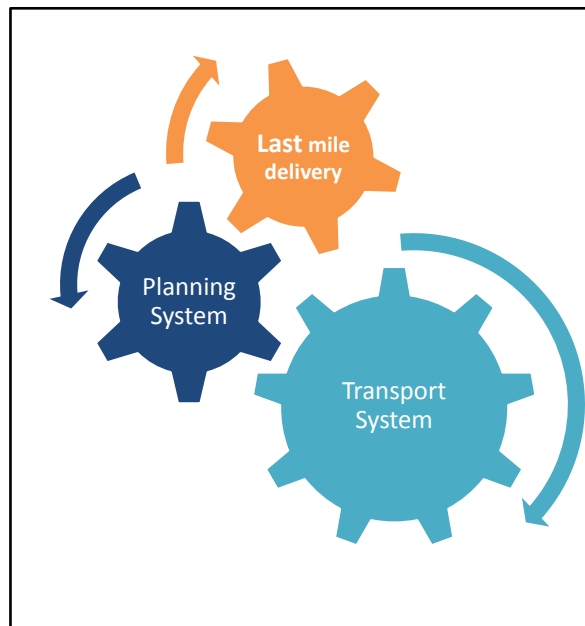


Figure 1: Inter-locking interactions between planning system, transport system and last mile delivery.

3.1 Planning System

The strict regulatory environment in most metropolitan cities is largely driven by the intention to mitigate negative aspects of city logistics. Song et. al., (2009) identifies growth in vans and large goods vehicles and stated that such vehicles accounted for only 29 per cent of the total growth in vehicle miles CO₂ emissions in the UK. Allen et. al., (2012) investigates relationships between road freight transport, facility location, logistics management and urban form in UK. Bozzo et al., (2014) are of the opinion that last mile delivery accounts for 32% of energy consumption, and for 40% of all CO₂ emissions of road transport, and up to 70% of other pollutants from transport. Gonzalez-Feliu et. al., (2012) evaluates the impacts of urban goods transport in terms of road occupancy in the city of Lyon, in France. Gonzalez-Feliu et. al., (2012) established that last mile delivery amount to 20% of the total road occupancy rates by running vehicles, and to 25% CO₂ emissions of the overall urban transport. Boyer et. al, quoting (Peralta, 2007) states that “Walmart’s customers driving to the store account for 15.4 million metric tons of CO₂, more than all of Walmart’s domestic CO₂ output combined”. However, Morris (2009) observed that the repeated cycling of the last miles trucks can be as a result of lack parking spaces (curb space) or insufficient off-loading facilities. She concluded that space restrictions in CBDs, compounded by increased land values foster compact development, that negatively impact last mile city logistics.

The planning System utilise zoning, overlay and particular provisions to achieve its objectives. The zoning, overlay and particular provisions are contained in Clauses 30’s, 40’s and 50’s. The identified zones includes principally Residential, (General Residential, Neighbourhood Residential, Mixed Use, Commercial, Activity Centres and Industrial)

Given that the business to be considered are located within the Activity Centre, Mixed Use Commercial and Industrial, the study examines how these zones positively or negatively impedes last mile delivery.

Particular Provision of the Victoria Provision is another measure of consideration. The specific provisions of considerations will be Loading & Unloading. These are contained in Clause 52.07 of the Planning Scheme.

3.1.1 Zones.

Zoning as a planning tool used to separate different from one another. Particularly, it is often used to separate more impactful uses (manufacturing) from more sensitive uses (residential). These planning

tools identifies zones to include residential (General to Neighbourhood Residential Zone), Mixed uses, Commercial, Activity Centre and Industrial (VPP 2105). Generally, planning utilise different zoning ranging from more restrictive to some uses to a more open uses. The more the restrictive these zone, the more restrictive the hierarchy of road, and the more the impedance to last mile delivery. The hierarchy and speed limits that operates within the different zone are computed to determine the level of impedance to last mile delivery.

3.1.2 Loading and unloading.

Urban Planning efforts including transport system and traffic management, often fail to consider negative impact of pick-ups and deliveries upon last mile delivery (Morris, 2009). She identified obstacles like inaccessible curb, gridlock lack of insufficient freight elevators and loading bay as impedance to last mile delivery.

Within the Victoria Planning Provision, Clause 52.07 specifically discusses loading and unloading of vehicles. The Purpose of the Clause is to set aside land for loading and unloading commercial vehicles to prevent loss of amenity and adverse effect on traffic flow and road safety. It specifies the requirements for loading and unloading prior to construction of building for the manufacture, servicing, storage or sale of goods or materials.

The requirements include provision of space on the land for loading and unloading vehicles, the width of access ways and driveways. However, there are opportunities to reduce or totally waive the requirements. The provision, reduction or waiver of this requirement creates positive or negative impedance to last mile delivery.

3.2. Transport System

While other leg of the supply chain can be carried out via different modes of transportation, last mile delivery is often carried out on road ((SKAL, (2013), Reisman, (2011). Eppell et al (2001) identified transport system as a key component of the built environment. They identified arterial roads, subarterial roads, collector streets and local streets as the four major road hierarchies within the urban environment. These hierarchies of roads within the transport system service all the uses within the urban environment and also serve as connecting link between the uses. These roads hierarchy are identified as Road Zone 1 and 2 and street within the Victoria Planning Provisions. This study focus on the arterial roads, subarterial roads, and collector street. Local street will not be the focus of this study given it consideration of business to business last mile delivery.

Scholars have been able to identify various road attributes. (Gülgen & Gökgöz, 2011). Mackaness and Beard (1993), Li and Choi (2002), Jiang and Claramunt (2004), and Jiang and Harrie (2004). Zhou and Li (2011). Li and Choi (2002) identified hierarchy, length, width, number of lanes, number of traffic directions and connectivity of arcs on junctions as the six road attributes in their study. In their comparative analysis among the road attributes Zhou and Li (2011) identified road class, road length and centralities of degree, closeness and betweenness in road generalisation process. Considering semantic in road attributes, Zhou and Li (2011) added traffic directions, speed limit and road surfaces to the attributes mentioned above.

These attributes are often contained within road network segments, where a segment is a stretch of road between two intersections. Each segment can thereafter be separated into sub segments as a result of intersection, roundabouts, speed limits and traffic lights. The number of separated segments considered as a ratio of the overall length of the road segments forms different level of impedance to last mile delivery.

4. Research Methodology

4.1 Study Area

For the purpose of this study, Maribyrnong City Council is selected as a case study due to its proximity to the Melbourne Ports and identification as gateway to the western part of Melbourne Metropolitan areas. It is also an inner city suburb with severe transportation bottlenecks and last mile delivery delays. In addition, local council and state government implemented a compact city model

which permits higher density living, mixed land use and greater compactness around strategic nodes such as activity centres and transportation hubs.

4.2 Datasets

For the purpose of this study, Maribyrnong City Council is selected as a case study due to its proximity to the Melbourne Ports and identification as gateway to the western part of Melbourne Metropolitan areas. Datasets are generated through Geographical Information System for planning and transport systems. (See table 1)

The planning and transport systems attributes are extracted from the Geographical Information System (GIS) mapping. Geographical Information System is a computerized data management system used to capture, store, manage, retrieve, analyse, and display spatial information. Some of these attributes listed in Table 1 are generated through GIS mapping, and computed. The layers are then combined into planning system layer and transport system layer and thereafter combined to form a single last mile delivery impedance layer.

Attributes to be considered under planning systems are zones and loading and unloading. With regards to transport system, attributes for consideration includes speed limits, road width, kerbside, traffic lights, school zones, parking, trucks access/curfew etc. GIS are then applied to examine the extent of impedance of the attributes on last mile delivery. The measures and attributes for considerations within the Planning System and the Transport System are as presented in the table below. (The entire attributes listed will be considered in subsequent research)

Planning and Transport Systems attributes identified are as presented in Table 1. This includes Zones and Particular Provisions in the Planning System. This is as contained within the Victoria Planning Provisions. These two attributes are can directly impact last mile delivery. The type of zone influences the hierarchy of Roads. (Eppell et al, 2001). The hierarchy of road subsequently determine the speed limit. Loading and unloading are as required by the particular provisions of the Victoria Planning Provisions. The availability and adequacy of loading and unloading will impede last mile delivery positively or negatively.

Within the Transport System, attributes identified are as identified by Gülgen & Gökgöz, (2011). Mackaness and Beard (1993), Li and Choi (2002), Jiang and Claramunt (2004), and Jiang and Harrie (2004). Zhou and Li (2011). Li and Choi (2002) and listed in Table 1.

Table 1: Planning System and Transport System Attributes

Systems	Dimensions	Attributes
Planning System	Planning Controls	Zones – Industrial mix • Residential, • Commercial, • Activity Centre, • Industrial.
		Particular Provision: • Loading and Unloading
Transport System	Transport Controls	• Speed limit • Road width • Number of lanes • Intersections • Traffic lights • Railway crossing • Zebra crossing • Tram and Train crossing • School Zones • Truck curfew and restrictions • Parking Restrictions • Overhead restriction (bridges, power lines and trees) • Surface type • Bicycle lanes • Kerb side • Service lanes

4.3 Methods

The proposed research method consists of 5 stages.

4.3.1 Stage 1: Identification of the key attributes of last mile impedance.

The last miles attributes are as listed in Table 1 above. The attributes are categorised into Planning and Transport Controls.

4.3.2 Stage 2: Standardisation of attributes

Data standardisation involves the process of converting a batch of data values into standardised units by removing the effects of the average size of the values in the batch and the size of the spread of values of data. For example, data such as speed limit in kilometre per hour or dwelling density per square kilometre are standardised using a common technique of 'max-min procedure'. The original data are converted into measures ranging from 0 - 100 to 0 - 1, based on minimum and maximum values in a set of reference points.

The new set of values are derived by subtracting the minimum value in the distribution from each observed value for each data layer (variable) and expressed as a percentage of the difference between the maximum (max) and minimum (min) values in the distribution.

Formally:

$$I = [(V - \min) / (\max - \min)] \times 100$$

where,

V is the observed indicator value (after imposition of bounds), and

I is the new, rescaled, index-number representation with a value ranging from 0 to 100.

The formula is reversed for data variables, which have a negative impact on last mile delivery. For these variables, the formula is:

$$I = [(max-V)/(max-min)] \times 100$$

The measures are then calculated in such a way that the higher the value of the component variables, the higher the levels of last mile delivery impedance (and vice versa).

4.3.3. Stage 3: Assessment of attributes for its potential impact on last mile impedance

The identified attributes are examined in relation to road segments as the independent variable. Other attributes are assessed against the identified roads. A segment is a stretch of road between two intersections. Each segment can thereafter be separated into sub segments as a result of intersection, roundabouts, speed limits and traffic lights. The number of separated segments is considered as a ratio of the overall length of the road segments which form different level of level of impedance to last mile delivery. For example, the higher the number of traffic lights, roundabouts, intersections, etc. and expressed in ratio of the overall road segments. The higher the ratio on a segment of road, the high the level of impedance. Also, speed limit are from the high impedance to low impedance, where 40 kilometre limit represents high impedance and 100 kilometre limit represents low impedance.

4.3.4 Stage 4: Development of the last mile network impedance index

Once the data variables are standardised and converted into same unit (0 -100), an overlay function is then employed to generate a new layer of last mile delivery impedance and a composite index applied to define the mathematical function, whereby each of these layers are added and divided by the total number of layers.

A Weighted composite index is also be calculated where the data layers are multiply with their associated weights and then added together to construct the overall weighted last mile delivery impedance index.

The formula for composite index described as follows:

$$\text{Last mile impedance} = V_1 + V_2 + V_3 + \dots + V_n$$

$$\text{Weighted Last mile impedance} = W_1(V_1) + W_2(V_2) + W_3(V_3) + \dots + W_n(V_n)$$

4.3.5. Stage 5: Mapping of the last mile network impedance

Mapping of the last mile network impedance are carried out using geographic information systems (GIS). Impedance levels are mapped at the road network of the city council using thematic mapping technique. Thicker the transport network shows the greater the impedance; whilst thinner lines show lower levels of impedance. (Figure 3) Visualisation of impedance enables the key transport hotspots to be identified. Based on the mapped outputs, a new logistics zoning system are developed to demarcate areas of high impedance to help improve the efficiency of last mile delivery to retail businesses within the Council. (Figure 2)

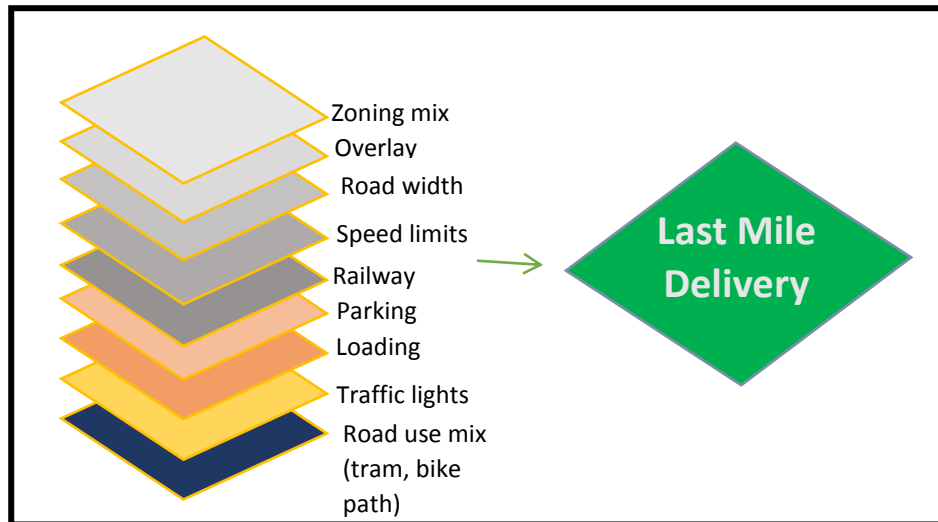


Figure 2: A GIS Overlay Function

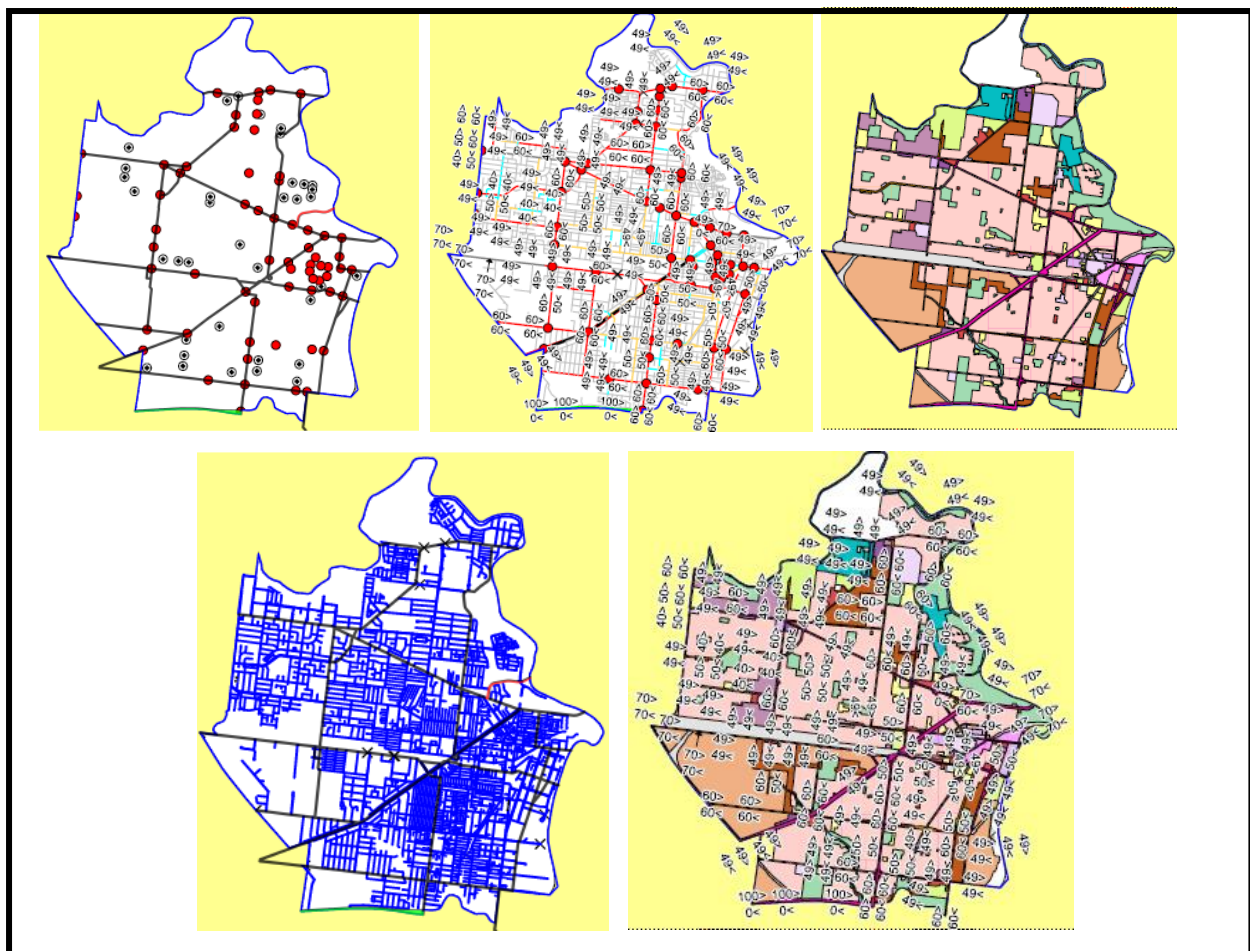


Figure 3: Examples showing different measures of planning controls (Traffic lights and roundabout, speed limits including Traffic lights and Maribyrnong City zoning map, road network layer, speed limit and zoning).

5. Results and Analysis

A number of GIS layers were overlaid to generate the transportation network last mile impedance. The overlays include speed limit, traffic lights, crossings, bus route and train routes. Travel time in last mile delivery is a sensitive element and affected by various factors. A problem or malfunctions in an element has the potential for a high last mile impedance. Speed limit for example is identified to impact travel time. Taylor (1997) states that travel times increase with lower speed limits. Also, traffic lights functions, crossings and train/tram routes impact travel time (Greater London Authority, 2009) and more importantly last mile delivery (Lin, 2005). These elements can have quite different travel time last mile delivery impedance (Li and McDonald, 2002).

Of the identified road hierarchy identified by Eppell et al (2001), arterial roads, subarterial roads, collector streets are utilised for the last mile impedance index. The local streets are left out of the impedance given the consideration of B2B last mile delivery in the study.

A transportation network last mile delivery impedance index is mapped using a thematic technique. Figure 4, 5 and 6 shows that different segment of the transport networks have different impedance scores due to their attributes which acted as hindrances to movement.

Three maps are generated to show the impedance levels in high freight activities. These are: Barkly street linear strip with an agglomeration of retail, restaurants and shopping outlets, West Footscray with limited retail outlets and West Gate Highway-Melbourne port freight route. Figures 4, 5 and 6. The calculated last mile impedance scores are classified into High, Medium and Low impedance.

In figure 4, Barkly Street, Hopkins Street, Droop Street, Geelong Road are with high impedance Index due to their proximity to Footscray Activity Centre – the Maribyrnong Council City Centre. Barkly Street, Droop Street, Hopkins Street, Paisley Streets are within the Footscray Activity Centre and shopping strip with reduced speed limit, high number of traffic lights, pedestrian crossings, tram crossings/stops and bus routes/stops. The entire length of Droop Street is shared with tram line accounting for the high impedance index. Figure 4.

Figure 5 reveals an overall medium impedance index. Somerville Road, Francis Road returns high impedance. The mapped area is in proximity with the Port of Melbourne and warehouses serving the western suburb of Melbourne. Road network in the mapped area traverse through residential developments with reduced speed limit, crossings, overhead bridges (from train tracks) truck restrictions, more traffic lights and bus routes.

Figure 6 reveals a low impedance index. Most of the roads in the map return a low impedance scores. The road network in the mapped area are characterised with less intersection, traffic lights. The mapped area does not have any shopping strip, tram routes and less bus routes/stops resulting in an overall low impedance index.

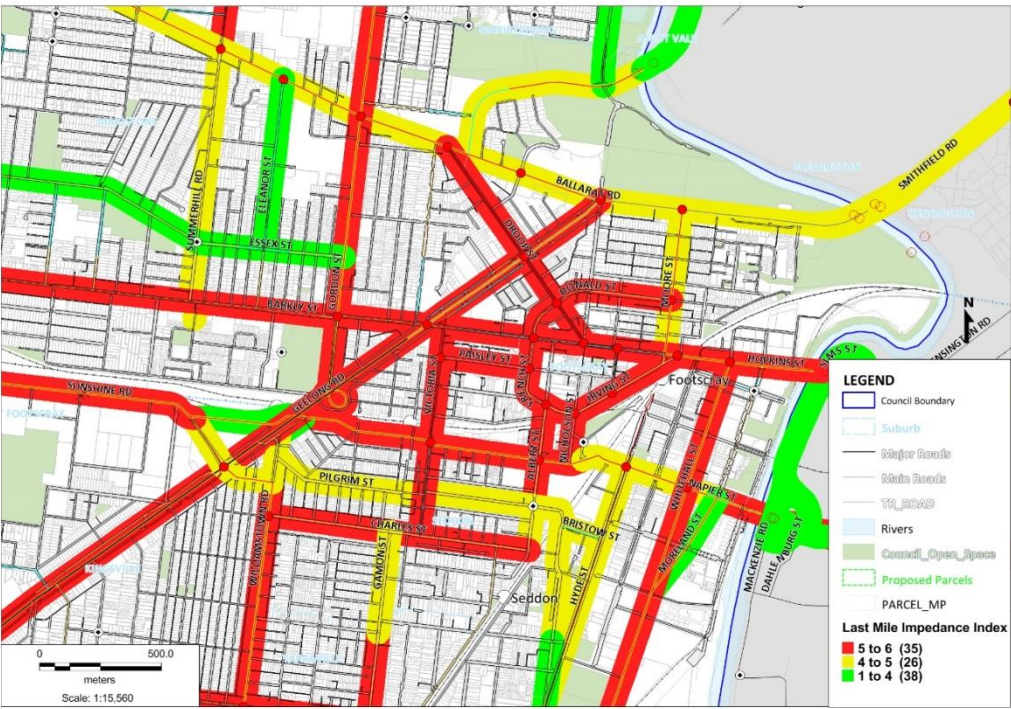


Figure 4: Barkly Last Mile Impedance Index

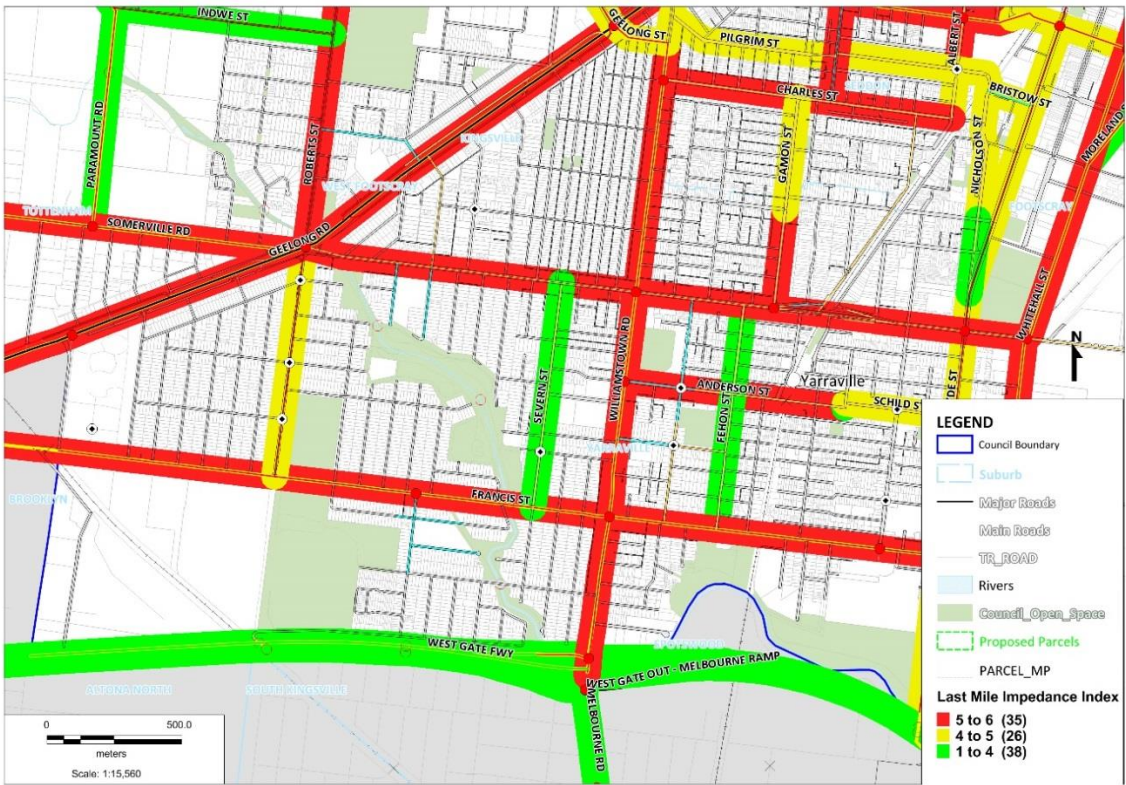


Figure 5: West Gate Last Mile Impedance Index

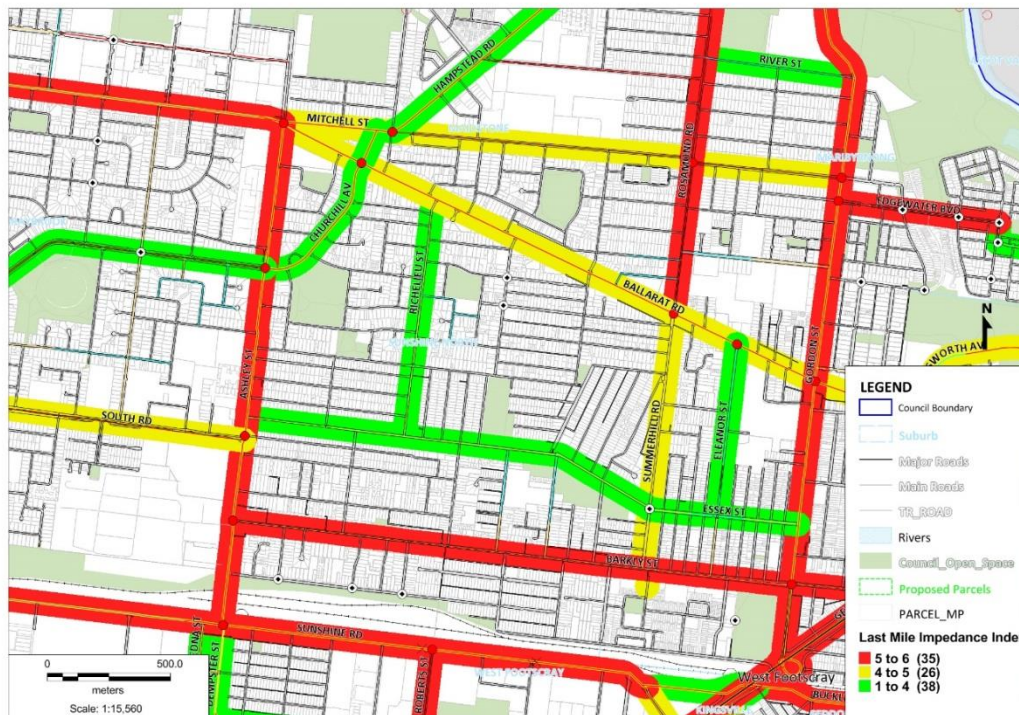


Figure 6: West Footscray Last Mile Impedance Index

5. Conclusion

The paper is a methodological discussion of last mile delivery impedance. It identified the potential planning and transport systems attributes of the last mile delivery impedance for B2B delivery. GIS is proposed as the key tool to map the last mile transport network impedance. A five stages research method is proposed. This consists of identification of the key indicators of last mile impedance; standardisation of indicators; assessment of indicators for its potential impact on last mile impedance; evaluation of importance weighting; development of the last mile network impedance index and mapping of the last mile network impedance for the study area. The index can be applied to other city councils for comparison of last mile delivery impedance.

The key findings from the mapped road networks of the city council reveals that level of last mile impedance varies in different part of the study area. The level of impedance is also affected by Activity Centres, Shopping areas, planning zones and the transport attributes. Visualisation of the impedance as presented in the map allows the identification of transport hotspots.

The mapped outputs will help urban planners and logisticians in mitigating potential delay in delivery of goods in the last mile component of supply chains. Localised strategies such as the designing of a dedicated delivery corridor, alternative routing and time-window based loading/unloading can then be deployed to improve the delivery lead time to retail businesses, particularly in the Central Business District or a pedestrianised precinct.

This paper is the first stage of the estimation of planning and transport systems on last mile delivery. The complete dataset are still lacking and evolving, hence the use of the 6 road network attributes at this stage to carry out the mapping. Other identified planning and transports attributes will be included in future mapping of the impedance index as this cannot be said to have been carried out at this stage. The listing of the attributes is not exhaustive and cannot be seen as actual impedance registered by drivers or on GPS devices. This would be evaluated using a questionnaire based survey, which will be implemented to last mile delivery drivers. In addition, different weighting of the indicators will be addressed in future research.

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