Estimating transportation network impedance to last-mile delivery

A Case Study of Maribyrnong City in Melbourne

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Abstract

Purpose – The purpose of this paper is to measure and map the potential transportation network impedance to last-mile delivery (LMD) using spatial measures representing attributes of road network and planning controls.
Design/methodology/approach – The transport network impedance is estimated as the potential hindrance to LMD as imposed by the characteristics of the built and regulatory environment. A matrix of key transport and planning measures are generated and overlaid in geographical information systems to compute and visualise the levels of transportation network impedance to LMD using a composite indexing method.
Findings – The mapped outputs reveal significant spatial variation in transportation network impedance to LMD across different part of the study area. Significant differences were detected along the road segments that connect key industrial hubs or activity centres especially along tram routes and freight corridors, connecting the Port of Melbourne and logistic hub with the airport and the Western Ring Road.
Research limitations/implications – The use of static measures of transport and urban planning restricts the robustness of the impedance index, which can be enhanced through better integration of dynamic and real-time movements of business-to-business LMD of goods. Spatial approach is valuable for broader urban planning at a metropolitan or council level; however, its use is somewhat limited in assisting the daily operational planning and logistics decision making in terms of dynamic routing and vehicle scheduling.
Practical implications – The built and regulatory environment contributes to the severity of LMD problem in urban areas. The use of land use controls as instruments to increase city compactness in strategic nodes/hubs is more likely to deter the movement of urban freight. The mapped outputs would help urban planners and logisticians in mitigating the potential delay in last-mile deliveries through devising localised strategies such as dedicated freight corridors or time-bound deliveries in congested areas of road network.
Originality/value – This is the first study that measured the potential transport network impedance to LMD and improved understanding of the complex interactions between urban planning measures and LMD. Micro-scale mapping of transportation network impedance at the street level adds an innovative urban planning dimension to research in the growing field of city logistics.

Keywords Australia, Literature review, Retail logistics, City logistics, Last miles, Planning controls, Last-mile delivery, Transport network impedance, Planning controls and land use

Paper type Research paper

1. Introduction

The "last-mile" delivery (LMD) in cities is not merely a logistics problem, but also a significant urban planning challenge. Last-mile deliveries are expected to grow as a result of increased online retail transactions, changes in demand for products from overseas and the increased complexity of logistics and supply chain networks. In addition, it is further aggravated by increasing requests for a greater variety of goods by consumers, noticeable reduction in life cycle of products as well as limited capacity in warehousing sales floor. The increased demand for products and the reduction in warehouse capacity result into increased last-mile demand frequency in business to business (B2B) LMD (McKinnon *et al.*, 2010). B2B LMDs include

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retailers and distributors, suppliers of groceries, parts and large items usually delivered via the road. It also results in an increased demand for business to consumer (B2C) deliveries.

LMD is critical to the efficiency of supply chain and logistics management. Australian Bureau of Statistics (2013) indicated that between 2000 and 2012, the volume of LMD by road increased from 139 billion to 201 billion tonne kilometre. This is projected to be 1.8 times by 2030 from its 2010 level. Christopher (2011) estimated last-mile city logistics to account for 20-30 per cent of all vehicles in kilometres; whilst Goodman (2005) calculated LMD to account for 28 per cent of all transportation within the supply chain. Gevaers *et al.* (2009) estimated it to account for between 13 and 75 per cent of the total supply chain cost, depending on different urban contexts. In addition, LMD has continued to increase in terms of volume, distances and fuel consumption. These developments, together with the need for an agile, lean and just-in-time logistics, have accelerated the magnitude of LMD problems (Stratec, 2001).

Adding to the LMD complexity, some governments have adopted urban intensification designs and policy interventions to contain urban growth and to increase population density within the inner city suburbs and around key activity centres. Driven by the compact city theory, the general purpose of intensification includes a reduction in urban sprawl and greater utilisation of existing infrastructure and services in more established areas, particularly in the inner- and middle-ring suburbs. City compactness measures thus aim at increasing density of housing, population, retail and employment in strategic nodes such as transport hubs and activity centres. Furthermore, roads are getting narrower and parking spaces are reduced, with increased congestion resulting into transportation delays and loss of productive time.

LMD problems pose significant challenges for large urban agglomerations. In the USA, illegally parked pickup/delivery vehicles of 500 million vehicle hours annually costed about $10 billion in lost time (Morris *et al.*, 1999). 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 planners considered population growth and spatial spread of city separately or in isolation from each other (Agunbiade *et al.*, 2012). By extension, last-mile logistics characteristics are neglected in the policy-making process by policy makers (Angel *et al.*, 2011).

Urban freight plays a central role in seamless operations of LMD, which should take into account the provisions of urban and land use planning. The constantly changing transportation systems (Stank and Goldsby, 2000) should be considered in planning LMD. In the discussion of supply chain management, however, manufacturing has been taken greater attention, whilst issues relating to transportation are considered as marginal (Stank and Goldsby, 2000). This neglect can be argued to contribute to ineffective and inefficient LMD. Hence, Vasco Sanchez-Rodrigues and Mohamed (2010) argued the importance of urban planning and the need to take the capacity and design of transport network into account in supply chain management. In this paper, the transport network LMD impedance is defined as the amount of road network resistance imposed on B2B deliveries from the point of pick-up to the point of delivery.

This study, for the first time, aims to integrate measures of land use and planning controls to estimate potential transport network impedance to LMD. It will improve the understanding of the complex interactions between aspects of urban planning and LMD operations. In addition, it will explore a range of local strategies to help mitigate potential LMD bottlenecks on the transport network. The following research questions are set out to answer the above mentioned aim:

RQ1. What are the key spatial indicators of LMD impedance in an urban setting?

RQ2. How are built and regulatory environments linked to LMD in a compact city model?

RQ3. What strategy can be formulated to mitigate potential transport network impedance to LMD?

This paper begins with a brief review of literature in the city logistics discussion, with a particular focus on LMD. The theoretical underpinning of compact city as relates to LMD was carried out. The research methodology then outlined the data sets used and the methods employed. Results and analysis are then presented. The paper finally concluded with a summary of major findings and proposed local strategies to mitigate transportation network LMD impedance.

2. Transport network impedance to LMD

The transport network impedance to last mile is defined as the amount of resistance required to traverse through a route on a road network from the pick-up to the delivery point. The impedance on a road network deters goods movements in and out of urban areas as well as goods travelling within the city. These movements are often referred to as "last-mile" delivery. Gevaers *et al.* (2014, p. 1) denoted last mile as the "the last part of the supply chain". The last mile has been studied to include processes and activities within a city (Morris *et al.*, 2003; Ehmke, 2012; Gevaers *et al.*, 2014), the mode of delivery (Aized and Srai, 2013) and distances covered (Ehmke, 2012), including B2C and B2B deliveries (Lindner, 2011; Harrington *et al.*, 2012). Various issues associated with pick-up and deliveries over shorter distances have also been highlighted (Morris *et al.*, 2003; Ehmke, 2012). Specifically, Morris *et al.* (2003) examined last mile to deliveries in commercial premises, where the focus remained on B2B deliveries, often using smaller trucks (Ehmke, 2012). Hence, LMD is an important activity (Aized and Srai, 2013; Lindner, 2011), which involved distribution of goods (within the urban environment and delivery to retailers via road; Morganti, 2011b, a; Morganti and Gonzalez-Feliu, 2015; Aized and Srai, 2013). LMD is characterised by high frequency and low capacity in comparison to low frequency and high capacity at the initial leg of the supply chain (Rodrigue, 2013). It is an integral part of city logistics, being the delivery of final products in low volumes and at high frequencies. It involved a series of activities and processes that are necessary in the delivery process from the last transit point to the final drop point of the delivery chain (Rodrigue, 2013; Anderson *et al.*, 1996).

The intricacies of LMD are analysed from different perspectives. Esper *et al.* (2003), Boyer and Hult (2005) and Browne *et al.* (2005), for instance, discussed last mile in the context of online retailer deliveries, online groceries deliveries and urban freight consolidation. Knott (1987) and Morganti (2011b, a) considered last mile in terms of food delivery with trucks from a distribution centre to a number of camps, while Balcik *et al.* (2008) examined LMD in humanitarian relief operations from local distribution centres to the affected areas. Morganti (2011b, a) and Morganti and Gonzalez-Feliu (2015) analysed last mile to reflect small-scale distribution of perishable goods to food retailing and catering operators in cities. The effectiveness of LMD depends heavily on five key decisions. These decisions include: facility location decision: number of distribution centres (Balcik *et al.*, 2008); inventory decision: inventory in each facility (Hoekstra and Romme, 1992; Jaller *et al.*, 2013); inventory policy (Zipkin, 2000; Chopra and Meindl, 2007); transportation policy: number of vehicles, route planning, capacity of vehicles and scheduling (Barbarosoglu and Arda, 2004; López *et al.*, 2013; Melo *et al.*, 2009; and distribution decision (Tzeng *et al.*, 2007; Vitoriano *et al.*, 2011; Balcik *et al.*, 2008).

The focus of this study is centred on the measurement of potential transport network impedance instead of LMD. The potential impedance was estimated, as the origin and destination (OD) points are unknown. Higher potential impedance scores indicate greater resistance to LMD, and a value of "0" indicates negligible or no resistance. Therefore, 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 LMD was computed as the potential hindrance or obstruction to LMD as imposed by transportation and planning constraints to movement of goods on the network and not in terms of time or monetary value. With regards to scaling of impedance, Novaco (1990) classified the level of impedance as low, medium and high. Higher impedance scores indicate greater resistance to LMD, and a value of "0" indicates no resistance. Considering that the impedance is estimated for B2B delivery, which is directly dependent on road network consisting of highways and major roads. Local roads are excluded as they are required for B2C delivery. Impedance to LMD was computed as the potential hindrance or obstruction to LMD as imposed by transportation and planning constraints to movement of goods on the network and not in terms of time or monetary value.

3. LMD in compact city

The compact city theory is a planning concept, which has been widely used in developed countries to set direction for cities. It is also known as a city of short distances in the urban planning literature, an opposite view to urban sprawl (Morrison, 1998). The use of the compact city as a concept often combined various principles of city planning (Jenks *et al.*, 2008). In general, compactness is 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). Gordon and Richardson (1997) defined compactness as high-density often built to promote monocentric city structure, while Ewing (1997) defined it as concentrations of employment and housing and 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.

Studies such as Dantzig and Saaty (1973), Breheny (1992), Beatley (1995), Morrison (1998), Burton (2000) and Jenks *et al.* (2008) placed population density as the single operational measure of compact city. Chhetri *et al.* (2013), however, considered compactness as a multi-dimensional construct which they formulated using seven major characteristic of compact city including intensification, consolidation or densification, particularly around inner suburbs and greater dwelling density and reurbanisation. The Metropolitan Strategy Melbourne 2030 introduced the concept of creating a more compact city (Department of Infrastructure, 2008). These policies have been taken further by Plan Melbourne 2017-2050 in the identification of Central City and 11 Metropolitan Activity Centres as the population of Metropolitan Melbourne is projected to increase from 4.5 million to 8 million in 2051 (Department of Environment, Land, Water and Planning (Vic), 2017). Melbourne 2030 introduced the Activity Centre Policy and enshrined it into the planning policies. The policy includes:

- to build up activity centres as a focus for high-quality development, activity and living for the whole community;
- broaden the base of activity in centres that are currently dominated by shopping to include a wider range of services over longer hours, and restrict out-of-centre development; and
- locate a substantial proportion of new housing in or close to activity centres, and other strategic redevelopment sites that offer good access to services and transport.

Higher accessibility to key transport nodes is the key consideration for proponents of the compact city theory (Ewing, 1997; Jenks *et al.*, 1998; le Clercq and de Vries, 2000; Melia *et al.*, 2011; Gaigné *et al.*, 2012) without any thought on freight delivery to service the compact city created. Burton (2000) noted that urban compactness improves public transport use, reduces social segregation and provides better access to facilities. On the other hand, the negative effects of compactness are a reduction in domestic living space, lack of affordable housing and increased crime levels (Chhetri *et al.*, 2013).

In the creation of intensive use of urban land, roads are partitioned to create bicycle paths, dedicated public passenger bus lanes with more controls on LMD vehicles, lowered speed limit, etc. The work of Morris *et al.* (2003) only identified the reason why LMD continues to cycle around as a result of lack of loading space. In addition, the compact city model tends to impede city logistics operations which this study used as an argument for computing transport network LMD impedance levels.

From a measurement perspective, transport network impedance can be a measure of transport distance, travel time, transport cost or the speed of travel if the OD points are known (McNally, 2007; Wang and Hofe, 2010). Alternatively, the impedance to LMD can also be calculated using a range of spatial indicators; in this instance, using the attributes of transport network and urban planning controls. Availability/unavailability of data constraints the usage of such attributes (Novaco, 1990). Road network attributes identified in the literature includes: land use on sides of the road, area type (urban or rural), speed limit (differences), median type, shoulder, intersection type, road volume, number of lanes, lane width, curvature, road conditions, street lightings, pedestrian crossings, vehicle parking, presence of a service road, bike path and bicycle facility, and sight distance among others (Forkenbrock and Foster, 1997; Gülgen and Gökgöz, 2011; Mackaness and Beard, 1993; Li and Choi, 2002, Jiang and Claramunt, 2004; Jiang and Harrie, 2004). Speed limit, vehicle volumes, number of lanes and intersections are important attributes common to the literature.

The number of attributes identified and used by each of the authors depends on the type of study carried out. Forkenbrock and Foster (1997) identified seven attributes relating to road accidents, while the International Road Assessment Programme (2015) broadened the attributes from 7 to 64 to reflect various characteristics of road networks. Li and Choi (2002) identified road hierarchy, length, width, number of lanes, number of traffic directions and connectivity of arcs on junctions as the six major attributes of road network in their study.

In a comparative analysis of road attributes to capture potential impedance to movement of goods, Robert and Rupert (2007) identified road class, road length and centralities of degree, closeness and betweenness in road generalisation process. He and Zhao (2014) identified intersections (traffic lights and roundabouts) and the amount of traffic (traffic volume) as impedance function on distance and traffic in addition to speed. Specifically, however, Luo *et al.* (2015) utilised signalised intersection in their road impedance model.

The selection of attributes hinged on the impact they impose on the movement of LMD vehicles as well as on the availability of geo-referenced digital data. The commonly used transportation network attributes in recent studies as in above included speed limit, traffic light, number of lanes, tram lanes, bus lanes, railway crossing, service lanes and school zones.

In addition to these road network attributes, the characteristics of the built environment and planning controls such as population or dwelling density, proximity to activity centres, land use zoning, land use mix, location within a school zone have been considered in transport modelling (Agunbiade *et al.*, 2012). Despite the wide use of these variables in modelling transport systems, the attributes representing the built or regulatory environment are yet to be spatially integrated in examining transport network behaviour and impedance levels to LMD. A consideration of these attributes will further enhance the overall assessment of B2B LMD literature from an urban planning perspective.

There are often interplay between the built and regulatory environment and LMD provisions. Anderson *et al.* (2005) and Dablanc (2007) identified the controls and restrictions dimensions that hindered LMD. These restrictions create impedance to LMD. The different dimensions (built environment, planning control and transport control) and their measures are conceptually presented in Figure 1.

The built environment is governed by the land use controls and the transport regulations. Specifically, in Victoria, the urban system is governed by the Planning and Environment Act 1997 (The Act), and the National Transport Commission

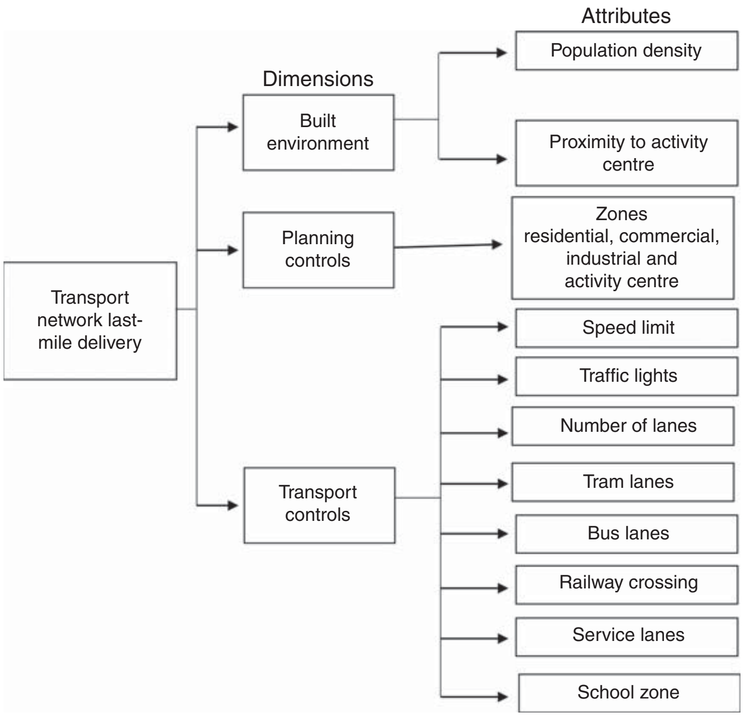

Figure 1.
Key dimensions and attributes underpinning the transport network impedance to last-mile delivery

(Road Transport Legislation – Australian Road Rules) Regulations 2006 – Australian Road Rules. These two policy documents guides urban planning and associated LMD through their legislations and controls.

Planning control is rested on public authorities (municipalities and councils) which Wolpert and Reuter (2012) identified as one major stakeholder in LMD of logistics management. Planning controls here are legislated by the Planning and Environment Act (1997) and implemented through different Local Government Planning Schemes. On the other hand, transport controls are governed by the National Transport Commission Road Transport Legislation – Australian Road Rules Regulations 2006 and Councils local laws.

There has been little intervention by local councils especially in Australia (Casey *et al.*, 2014) to tackle LMD problems. Issues faced by the freight industry are diverse and still not fully understood. Also, problems faced by local authorities are not unique to one country or any specific category of urban area (Ballantyne *et al.*, 2013). In Europe, a large number of policy measures have been used and local authorities are slowly beginning to acknowledge the need to consider freight in their overall transport planning processes (Ballantyne *et al.*, 2013). Local authorities are getting the awareness that LMD planning can be improved by involving a wider range of stakeholders (City of Melbourne, 2015).

The next section presents the research methodology adopted in the study of LMD impedance.

4. Research methodology

4.1 Study area

Maribyrnong City is selected as a case study due to its proximity to Melbourne Port and its identification as a gateway to the western part of Melbourne Metropolitan areas.

The city is experiencing change with significant new residential development now occurring. Maribyrnong City is a "gateway" to Melbourne's western region, sitting between Melbourne's Docklands and port, and the outer western industrial and residential areas. The city, with its land supply, major transport routes and accessibility to the port and airports, is a significant growth area in metropolitan Melbourne. The changing pattern of land use and the extent of new development within Maribyrnong over the past ten years have changed the appearance and form of the city significantly. The dominance of the industrial character and image has receded and the city's "renewal" is bringing about a greater residential character and reputation.

Footscray in Maribyrnong City is one of the target areas, which is a pedestrianised cultural precinct with a mix of retail, manufacturing and knowledge hub. The activity centre zone (Clause 37.08) was introduced into the Maribyrnong Planning Scheme on August 2013. The purpose of the zone among others is to deliver a diversity of housing at higher densities to make optimum use of the facilities and services. This is proposed to allow high rise buildings to accommodate the higher population densities (Maribyrnong Planning Scheme, 2017).

The City's proximity to the Melbourne CBD allows for convenient access to employment, education, retail and business services. The City of Maribyrnong is traversed by several important east-west metropolitan road and rail transport routes. Close proximity to the Port of Melbourne also results in significant adverse impacts on the local community due to increased congestions and heavy truck traffic. Activity centres such as Footscray Metropolitan Activities District and Yarraville are detrimentally impacted by heavy truck movements through and around the centres. Clause 37.08 of the Maribyrnong Planning Scheme introduced the activity centre zone aim at delivering of housing at higher densities towards the development of a compact Footscray Metropolitan Activity Centre.

4.2 Data set

Built environment attributes of population density and proximity to activity centres are identified as major characteristics of a compact city. Planning controls attributes are identified from the Victorian Planning Provisions, while the transport controls are derived from Australian Road Rules (Table I). The different zones (residential, commercial, industrial and activity centre zones) and particular provisions of loading and unloading are the planning controls as contained within the Victoria Planning Provisions. These two attributes can directly impact the LMD. The type of zone influences the hierarchy of roads (Eppell *et al.*, 2001). The hierarchy of roads within these zones subsequently determines 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 LMD positively or negatively.

Within the transport system, attributes identified are from the Australian Road Rules (2006) and include: speed limit, traffic lights, number of lanes, tram lanes, bus lanes, railway crossing, service lanes and school zones.

Data used are extracted from VicData spatial layer in Shape file (SHP) format. The spatial data are then used to compute and visualise transportation network LMD using the geographical information system (GIS). GIS is a computerised data management system used to capture, store, manage, retrieve, analyse and display spatial information. The spatial dimension makes GIS highly applicable to the examination of topological accessibility in a system of nodes and paths – that is, a transport network – and contiguous accessibility, a measureable attribute of location (Maguire *et al.*, 2005).

The types of variables and measurement units of each attributes including the impact of different sets of attributes on transportation network LMD are assessed through literature review discussed in Section 3 and listed in Table I. This provided multi-dimensional analysis and graphical output capabilities that can result in more effective LMD decisions.

Systems/dimensions	Attributes	Impact on LMD	Key studies
Built environment	Population density	−	Burton (2000), Jenks *et al.* (2008), Eppell *et al.* (2001), Chhetri *et al.* (2013)
	Proximity to activity centres	+	Ewing (1997), Jenks *et al.* (2008)
Planning system/controls	Zones Activity Centre Zone	−	Victoria Planning Provisions
	Overlays Parking (loading and unloading)	+	Victoria Planning Provisions; Morris *et al.* (1999, 2009)
Transport systems/controls	Speed limit	+	Eppell *et al.* (2001), International Road Assessment Programme (2015)
	Traffic light	−	He and Zhao (2014), Luo *et al.* (2015)
	Number of lanes	+	Forkenbrock and Foster (1997), International Road Assessment Programme (2015), Li and Choi (2002)
	Tram lanes	−	National Transport Commission Regulations (2006)
	Bus lanes	−	National Transport Commission Regulations (2006)
	Railway crossing	−	National Transport Commission Regulations (2006)
	Service lanes	+	Forkenbrock and Foster (1997), International Road Assessment Programme (2015), Jiang and Claramunt (2004), National Transport Commission Regulations (2006)
	School zone	−	International Road Assessment Programme (2015), National Transport Commission Regulations (2006)

Table I. Built environment, planning system and transport system attributes

Data representing each of the attributes were downloaded for geo-processing, mapping and visualisation using data management tools in MapInfo.

A total of 134 road segments are identified within Maribyrnong City. These roads are highways and known as "VicRoads declared roads" on the VicData spatial layer. These roads are important routes for LMD vehicles. None of the roads considered is residential. Council "No Trucks" restrictions are not placed on these roads. Analyses and mapping are carried out on roads using MapInfo GIS software.

4.3 Research framework

The research methodology used for this paper consists of four stages.

4.3.1 Stage 1: identification of the key attributes of last-mile impedance. Stage 1 identified the key attributes that impede LMD in cities. These attributes are categorised into three groups: built environment, transport network and planning controls. The attributes includes zoning and particular provisions (planning system) and speed limit, road width number of lanes, tram lanes, traffic light and service lanes (Table I). Figure 2 shows the spatial variability in speed, traffic lights, location of activity centres and tram lanes within the Maribyrnong City. The activity centres includes Footscray Metropolitan Activity Centre, the Highpoint Activity Centre, Central West Major Activity Centre in Braybrook and the Neighbourhood Activity Centres of Yarraville, Seddon West Footscray and Edgewater.

4.3.2 Stage 2: standardisation of attributes and assessment of attributes for their potential impact on last-mile impedance. Stage 2 involved the standardisation of attributes and assessment of attributes for its potential impact on last-mile impedance.

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 (Blind, 2004). Data are standardised using the

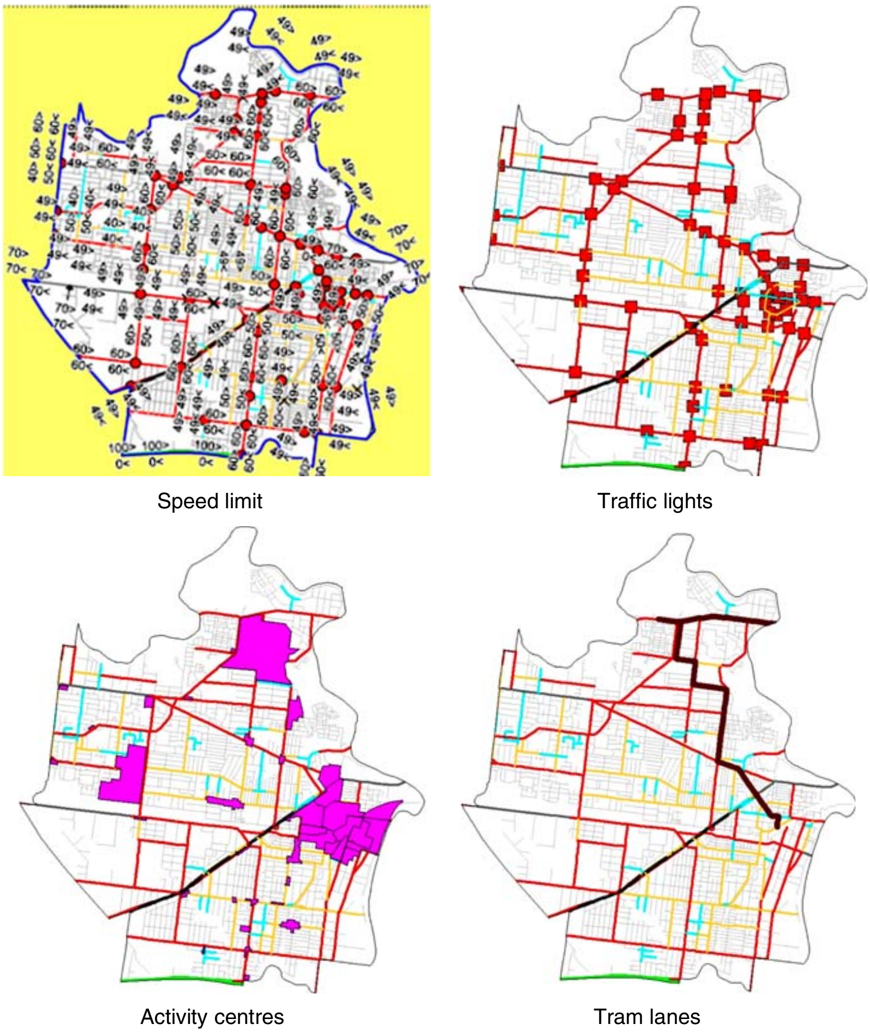

Figure 2.
Visual representation of the speed limit, traffic lights, location of activity centres and tram lanes within the Maribyrnong City

maximum-minimum procedure. While average values derived from the buffer (5, 10 and 20 metres) around attributes like proximity to activity centre, tram lanes, planning zones, bus lanes, railway crossing, school zones are used, the values derived for speed limit (in kilometre per hour) and population density (per square kilometre) are taken from spatial join.

The new set of values were then 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, which is given as:

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

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 was reversed for data variables, which have a negative impact on LMD. For these variables, the formula is:

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

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

4.3.3 Stage 3: development of the transport network impedance index to LMD. Once the data variables was standardised, a composite index was applied to define the mathematical function, whereby each of these layers are added and divided by the total number of layers. The formula for composite index described as follows:

$$\text{Transport network impedance} = V_1 + V_2 + V_3 + \ldots . V_n$$

4.3.4 Stage 4: mapping of the last-mile network impedance. Stage 4 proceeded to mapping of the last-mile network impedance. Mapping of the transportation network last-mile network impedance was carried out using GIS tools. An overlay function was employed to generate a new layer of transport network impedance to LMD. Impedance levels are mapped across the road network of the Maribyrnong City using a thematic mapping technique to classify networks into three categories. Visualisation enables the key transport hotspots of high LMD to be identified. Based on the mapped outputs, a new logistics zoning system is developed to demarcate areas of high impedance to help improve the efficiency of LMD to retail businesses within the City.

5. Results and analysis

The results of the levels of transport network impedance to LMD are shown in Figure 3. The analyses revealed significant differences in transportation network impedance levels across Maribyrnong in Melbourne City. This spatial variability indicated the differences in network capacity and planning controls imposed through land use regulations. The potential last-mile impedance on transport network is estimated and mapped, which reveals that different segment of the transport networks have different impedance scores, which are attributed to hindrances imposed to movement.

There are no specific provisions for loading and unloading along transportation network corridors beyond the requirements for individual development as provided under Clause 55.28 (loading and unloading) of the Victoria Planning Provisions. This might explain why there are high transportation network LMD impedance along Sunshine Road and Gordon Street.

The calculated potential LMD impedance scores are categorised as high, medium and low. Overall, a higher percentage of the road network presented a medium impedance level. Network with low impedance remained restricted to areas with lesser number of intersections, and traffic lights. Of all the roads segments, 34 (25.37 per cent), 72 (53.73 per cent) and 28 (20.9 per cent) accounts for high, medium and low impedance index, respectively (Figure 3).

Higher levels of impedance are registered in the Footscray Central Activity Centre, which represents high density living and mixed land use. In particular, the northern part of the centre which currently experienced high population growth has returned a high impedance level. This is despite the fact that the proposed population density increase within the activity centre in accordance with the policy direction of Clause 37.08 of the Maribyrnong City Planning Scheme is yet to take full effect.

High transportation network LMD impedance index are revealed within the higher population density areas which are established residential area zoned residential (general residential zone and neighbourhood residential zone). Overall, 75.4 per cent of the road segments within these area represented high and medium population density. Only 24.6 per cent are of

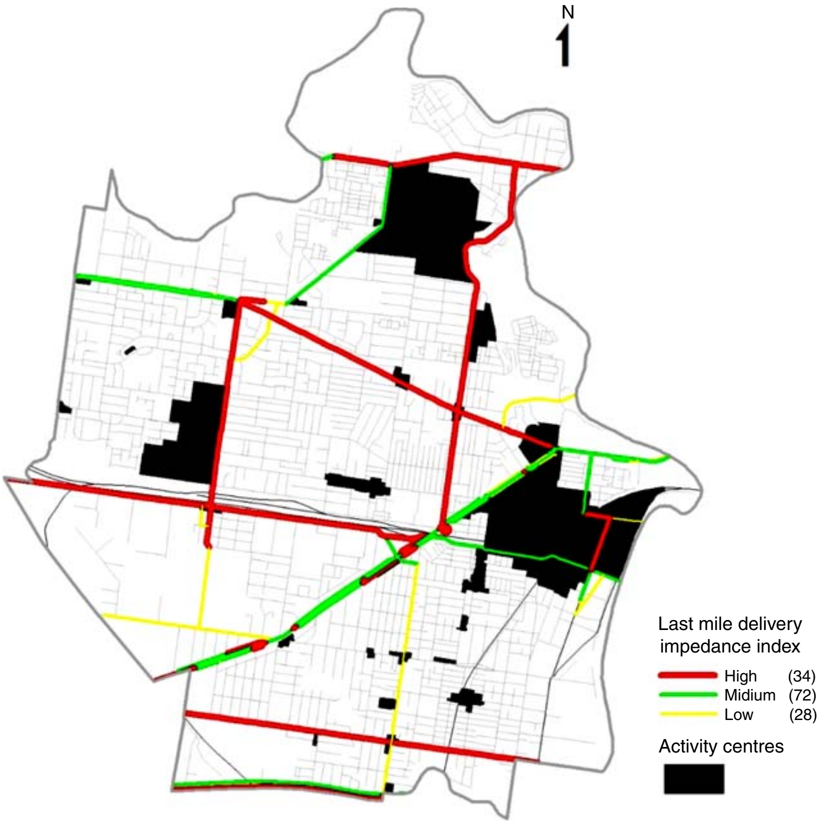

Figure 3.
Last-mile delivery transportation network impedance index

low impedance scores. This might be linked to the proximity factor as Maribyrnong City is located within 9-15 kilometres and between 10 and 20 minutes travel time to Melbourne CBD, making the freight transiting through the council to experience higher impedance.

Overall, Gordon Street, Ballarat Road, Raleigh Road, Francis Road and Whitehall Road, Sunshine Road, and Ashley Street are of high impedance levels (shown in precinct level maps in Figure 4) as they attract significant number of heavy trucks that operates along these routes. Gordon Street is further congested because of tram lanes that run along the street, connecting Footscray Activity Centre to Highpoint Shopping Centre. Specific LMD strategies including clearway and delivery corridors to address movements of trucks with the city are lacking.

In addition, the areas are in proximity with the Port of Melbourne and warehouses serving the western suburb of Melbourne. These road networks traverse through residential developments with reduced speed limit, prevalence of railway crossings and overhead bridges (from train tracks), truck restrictions, higher traffic light density and bus lanes, and lacks service lanes. Specifically, Sunshine Road and Ashley Street are characterised by single lane width, and traffic lights, which impede the delivery of goods within the inner city locations (Figure 4).

In contrast, roads segments that reveal medium and low transportation network impedance levels are characterised with few intersections and traffic lights. In addition, these routes do not have any major shopping strip, tram lanes and less bus lanes/stops.

With increased density in urban economic space, the costs and lead times of LMD would increase (Boyer *et al.*, 2004). Mapped transportation networks in Maribyrnong City exhibit

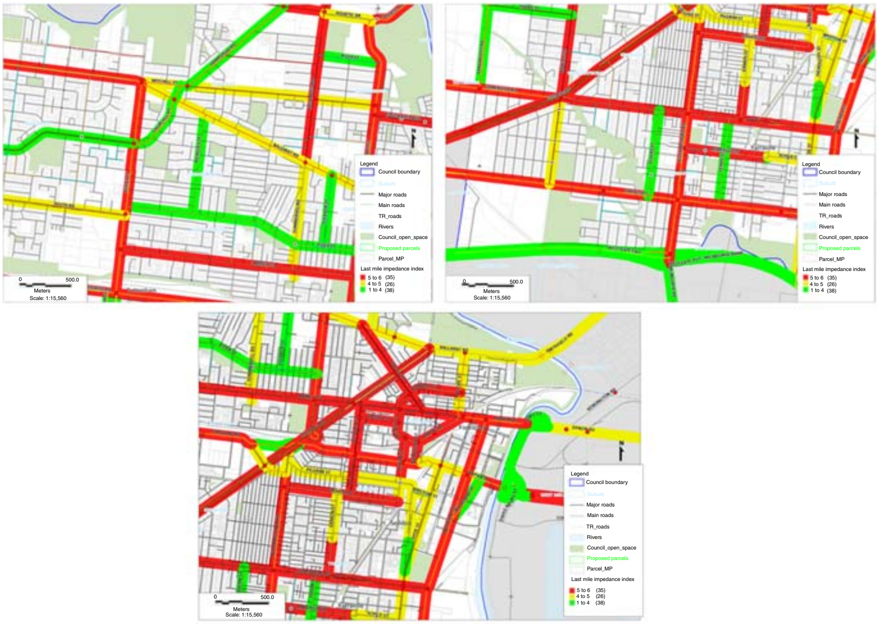

Figure 4. Localised representation of transport network impedance to last-mile delivery

different levels of potential transportation network impedance to LMD. Some links in the network impede LMD more than others. The efficiency of last-mile logistics thus varies across different parts within the city and over different times of the day.

6. Strategies to mitigate LMD transportation network impedance

More geo-targeted strategies to mitigate potential transport delays or increased delivery costs are required to tackle the potential challenges associated with higher transport network impedance to LMD. Strategies to mitigate risk and to improve delivery lead-time to retail businesses, particularly in the CBD or activity centres could include regulatory measures, techno-institutional reforms, infrastructural improvement or operational alignment. In this study, three key spatially explicit strategies are suggested, which could be considered by the local government, industry and the community to help manage the provision of city logistics with particular reference to LMD. Figure 5 schematically presents the spatial plan to illustrate various aspects of these strategies:

(1) Land-use zoning strategy requires demarcating LMD logistics zones to differentiate the levels of freight movements and operational requirements along activity centres especially within the Footscray Metropolitan Activity Centre. Such should include designation of off-street loading and unloading provision into the Victorian Planning Provisions and in the Maribyrnong Planning Scheme. Strict adherence to the loading and unloading provision (Clause 52.08 of the Victoria Planning Provision) and introduction of loading overlay is a necessary step that needs serious consideration. The logistics zoning system can be developed to demarcate zones representing different levels of last-mile transportation network impedance to freight flows to help improve the efficiency of LMD to retail businesses within the council especially between the proposed Urban Distribution Centre (UDC) and the Footscray Metropolitan

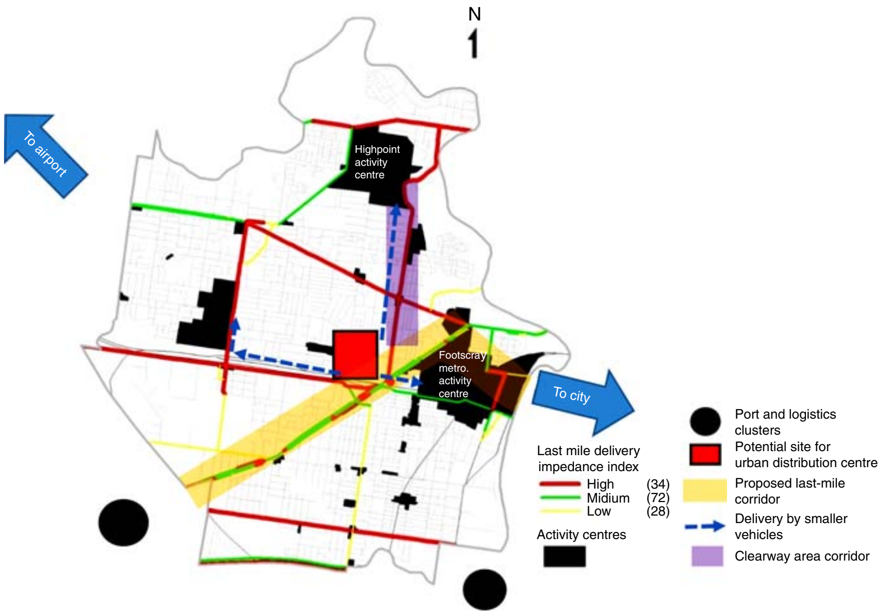

Figure 5.
Spatial plan to augment the efficiency of last-mile delivery in Maribyrnong

Activity Centre and the Highpoint Activity Centre. In addition, the designation of off-street loading/unloading and curb side loading zones including cut-outs of wide sidewalks for delivery is important in this strategy.

(2) Last-mile corridor strategy can be implemented along the main arterial networks through a linear freight route to improve last-mile efficiency between key business hubs (Boyer *et al.*, 2009; Srai and Harrington, 2014). The use of such dedicated delivery corridor including time-window-based loading/unloading will help reduce the environmental footprint of LMD, ease traffic bottlenecks and user conflicts between LMD trucks and other road users. Designation of last-mile corridor will also reduce LMD operational costs. Certain vehicles may be allowed in specified zones of the Footscray Metropolitan Activity Centre only at specified times, or they may simply be excluded from an area all together. These strategic routes especially along Hopkins, Barkly and Irving Streets can be made clear during the peak hours via implementing a clearway policy where no parking is permitted along the road side or curb.

    Optimisation of LMD networks within the Footscray Metropolitan Activity Centre in inner city region can potentially solve problems caused by increased commercial vehicle movements (Fusco *et al.*, 2003; Taniguchi *et al.*, 2003). Multi-use lanes for LMD and off-peak delivery can be included more specifically for loading and unloading of freight within the city centre at specific hours of the day. Off-peak hour and night delivery should involve silent trucks to operate within the city centre in late hours to avoid road congestion and manage noise pollution.

    The Somerville Road and Rosamond Road can be dedicated a clearway area corridor to facilitate delivery between Footscray Metropolitan Activity Centre and the Highpoint Activity Centre.

(3) Distribution network strategy: this strategy holistically integrates people, facilities and transportation infrastructure as a single unified logistics system to enhance

LMD efficiency. The development of Urban Distribution and Consolidation Centres closer to the Activity Centres of Footscray and Highpoint will help improve coordination and reduce the number of trucks driving into or through the activity centres. Freight can be directly shipped to and from the distribution centres through single tier or two-tier “carrier systems”.

Establishing the distribution centres near the rail route will provide opportunities for the use of available train services for delivery and intra-modal transfers between the distribution centres and the retailers – final destination (Toth and Vigo, 2002; Lee and Jeong, 2008; Crainic *et al.*, 2009). Efficient functioning of UDC, however, necessitates logistics collaboration between key stakeholders which should be based on openness, risk sharing, mutual trust and shared reward to help mitigate potential delay in delivery of goods in the last-mile component of the supply chain (Naesens *et al.*, 2009; Lindawati *et al.*, 2014; Park *et al.*, 2016).

At the distribution centres, goods can be de-bundled, reorganised, stored and redistributed via a more sustainable form of transportation within the city centres and activity centres. The delivery from the distribution centres can be carried out through the use of electric vehicles and manual cargo bike. Where a permanent distribution centre is not appropriate or less desirable, a mobile depot can be establish to distribute goods with greater agility to adapt to shifting demand over time and space and changing traffic conditions (Bailey *et al.*, 2014). Footscray Market and the Little Saigon Market can take advantage of this type of delivery.

Figure 5 presents potential location of UDC. The location is selected given the availability of space, proximity to Footscray Metro Activity Centre and adjacency to railway line to help encourage the use of multi-modal transport in tackling future growth in freight volume emanating from the Port of Melbourne (Toth and Vigo, 2002; Lee and Jeong, 2008; Crainic *et al.*, 2009). From the UDC, freight to the Footscray Metropolitan Activity Centre and the Highpoint Activity Centre can be sustainably distributed out via smaller non-motorised mode like a cargo bike.

7. Conclusion

The “last-mile” logistics in cities is becoming increasingly complex. As global sourcing and online shopping expands, last-mile logistics of both inbound and outbound commodity chains within cities will become increasingly difficult for retailers to manage the growing demand for fully integrated omni-channel retailing. Urban restructuring and growing compactness of non-residential areas affect the capacity and utilisation of transportation infrastructure, which further reinforce the need to enhance the efficiency of LMD. One way to mitigate the risk of last-mile delays is to reduce the transportation network impedance to freight movement on transportation network.

This study computed and mapped the potential transport network impedance levels to LMD using spatial measures representing transport attributes and planning controls. A four-stage methodology is implemented in this study. It includes the identification of the key attributes of last-mile impedance, standardisation of these attributes, development of the last-mile transportation network impedance index and, finally, mapping of the last-mile network impedance levels using GIS tools.

The key results from this study show the significant spatial variation in transportation network impedance to LMD across different parts of the road network. Notable differences were detected along road segments that connect industrial areas or activity centres especially along tram routes, and freight corridors connecting the Port of Melbourne and warehousing industrial district with the airport and Western Ring road. In addition, the level of transport network impedance within the Activity Centres, retail zones and pedestrianised streets tends to be relatively moderate to high. It can be implied that more compact areas of Maribyrnong City tend to have some association with the inefficiency of LMD.

Three key spatially explicit strategies are recommended to tackle the challenges of last-mile logistics. These include logistics zoning strategy, last-mile corridor strategy and adaptive distribution network strategy. Based on mapped outputs, a new logistics zoning system can be introduced and legislated to demarcate logistics zones to differentiate the scale and intensity of freight movements. A parking clearway rule can be implemented in strategic routes to reduce the traffic bottleneck in peak hours. Traffic diversion technique to traffic flows can also be deployed to divert freight traffic from more congested routes to low transportation network impedance routes. These strategies can be implemented to reduce transport network impedance to LMD to help enhance the efficiency of LMD within a compact city. However, an efficient LMD hinges on the support from all stakeholders which includes public authorities, private operators and the local community (Gammelgaard, 2015; Macharis *et al.*, 2014).

This study has three key limitations. First is the dearth in LMD data which has restricted the level of analysis presented in this study. Integration of OD fright data, for instance, would enable estimating the actual transportation network impedance to LMD. Second is the use of static measures of transport and urban planning which reduced the robustness of the transportation network impedance index. Integration of dynamic and real-time business-to-business LMD of goods in the cities is critical to indexing impedance levels. Finally, the spatial approach adopted in this study is valuable for generating evidence for broader urban planning at metropolitan level, but its use is somewhat limited to assist in daily logistics operational planning and scenario-based decision making. Further research is needed to examine the competitiveness of different types of LMD modes (i.e. collection-and-delivery points (CDPs), attended-home delivery (AHD) and reception box (RB)).

Future research will specifically tackle the limitations of this study. It will incorporate fleet movements GPS logged data coupled with integrated technologies such as cloud-based solution combined with mobile applications and internet of things to connect transportation and warehouse management systems with vehicle sensors and other integrated devices. This will help estimating the impedance to LMD in real time.

Future research will also consider several factors when applying innovative strategies to optimise LMD. LMD options can be formulated to adjust changing consumer demand which often requires a trade-off between flexibility, security, speed and cost of delivery. The effectiveness of different types of LMD modes (i.e. CDPs, AHP and reception box) in different urban contexts will also be evaluated. Innovative strategies to optimise LMD will be developed and tested to assess the LMD performance across different urban designs and planning options.

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