The Relationship between Pedestrian Connectivity and Economic Productivity in Auckland's City Centre. Second Edition. Network Scenarios Analysis

Mehrnaz Rohani and Grant Lawrence

November 2017 Technical Report 2017/007-2

Auckland Council
Te Kaunihera o Tāmaki Makaurau

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Executive summary

City centres are important to the economic prosperity of cities and nations. High concentrations of people, firms, and activities enable ideas and knowledge to be generated and easily shared. Much of this transferring of ideas and knowledge takes place face-to-face. There is a strong relationship between connectivity[1] and productivity. This relationship is referred to as agglomeration economies.

This report describes the value of walking (pedestrian connectivity) to the Auckland city centre's economy. Quantifying the economic benefits of walking to Auckland's city centre is one of several work streams to inform the Auckland Design Office, Auckland Planning Office, Auckland Transport, Panuku and Auckland Tourism, Events and Economic Development's work.

This is the second version of the report published in March 2017[2] and it includes four changes:

- The network scenarios analysis is now included.
- The expansion area's analysis, as a secondary part of the study, available in section 4 of the March version, was replaced with the scenario testing in this report.
- The pedestrian network was updated based on some real life movement assumptions resulting in a minor change to the result of the total Effective Job Density (EJD) and its association with labour productivity.
- A revised list of references.

Methodology

The methodology used in this study is conceptually consistent with established practices for estimating the impact of transport and land use projects on economic outputs both in international and New Zealand literature (e.g. New Zealand Transport Agency, 2016; SGS, 2012; Maré and Graham, 2009; Graham et al. 2009 and Maré, 2008).

It builds on a 2014 study on the relationship between walkability and economic productivity in the Melbourne city centre (SGS, 2014). The 2014 study measures the density and connectivity of jobs in Melbourne's city centre and examines the relationship to firms' productivity.

The density and connectivity of jobs (EJD) in the Auckland city centre is measured and compared with labour productivity. Connectivity is measured by the walking distance and

[1] This can be both physical and technological. The focus of this study is on physical connectivity.

[2] Rohani, M. and Lawrence, G. (2017). *The relationship between pedestrian connectivity and economic productivity in Auckland's city centre*. Auckland Council technical report, TR2017/007.

travel time between jobs incorporating traffic signal delays, pedestrian path types and deviations from a direct path.

The contribution of pedestrian connectivity to agglomeration economies was investigated using the relationship between walking EJD and labour productivity. Then, two high connectivity scenarios were tested to examine the impact of changes in pedestrian connectivity on Auckland's city centre economy.

Scenario one is a high connectivity scenario consisting of three subsets, each representing a different type of intervention to the pedestrian network, in different parts of the study area. The three sub scenarios include, additional through block links, a complete laneway network and improving permeability along Shortland Street.

Scenario two is positioned along Queen Street, the main street in the middle of the study area where a shared space has been proposed in conjunction with a light rail network (not tested). The shared space runs the length of Queen Street from Wellesley St to Quay Street.

Results

The research suggests that walkability within the Auckland city centre is likely to make a positive contribution to economic productivity. The results are consistent with the hypothesis that better pedestrian connections can increase the potential for agglomeration economies.

Auckland city centre plays a large role in both the regional and national economy. In 2015, the city centre contributed an estimated $16 billion to GDP (in constant 2010 dollars), accounting for 20 per cent of Auckland's GDP and seven per cent of New Zealand's GDP. The city centre contributes more to the national GDP than all but three other New Zealand regions: Canterbury (14% of national GDP in 2015), Wellington (14%), and Waikato (8%).[3]

This study concludes that there is a positive and statistically significant association between walking EJD and estimated labour productivity within the Auckland city centre, findings which are consistent with other studies (e.g. 2014 Melbourne city centre). Locations that are more walkable tend to have higher productivity. This relationship is robust with the inclusion of controls for estimated industry composition at a building level, suggesting that it does not simply reflect the fact that higher-productivity industries choose to locate in more walkable places.

Improving pedestrian connectivity through changes to light phasing and/or changes to the physical network, and consequently EJD improvement means decreases in time spent walking in the study area, enhanced face-to-face interactions and knowledge exchange.

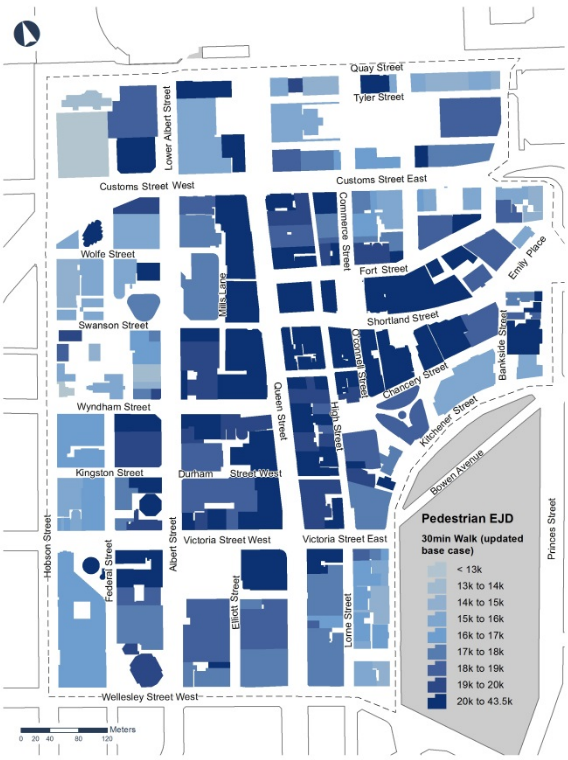
[3] http://www.stats.govt.nz/browse_for_stats/economic_indicators/NationalAccounts/RegionalGDP_HOTPYeMar15.aspx

This causes agglomeration effects to occur and potentially increases labour productivity and economic outcomes.

The research also found that within the city centre, there were significant variations in walkability, employment density, and industry composition. Employment data and walkability modelling show that:

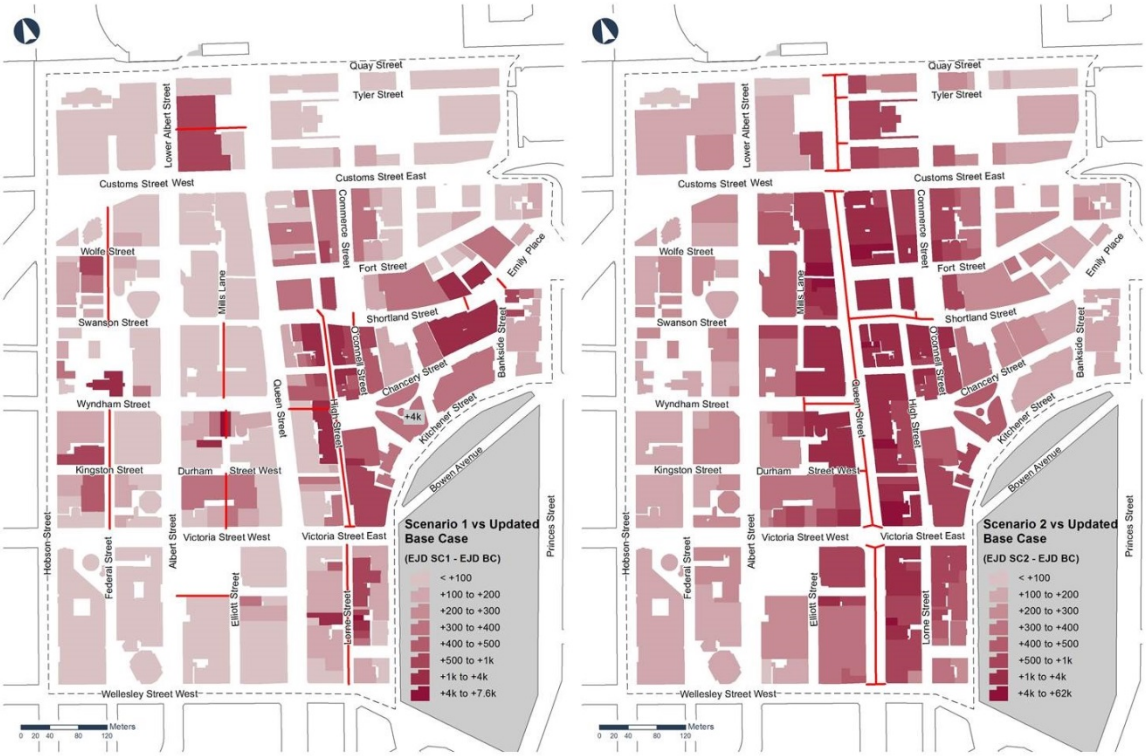
- The effective density of jobs by walking varies significantly within the study area. It is highest along Queen Street and Shortland Street, and generally drops off with increasing distance from these locations (Figure A).
- Retail is concentrated in the centre of the study area along Queen Street with high walking connectivity. This is likely to reflect the importance of accessibility and visibility to customers for retail businesses.
- The high productivity service industries - including finance and insurance services, administrative and support services, and professional and scientific services - are more dispersed throughout the area. Large finance companies are located in the northern half of the study area near Britomart, while administrative and support service firms are largely located in the south-eastern quarter of the area.
- The results of network scenarios assessments show that shared spaces would add higher value to the city centre’s economy compared to other changes in the network (Figure B). This impact is more significant when the shared space is centrally located which would allow for higher connectivity and greater impact on the surrounding network.

Figure A: Walking effective job density (updated base case)



Source: Authors' estimates

Figure B: Scenario 1 (left) and 2 (right) EJD index compared to the base EJD index



Source: Authors' estimates

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1.0 Introduction

This research examines the impact of walking connectivity on agglomeration economics. It is also the first study on agglomeration effects using fine geographic units. This is the second version of the report published in March 2017[4]. Compared to the previous version this report includes following changes:

- The network scenarios analysis is the main focus of publishing a new version of the report.
- The expansion area's analysis, as a secondary part of the study available in section 4 of the March version, was replaced with the scenario testing in the current report.
- The pedestrian network was updated based on some real life movement assumptions. It caused a minor change to the result of the total Effective Job Density (EJD) and its association with labour productivity.
- A revised list of references.

There is a positive relationship between connectivity and economic productivity. This relationship is referred to as agglomeration economies. Agglomeration economies arise when firms are more efficient by serving a larger number of users, or there is a positive spillover between firms, workers, or residents located close to each other. In other words, firms located in dense business districts where ideas and knowledge are easily shared via personal networks and face-to-face communications achieve additional economic advantage as they are more productive SGS (2014).

It is well established (Killer et al., 2013; Chatman and Noland, 2011; Graham and Dender, 2011 and Graham, 2007b) that transport infrastructure such as roads, railways, cycleways and pedestrian walkways can support the dynamics of urban agglomeration by enabling increased interaction between firms and workers. There are established procedures for estimating the impact of new roads and railways on economic productivity at the regional or inter-regional level. However, the role of walking in supporting agglomeration economies is not as widely understood.

Walking facilitates personal and business networking. Attractive public spaces and walkable streets create an environment for business and social exchange and support knowledge diffusion. Walkability is described as one of the central factors in six of the eight transformational shifts of the Auckland City Centre Masterplan (ACCM). For example, The East-West Stitch: Connecting the Western Edge of the

[4] Rohani and Lawrence (2017).

City to the Centre proposes a series of interventions to improve walking conditions and the public realm between the Queen Street Valley and the Victoria Quarter.

The Auckland Plan (2012) emphasises that Auckland productivity could improve through a number of avenues including improving transport links, and facilitating geographical clustering to achieve economies of scale.[5] The economies of scale and connectivity effects of Auckland's city centre will lead to agglomeration and productivity gains for Auckland's businesses and prosperity for the whole region (City Centre Master Plan, 2012).

Exploring the connectivity of firms through pedestrian networks and the value to Auckland city centre's economy will help decision makers to understand both the costs of disturbing infrastructure (e.g. long delay pedestrian crossings) and the benefits of improved walking conditions. Therefore, this project seeks to understand the value of walking to the city centre's economy. This research represents one of several work streams to quantify the economic benefits of walking by the Auckland Design Office within Auckland Council. The project is also of interest to Auckland Planning Office, Auckland Transport and Auckland Tourism, Events and Economic Development.

This report examines the dynamics of agglomeration economies in Auckland's city centre by replicating and improving on a pedestrian analysis methodology developed for the Melbourne city centre by SGS (2014)[6]. This methodology measures the density and connectivity of jobs within dense city centre environments and examines the relationship to firms' productivity. The SGS methodology is applicable to Auckland's city centre, where pedestrian accessibility is also affected by the natural setting and transport infrastructure in the area.[7]

Auckland's city centre in this study is defined as an area of three census area units (CAUs) within the Central Motorway Junction; namely Auckland Central West, Auckland Central East and Auckland Harbourside. The city centre is the hub of knowledge intensive industries in Auckland. In total 110,126 employees, or one in seven Auckland employees, work in Auckland's city centre.[8] It is the densest employment area in New Zealand with 277 workers per hectare.

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[5] "Auckland's productivity must improve. The Auckland Council and central government can support businesses to improve productivity by creating the right business environment, and working with firms to overcome barriers to productivity growth. These actions may include providing appropriate policy or regulatory settings, improving transport links, and facilitating geographical clustering to achieve economies of scale."(Auckland Plan, 2012. p.154).

[6] The SGS (2014) model used in this study designed a single variable correlation method. There are a range of other unobserved factors that may affect productivity, including proximity to other transport facilities and a range of unobserved factors that may arise at the local level.

[7] Both cities' transport systems are mostly dominant by road network.

[8] Infometrics, regional employment data and customised meshblock level data (2015).

The contribution of pedestrian connectivity to agglomeration economies was investigated using the relationship between EJD and labour productivity. Then, two high connectivity scenarios were tested to examine the impact of changes in pedestrian connectivity on Auckland's city centre economy. The first scenario (one) was broken down into components to better understand the influencing factors. The scenarios were developed by the Auckland Design Office within Auckland Council and depict potential interventions to improve walking accessibility.

This report is structured as follows:

The rest of section 1 describes the theory of the relationship between improved walkability and the economy and describes the Auckland city centre's economy.

- Section 2 outlines the methodology including the definition of the study area, data collection on employment location, and modelling of pedestrian travel time between city centre locations.
- Section 3 examines the dynamics of agglomeration economics and the relationship between walkability and productivity of firms in the city centre.
- Section 4 examines the impact of changes in pedestrian network scenarios on the city centre's economy.
- Section 5 concludes the report and makes recommendation for future research.

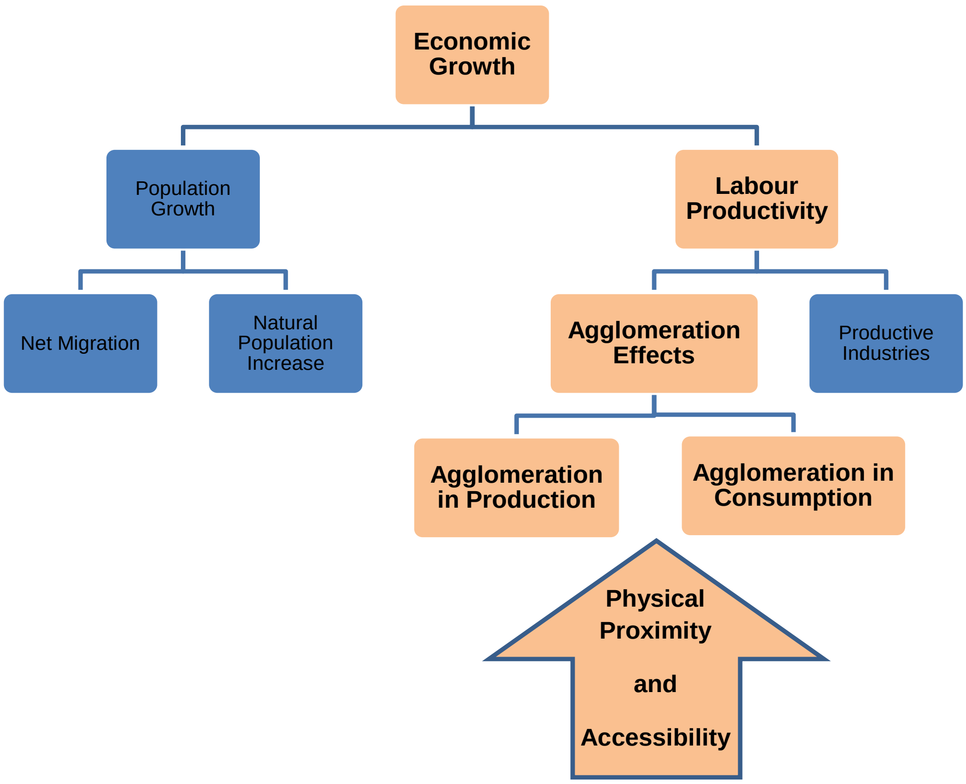
1.1 Theory of the relationship between walkability and the economy

The relationship between connectivity or accessibility, i.e. walkability, and economic output can be defined through agglomeration economies and their impact on labour productivity.

Changes in economic output can be measured by changes in the market value (inflation adjusted) of goods and services produced by the economy. Gross Domestic Product (GDP) is a common measure of aggregate economic activity. Labour productivity and the size of the labour force; determine the potential long-run economic growth (Economic Quarterly, January 2013).

Accessibility in this study is defined as face-to-face interactions through walkability between firms, employees, and customers which can result in higher productivity or improved consumption opportunities. Agglomeration economies arise when it is cheaper or more efficient to serve a larger number of users, or there is a positive spillover between firms, workers, or residents located close to each other (MRCagney, 2016). Figure 1 visualises the relationship between changes in physical proximity and accessibility and economic growth.

Figure 1: Relationship between connectivity and the economy



Source: Authors' estimates

There are a number of methods to measure the potential for agglomeration economies. This report employs a standard measure of agglomeration called effective job density.

1.2 Effective job density

Effective Job Density (EJD) measures the number of jobs accessible from a particular location weighted by travel time (Maré and Graham, 2009; SGS, 2014). Following Graham (2005), EJD is calculated as follows:[9]

$$EJD_i = \frac{E_i}{\left(\sqrt{Ai/\pi}\right)^{\alpha}} + \sum_j \frac{E_j}{d_{ij}^{\alpha}}$$ **Equation 1**

Where;

EJD_i = is the effective job density of jobs in location i

E_i = is employment in location i (origin)

E_j = is employment in location j (destinations)

A_i = is the land area of area i

$\sqrt{Ai/\pi}$ = is an estimate of the average distance between jobs within area i

α = is distance decay

The distance decay parameter reflects the fact that employment in the immediate neighbourhood of a firm may have a larger effect relative to employment located further away. The larger the value of distance decay, the more rapidly the potential effect of employment diminishes with distance.

Graham et al. (2009) estimated distance decay factors (α) for four broad sectors of the United Kingdom economy: manufacturing (1), construction (1.6), consumer services, i.e. retail, (1.8) and business services (1.8). Their study suggests that the effects of agglomeration diminish more rapidly with distance from the source for service industries and their relative impact of agglomeration on productivity is larger

[9] SGS (2014) used another measure of EJD which is recommended by NZTA (2016).This equation includes the density of the origin area as well as the destination area. The other EJD measure used by SGS (2014) and suggested by NZTA (2016) is designed for larger scale areas (e.g. cities) than the census meshblocks that are used in this study.

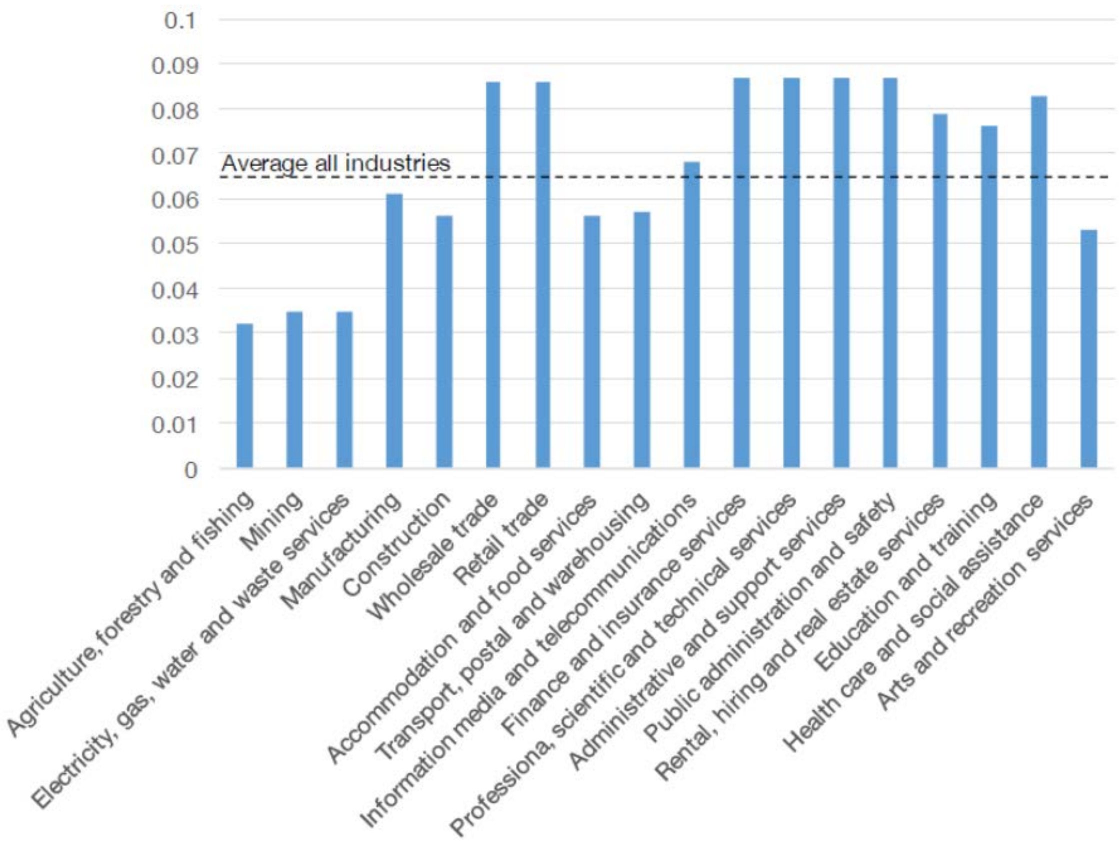
$$EJD_i = \sum_j \frac{E_j}{AGC_{ij}^{\alpha}}$$

Where;
AGC_{ij} = is the average generalised cost

than it is for manufacturing and construction. In SGS (2014) the distance decay has not been shown in the EJD equation and we assume it was set to equal to 1.

The relationship between EJD of jobs in different locations and the productivity of firms in those locations, in the New Zealand context, was studied by Graham and Maré (2009). Their result of average agglomeration elasticity for New Zealand industries (0.065) indicated that a 10 per cent increase in effective density results in a 0.65 per cent increase in GDP per worker or in other words, productivity. The elasticities vary significantly between industries with the lowest in agriculture (0.032) and the highest in finance and insurance services (0.087). Figure 2 shows the various agglomeration elasticities within New Zealand industries.

Figure 2: Agglomeration elasticities in New Zealand

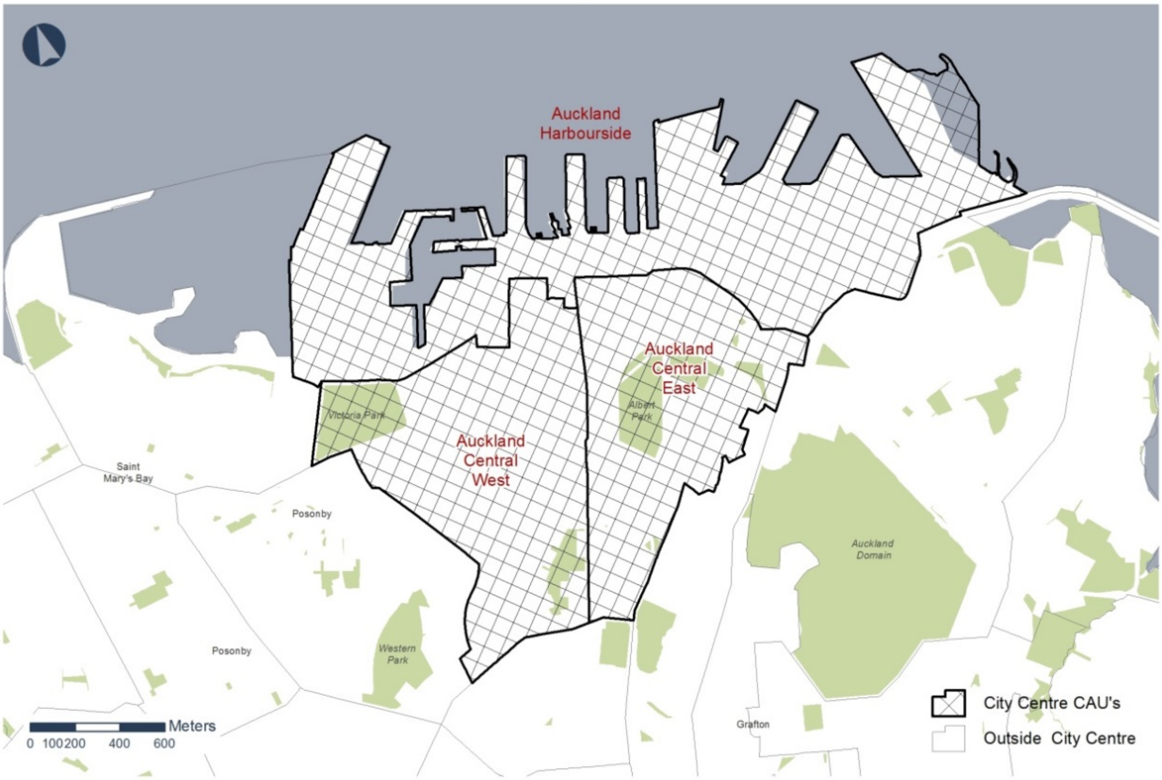


Source: Adapted from Nunns (2016), NZ Transport Agency (2016)

1.3 Auckland city centre's economy

This section provides a summary of two main elements of economic growth in Auckland's city centre, the size of the labour force and labour productivity. The city centre in this study is defined as an area of three census area units (CAUs) in Auckland; namely Auckland central west, Auckland central east and Auckland Harbourside (see Figure 3).

Figure 3: Auckland city centre as defined in this study



Source: Statistics New Zealand (2013)

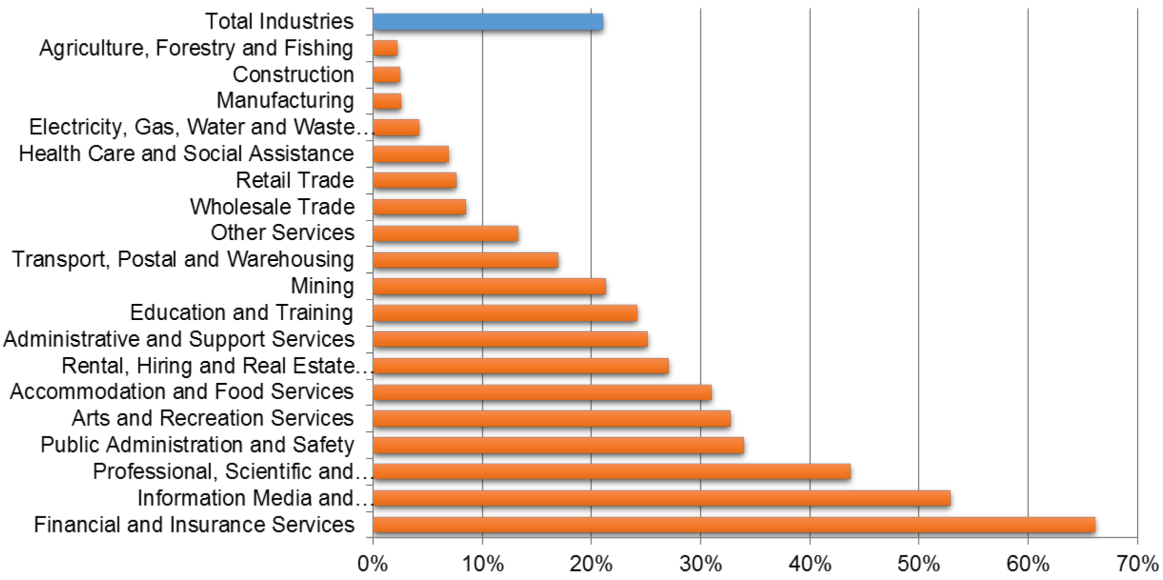
Auckland city centre comprises 0.08 per cent of the overall area of Auckland, but includes 14 per cent of the region's employment (110,126 of 787,500).[10] It is the hub of knowledge-intensive industries, i.e. those industries that tend to cluster in cities and depend on skilled labour, with high shares of Auckland's employment in financial (66%), media (53%) and professional services (44%). The Auckland city centre contributes more to national GDP than all but three other New Zealand regions; Canterbury (14% of national GDP in 2015), Wellington (14%), and Waikato (8%).[11]

[10] Infometrics, regional employment data and customised meshblock level data (2015).

[11] http://www.stats.govt.nz/browse_for_stats/economic_indicators/NationalAccounts/RegionalGDP_HOTPYeMar15.aspx

Figure 4 shows the share of the Auckland region's employment in the city centre by industry. Note that employment in 'agriculture and mining' in the city centre is made up of office-based employment (e.g. head offices services).

Figure 4: Share of Auckland region's employment in the city centre by industry (2015)



Source: Authors' estimates based on Infometrics customised (2015) data

There is no official data that relates specifically to the city centre's GDP or productivity. Infometrics' estimate of Waitematā Local Board GDP is the most detailed available data. They estimate that this area contributed $\$_{2010}$ 22.2 billion to GDP in 2015. In this study the GDP for the city centre was calculated based on data on regional GDP by industry and detailed geographic data on employment and wages / salaries.

The GDP per employee in each industry in the Auckland region was estimated and multiplied by the city centre's employment in each industry. To calculate the city centre's productivity premium, the city centre's mean personal income by industry[12] (MPI) was compared with the rest of Auckland's MPI. The premium results of average weighted personal income for all industries (18%) fits closely with Maré (2008) findings on the average CBD's Value Added Per Worker (VAPW) premium (industry adjusted) relative to Auckland region (22%). The approach is summarised in the following equation:

$$GDP_C = \sum_{i=1}^{19} \left(E_{Ci} * \frac{GDP_{Ri}}{E_{Ri}} * \frac{PI_{Ci} - PI_{RAi}}{PI_{RAi}} \right)$$

[12] Based on Statistics New Zealand (2013) census data on income by work address.

Where;

GDP_C = is the estimated GDP for the city centre

E_{Ci} = is employment in the city centre in industry i (from: Infometrics employment data)

E_{Ri} = is employment in Auckland Region in industry i (from: Infometrics employment data)

GDP_{Ri} = is the regional GDP within industry i (from: Infometrics regional GDP 2015 data)

$\frac{PI_{Ci} - PI_{RAi}}{PI_{RAi}}$ = is the formula for the productivity premium calculation

PI_{Ci} = is average weighted personal income for employment working in the city centre in industry i (from: Statistics New Zealand, 2013 census data on income by work address)

PL_{RAi} = is average weighted personal income for employment working in the rest of Auckland (except the city centre) in industry i (from: Statistics New Zealand, 2013 census data on income by work address)

Table 1 shows the GDP breakdown by industry for Auckland region and Waitematā Local Board and the estimated GDP for the city centre. It shows that the Auckland city centre comprises a quite significant share of New Zealand's GDP (7%), Auckland GDP (20%) and Waitematā Local Board GDP (73%).

Table 1: GDP by industry in the Waitematā Local Board and the City Centre (June 2015 year, million$_{2010\$}$)

Industry	Auckland GDP	Waitematā GDP	Estimated City Centre GDP
Agriculture, Forestry and Fishing	$338.3	$9.7	$8.5
Mining	$39.1	$14.6	$10.5
Manufacturing	$7,964.6	$282.8	$125.6
Electricity, Gas, Water and Waste Services	$988.4	$335.1	$19.1
Construction	$4,214.2	$341.1	$83.2
Wholesale Trade	$6,542.9	$895.7	$444.5
Retail Trade	$3,795.8	$551.2	$234.2
Accommodation and Food Services	$1,592.3	$481.8	$416.0
Transport, Postal and Warehousing	$3,781.7	$533.3	$525.6
Information Media and Telecommunications	$3,967.2	$2,590.7	$1,528.7
Financial and Insurance Services	$7,165.3	$4,213.9	$4,552.1
Rental, Hiring and Real Estate Services	$11,292.7	$3,127.9	$2,845.4
Professional, Scientific and Technical Services	$7,961.6	$3,985.0	$3,105.3
Administrative and Support Services	$1,973.5	$659.2	$491.9
Public Administration and Safety	$2,323.2	$491.2	$554.1
Education and Training	$3,458.1	$694.2	$548.2
Health Care and Social Assistance	$4,561.8	$668.5	$203.8
Arts and Recreation Services	$1,152.9	$355.2	$281.8
Other Services	$1,632.6	$295.9	$193.3
Unallocated	$5,923.1	$1,626.4	
Total	$80,669.3	$22,153.4	**$16,171.6***
Share of Waitematā GDP			**73.0%**
Share of Auckland GDP			**20.0%**
Share of New Zealand GDP			**7.4%**

Source: Infometrics regional GDP database (2015), real GDP in 2010 prices, for year ended March 2015. Statistics New Zealand (2013), Authors' estimates.

*It does not include 'not elsewhere included' GDP as there is no employment data in this category and the GDP could not be allocated to the city centre. The unallocated GDP is 7 per cent of both Auckland region's and Waitematā' Local Boards total GDP. The result of adding the 7 percent to the estimated GDP would result in the GDP for the city centre to be $\$_{2010}$17.4 billion which equates to 8 per cent of New Zealand's GDP.

2.0 Methodology

This section outlines the methodology. This study examines the dynamics of agglomeration economies in Auckland's city centre by replicating and improving on a pedestrian analysis methodology developed by SGS (2014) for a study of the Melbourne city centre.[13] This is consistent with the method that has been either applied or recommended to be used in an assessment of the impact of transport and land use projects on economic outputs both in international and New Zealand literature (e.g. New Zealand Transport Agency, 2016; SGS, 2012; Maré and Graham, 2009; Graham et al. 2009 and Maré, 2008).

To understand the value of walking to the city centre's economy, the density and connectivity of jobs (effective density) in the city centre is measured and compared with labour productivity. The connectivity is measured by the walking distance and travel time between jobs incorporating traffic signal delays, pedestrian path types and deviations from a direct path.

The steps of the analysis are summarised below and described in more detail from section 2.1 onward.

- The study area is the core business area within the city centre, which includes all commercial buildings in 33 census meshblocks between Quay Street and Wellesley Street, plus additional travel zones within 30 minutes walking distance from this area.
- A census of more than 3220 businesses in the study area was carried out to estimate employment by industry at a fine geographic scale.[14]
- A pedestrian network was developed based on the existing road network in the study area. This version of the report includes an update to the base network walking speeds and an update to the intersection delays.
- 'Network analyst software' (an extension of ArcGIS 10.2.1) was run to estimate the travel time between each origin and destination point.
- Pedestrian travel time matrices between buildings or model zones were created.

[13] The project team improved some of the aspects of the SGS (2014) methodology for it to be fit for use in Auckland's city centre.
[14] Building footprints or building outlines define the extent of permanent building or structures, captured from high resolution aerial photography. The analysis is done at building footprint level instead of address or parcel levels as it is the most suitable scale to aggregate economic, demographic and geospatial data.

- Pedestrian travel time matrices were combined with detailed estimates of employment to create a measure of the EJD by walking in all buildings within the study area.
- A proxy measure for labour productivity was estimated based on detailed data on average annual wages from Statistics NZ's Linked Employee Employment Data (2015).
- The association between EJD and productivity of employees in the building level in the study area was examined.
- Two network scenarios were examined to estimate the impact of changes of the network on GDP as the result of agglomeration effects.

2.1 Travel zones

Travel zones are the areas that contain the origin and/or destination of the distance matrixes. This study covers three travel zones, each with a different geographic specification, defined as follows:

- Study area: this area consists of 33 MBs in the Auckland City Centre with the highest worker density.
- City Centre: Auckland city centre in this study refers to three CAUs - Auckland Central West, Auckland Central East and Auckland Harbourside
- 30 min walking distance area: MBs within 30 minutes walking distance from the core study area are also included in the analysis.

Table 2 shows the geographic specifications of each zone.

Table 2: Travel zones specifications

Travel zone	Geographic unit	Number of units	Area ha. (gross)
Study area	**Building footprint**	**304**	**52.33**
Expansion area	**Meshblock**	**258**	**604.95**
• Rest of City Centre	MeshBlock	103	271.52
• 30 min Walking	MeshBlock	156	333.44

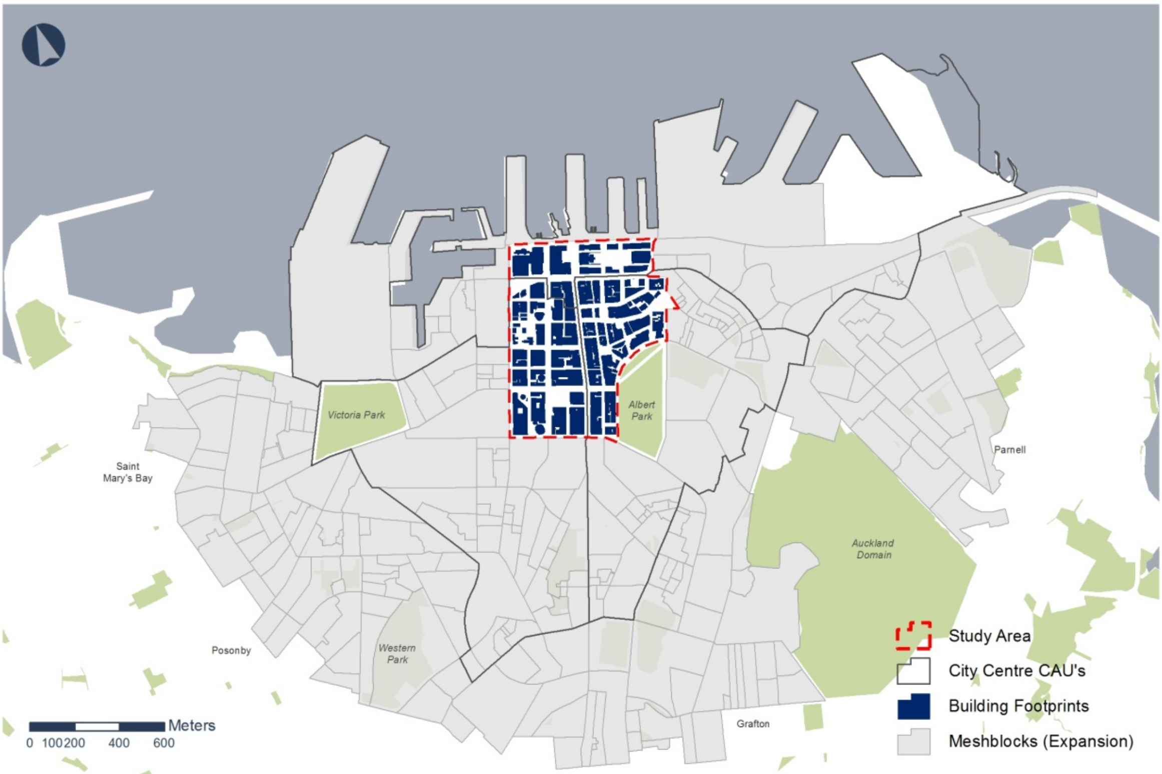
Source: Stats New Zealand (2013), Authors' estimates

Note: Eight meshblocks with more than 50 per cent of their area consist of public open space have been removed from the total number and area of meshblocks because they don't have any productivity or employment density to be used in the study. Therefore, they don't contribute to agglomeration effects.

‘Centroids’ are defined as the geographic centre of an area and are used to spatially locate the network origins and destinations for calculating travel time within and between travel zones. The centroids inside the study area are the centre of each building footprint and the centroids of the other two zones are the centre of each meshblock.

Figure 5 shows the position of travel zones in the Waitematā Local Board.

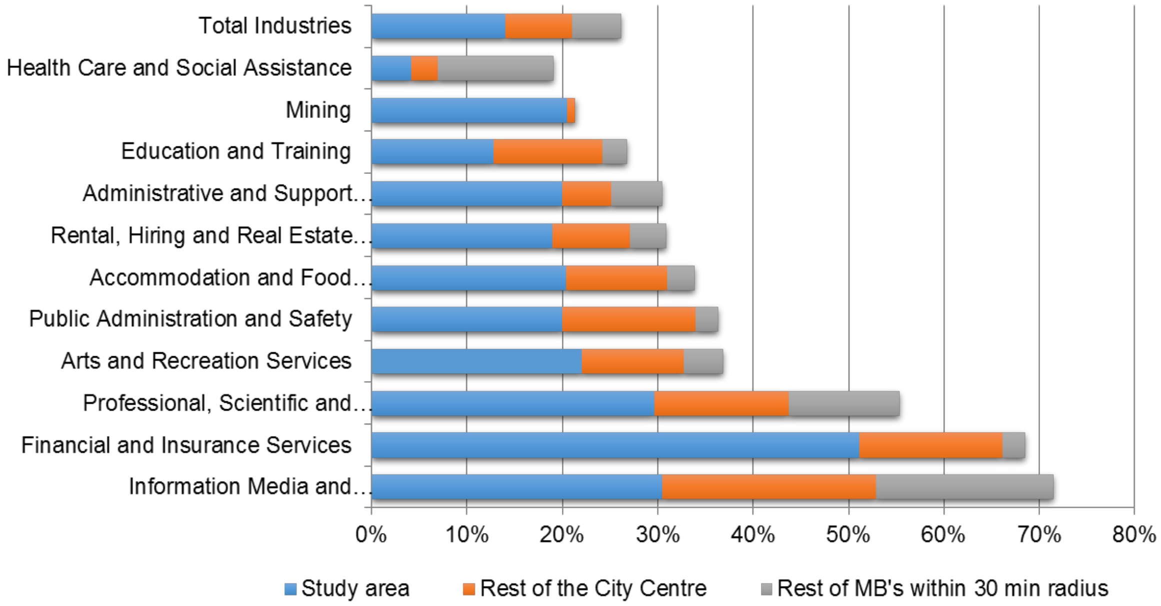
Figure 5: Travel zones used in analysis



Source: Statistics NZ (2013) and Authors’ estimates

The travel zones in total include 26 per cent of Auckland’s total employment. Figure 6 shows the share of Auckland employment by industry in the study area and the other travel zones. It shows that more than 50 per cent of Auckland’s employment in information media and telecommunications (71%), financial and insurance services (69%) and professional, scientific and technical services (55%), are located in the three zones.

Figure 6: Share of Auckland employment by industry in each travel zone



Source: Authors' estimates based on Infometrics customised data.

2.1.1 Study area

The study area is the core business area in the city centre between Quay Street and Wellesley Street. It consists of 33 meshblocks with the highest employment density and aligns with the 'engine room' area of the city centre defined by the City Centre Master Plan (2012). It is the main travel zone of the three travel zones defined in this study. Figure 7 shows the high employment density by meshblock in the study area compared to the rest of the city centre.

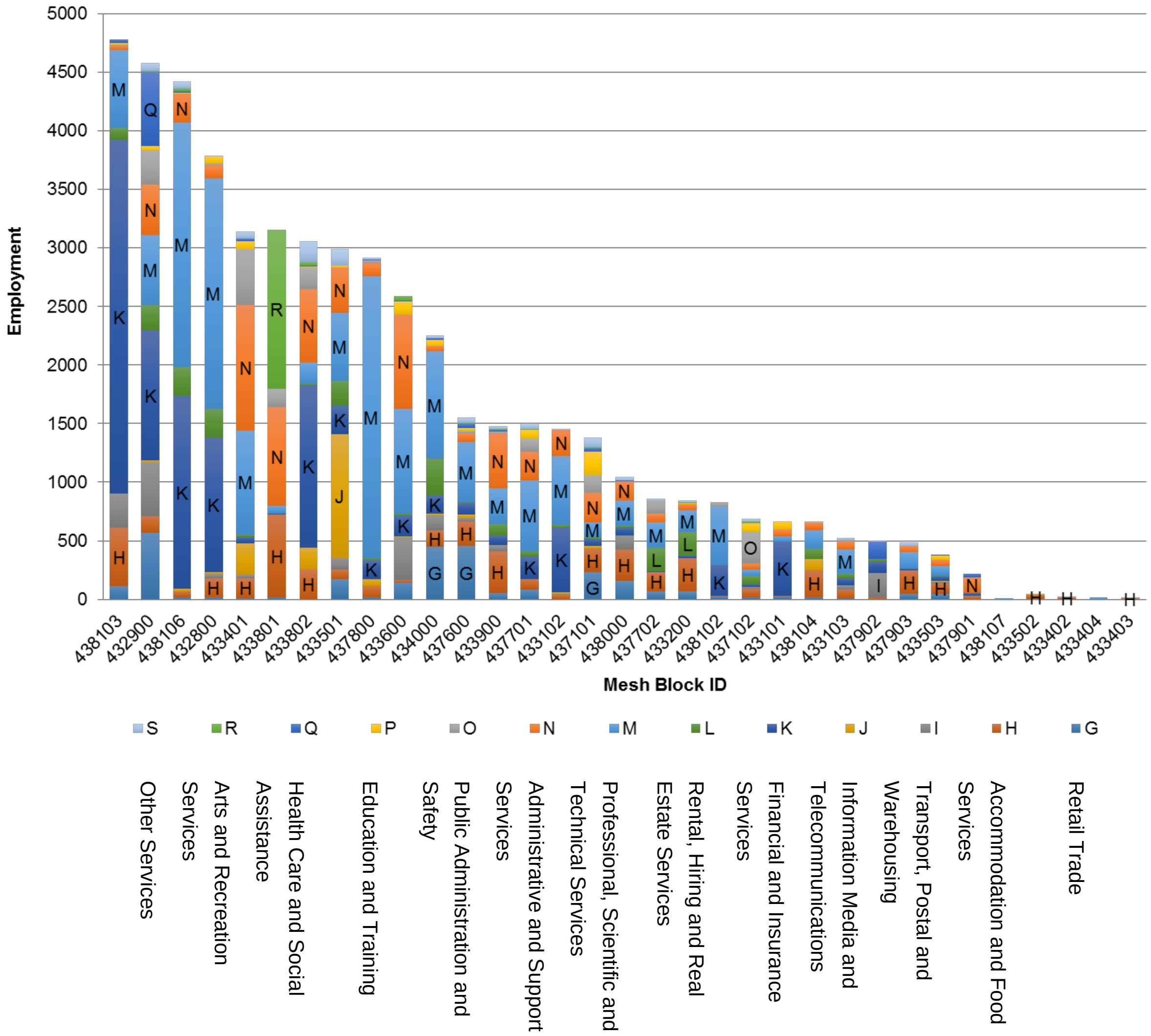
Figure 7: Employment density in the Auckland city centre

Source: Infometrics 2015 employment by MB, Statistic New Zealand (2013) MB area hectare

The study area is the knowledge hub of the Auckland city centre. Professional, scientific and technical services (M) is the main industry accounting for 28 per cent of the total employment followed by financial and insurance services (K) with 20 percent of total employment in the study area.

Figure 8shows the industry composition of employment in each of the 33 meshblocks for the selected industries in the study area. It shows that the meshblocks with employment higher than 4500 are primarily with financial and insurance services (K).

Figure 8: Employment in selected industries in the meshblocks within the study area[15]

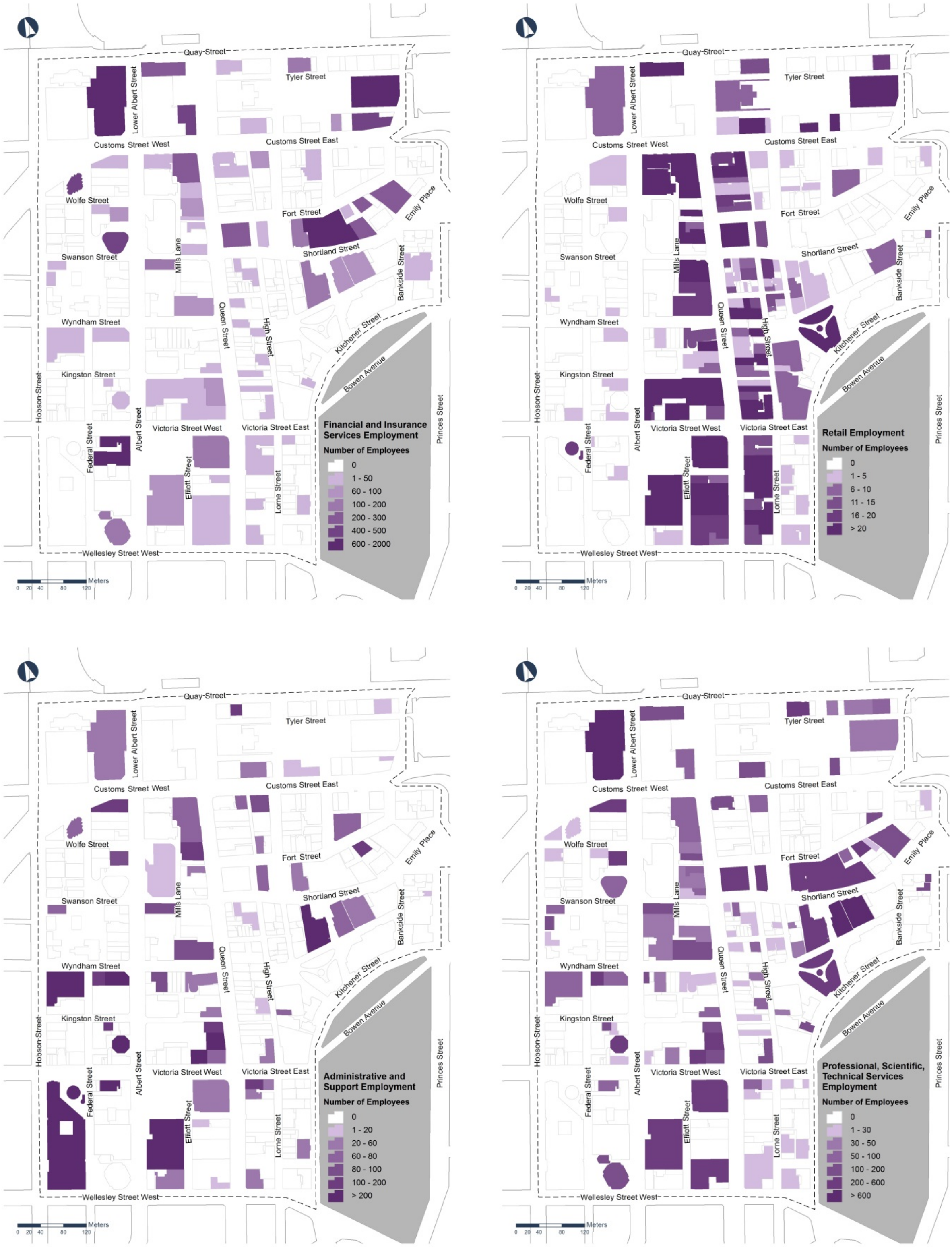


Source: Infometrics employment data by MB and industry (2015)

Figure 9 shows the location of some of the key industries[16] in the study area. It indicates that while the retail is concentrated in the centre of the study area, along Queen Street, other main industries, financial and insurance services, administrative and support services and professional and scientific services, are more dispersed throughout the area. This dispersion is the highest for larger professional services firms (i.e. those with higher employment). Large financial services businesses are located in the northern half of the study area and administration services with higher employment area are mostly located in the south-eastern quarter of the area.

[15] See ANZSIC Level 1 industries and their related coding in Appendix A.
[16] ‘Key’ here refers to geographical distribution not the employment number or density.

Figure 9: Location of some key industries in the study area



Source: Authors' estimates

2.2 Pedestrian network

Connectivity between travel zones is based on the pedestrian network developed for this project. Fine scale pedestrian network typologies were mapped for the study area whereas road centrelines were used to estimate walkability in the expansion area. The expansion network also enabled the walking and agglomeration impacts of the neighbouring areas to be captured. The speeds selected best represent real world pedestrian movement, having consideration for traffic light phasing and other delays experienced along a pedestrian route.

The base pedestrian network that was used in the previous sections (as per first version of the report in March 2017) of the report was updated to enable a more accurate analysis of pedestrian network interventions seeking to improve connectivity. This involved the reassessment of, and modification to, the travel speeds assigned to each of the network components and an update to the intersection delays. The updated speeds for pedestrian network types included lanes, arcades, shared spaces and through block links (from 4km/hr to 5km/hr). This adjustment gives identical walking speeds to all footpath types (with the exception of stairs). The assumption is that regardless of type, the travel time estimates were used to determine the connectivity from one destination to another. Therefore the simulation should not account for amenities values or other characteristics of the route typically associated with a slower walking speed (e.g. window shopping in pedestrian malls and arcades). The other adjustments include optimisation to intersection delays to better reflect real world disruptions to pedestrian movements through the intersections. Previously the network sections at intersections were assigned a reduced walking speed based on the average delay. The update includes intersection-specific delays and accounts for the actual time taken to travel the length of the intersection at the average walking speed of 4 km/hr.

Table 3: Network classification

Item	Average speed (Km/h)
Footpath	5
Lanes	5
Arcade	5
Shared Spaces	5
Through Block Links	5
Steps	2
Crossings	4

Source: Authors' estimates

Data provided by Auckland Transport was used to assign estimated speeds to the pedestrian crossings in the network. The walk, clearance and overall intersection cycle times were provided in seconds for each crossing in the study area. Average delay was calculated from the data using the following formula:

$$d = \frac{r^2}{2c}$$

Where:

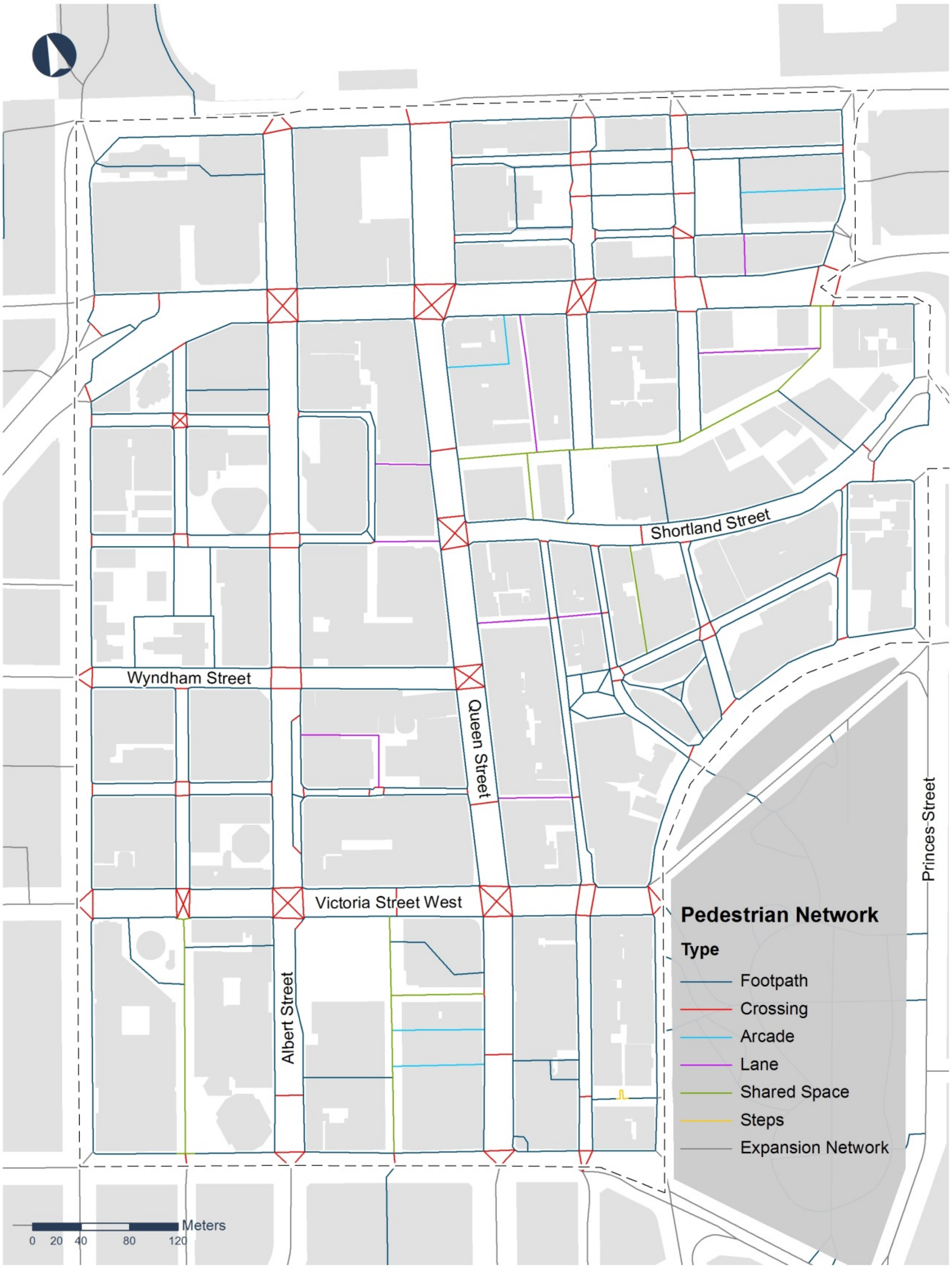
d	= is average delay
r	= is the red time
c	= is the cycle time

Delay times were individually assigned to network crossings and added to the total walk time. This measure of pedestrian delay assumes random arrivals at intersections and full compliance with signals.

Modelling pedestrian trips between travel zones was made possible by connecting the pedestrian network (depicted in Figure 10) with travel zone centroids of each origin and destination at the scale appropriate to the travel zone (shown in Figure 11).

The study area building footprint centroids were joined to property entrance points to best represent real world pedestrian access and movements, although internal movements such as between doors and lift or lift time is not accounted for. The expansion area travel zones were connected to the expansion portion of the pedestrian network at the centroid level.

Figure 10: Walking network within the study area



Source: Authors' estimates

Figure 11: Building footprint centroids and meshblock centroids used in analysis

Source: Authors' estimates

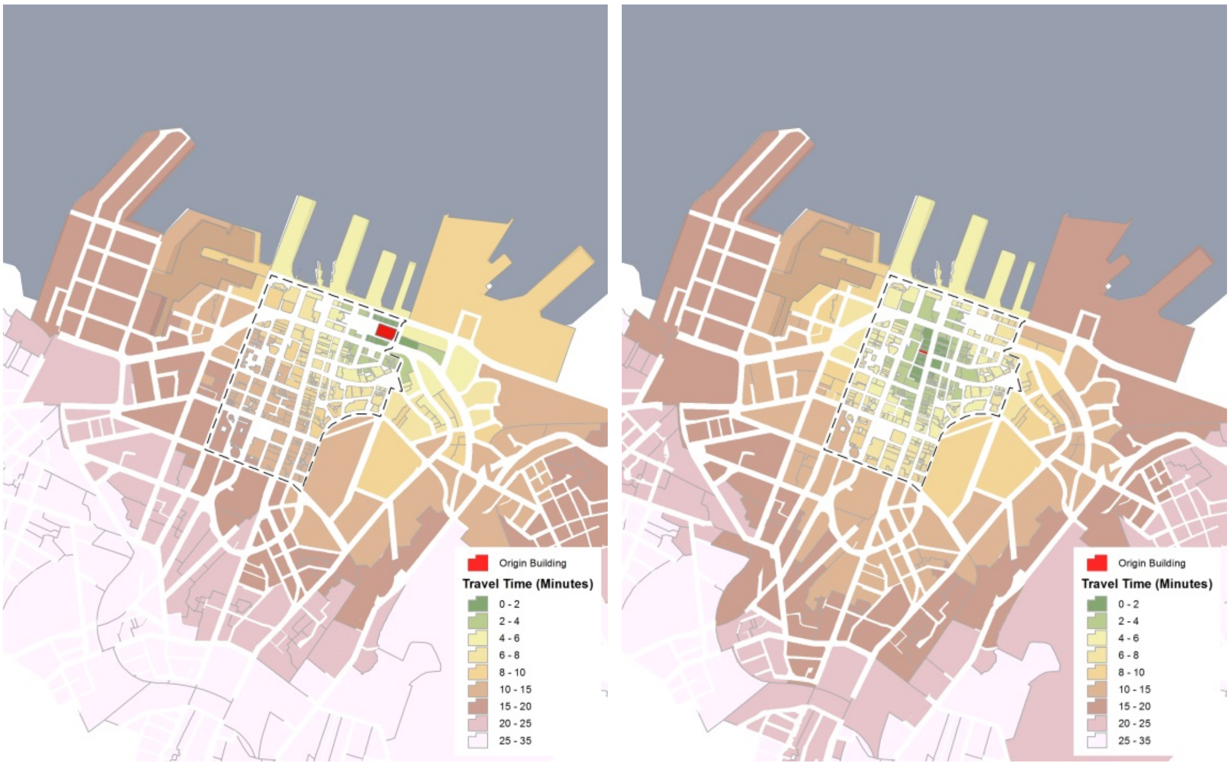
2.3 Travel time matrices

Two travel time matrices were created based on the distances between travel zones and the results of the geographic information system (GIS) analysis. The first 'door to door' travel time matrix is a matrix of walking time (in minutes) between each of 408 building footprint centroids in the study area to all other centroids in the area. The second 'door to meshblock' matrix is a matrix of walking time (in minutes) between each of the 408 building footprint centroids in the study area to centroids of 259 MBs in the other travel zones.

The travel time matrices were used to estimate the study area's agglomeration degree using Effective Job Density (EJD). The EJD for each building footprint is the sum of two EJDs estimated based on the two distance matrices.

Figure 12 visualises the walking time between a building footprint at the middle and one at the edge of the study area to all other centroids of travel zones.

Figure 12: Estimated walking travel time from two buildings in the study area



Source: Authors' estimates

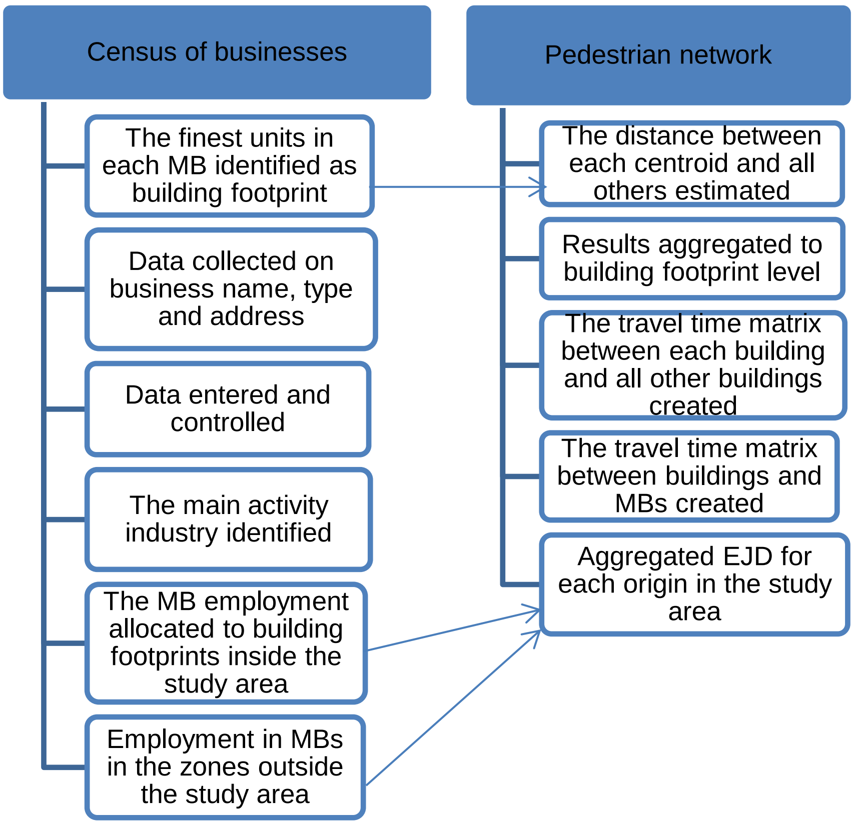
2.4 Effective job density estimates

As defined in the previous section, EJD is an agglomeration index that links job density and walking connectivity. Walking connectivity between buildings and meshblocks was estimated using the travel time matrices. Following Graham (2006), the distance decay (α) is set to equal to 1, to weight access to employment inversely with walking travel time.[17] We assume that within building footprints, employment is evenly distributed so that the first part of Equation 1 (see Section 1.2) is equal to the building job density.

Infometrics' employment data at the MB level was used to estimate the EJD for each origin in the study area. A census of businesses in the study area was carried out to estimate employment at the building footprint level (see Appendix C for more details).

The EJD for each building footprint was calculated using a process that is summarised in the following diagram.

Figure 13: The process of estimating EJD for each building footprint in the study area



Source: Authors' estimates

[17] This means that employment in the immediate neighbourhood of a firm will have 10 times more effect on the firm's EJD compared to those 10 km away.

Although the base pedestrian network was changed compared to the March 2017 report, the result of EJDs has not changed significantly[18].The results still show that buildings on both sides of Queen Street between Customs and Victoria Streets have higher EJD compared to the other parts of the study area. Figure 14 shows buildings located in the eastern part of the study area (Shortland Street) also have higher EJD compared to those located to the west (Swanson Street).

The two drivers of walking based EJD, employment density and walking connectivity could help understand the reasons behind the differences in EJD within the study area. Employment density (employment per hectare) shows the physical cluster of jobs. Figure 15 shows employment density based on allocated employment to building footprints.[19]

Walking connectivity represents the ease of walking between firms. It is calculated based on the destination's aggregated land area divided by the travel time from each origin. Figure 16 shows the difference in walking connectivity between buildings weighted by land areas.[20] It indicates high walk connectivity for buildings located in the Queen Street neighbourhood.

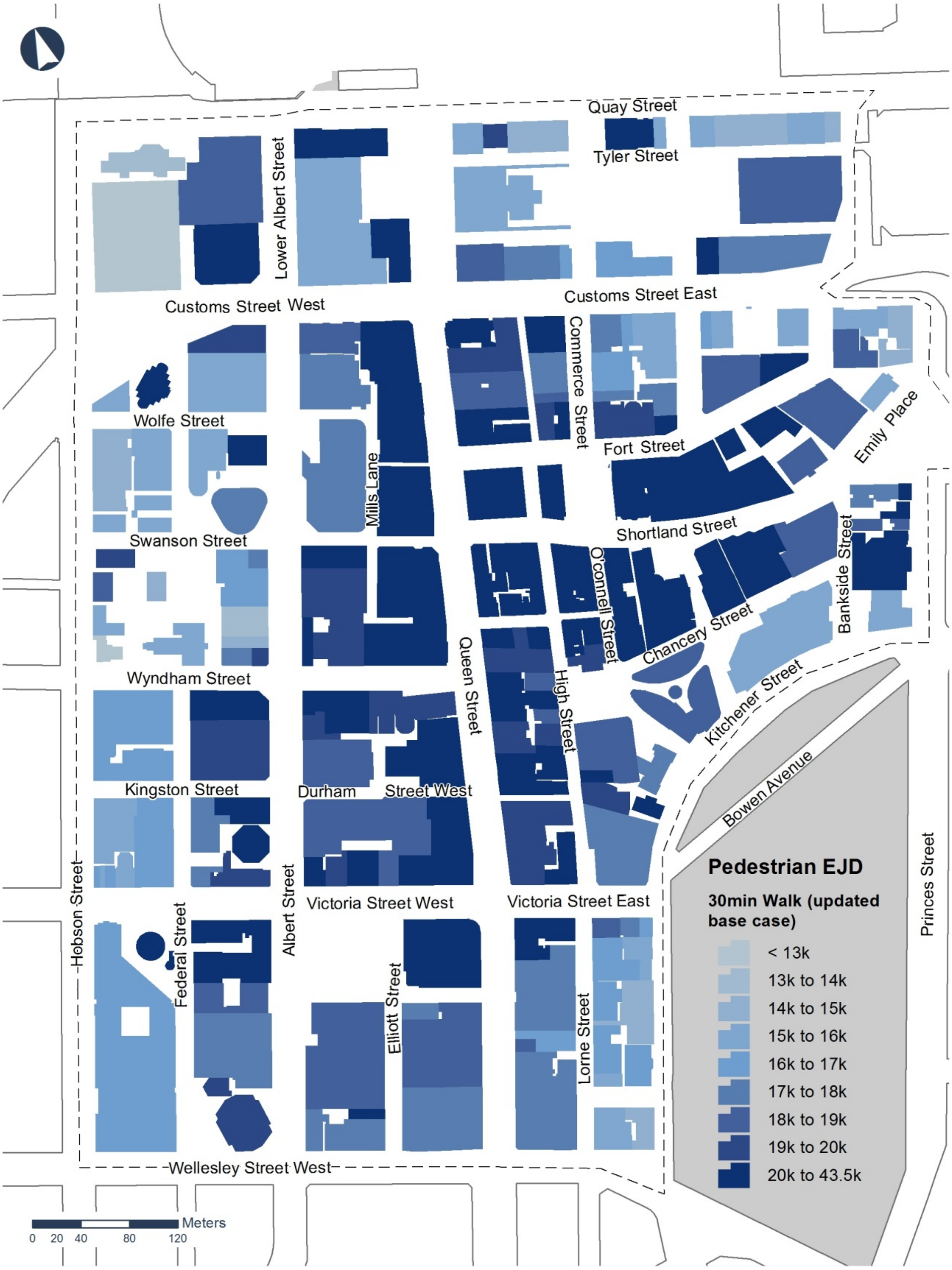
Comparing Figures 14-16 shows that the high EJD of some building footprints are due to high employment density with relatively low walking connectivity. For example the eastern part of the study area (Shortland Street); or due to high walking connectivity with relatively low employment density, for example buildings along Queen Street. Some buildings with high EJD have high employment density combined with high walking connectivity, for example the building at the corner of Customs Street West and Queen Street.

[18] The total EJD increased by more than 290 thousand (5.17%) in the updated base compared to the original base in March 2017 report.

[19] It is same as the previous version of the report.

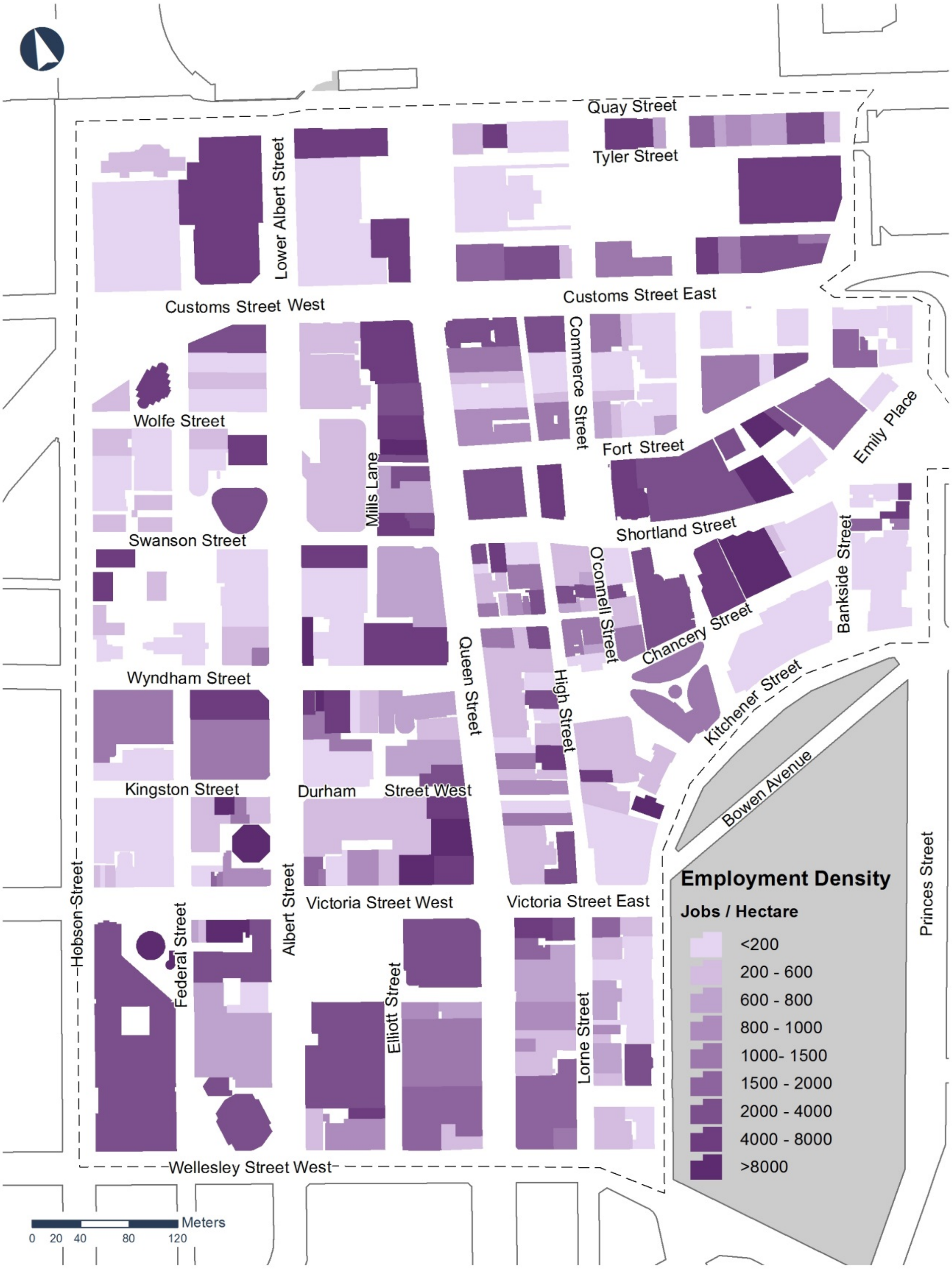
[20] It changed slightly but the general results are same as the previous version of the report.

Figure 14: Walk effective job density



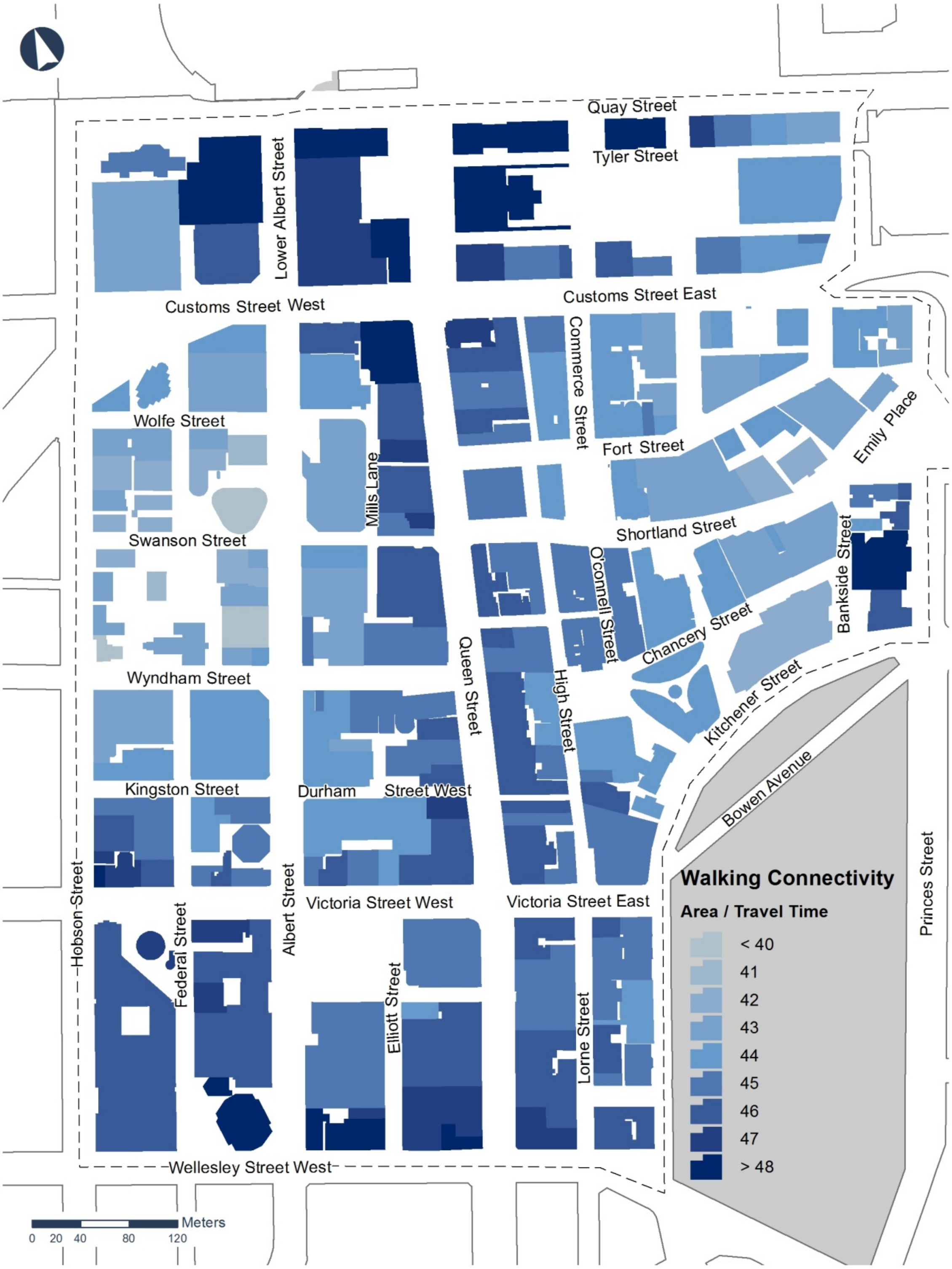
Source: Authors' estimates

Figure 15: Employment density



Source: Authors' estimates

Figure 16: Walking connectivity



Source: Authors' estimates

2.5 Labour productivity

Labour productivity is a measure of economic growth. It measures the amount of goods and services produced by one hour of labour.

SGS (2014) used the average gross value added (GVA) (sum of wages and profits) for each ANZSIC industry as a proxy for labour productivity.[21] This is one of the most common proxies used to measure productivity internationally.

Utilising the same methodology, adapted to available data, we used the mean wage per worker by industry in the study area from the Linked Employer-Employee Data (LEED) as a proxy for productivity.[22] The data shows a significant premium in wages in the study area compared to the rest of Auckland for most of the industries and specifically for knowledge intensive industries that are the main activities in this area (e.g. financial services 33%, professional services 18% and media 15%).

To avoid the industry effect and account for the productivity premium due to different industries in the study area compared to the rest of Auckland, the productivity measure was adjusted for industry. The adjustment is carried out using the weight of the mean wage in each industry in the rest of Auckland. [23]

Table 4 shows the estimated GVA per worker by industry in study area compared to the rest of Auckland.

[21] Labour productivity based on the GDP per hour worked reflects the contribution of all production factors including labour, land, capital and enterprise. We used average wages as a proxy for GVA to only reflect the labour value added.
[22] Labour productivity is higher than wages as it also includes profits.
[23] The weighted mean wage in each industry i in the rest of Auckland region is calculated using the following equation:

$$WMW_i = \frac{MWi}{\sum_i^n MWi}$$

Where:
WMW_i = Weighted mean wage in each industry i in the rest of Auckland region
MW_i = Mean wage in industry i in the rest of Auckland region

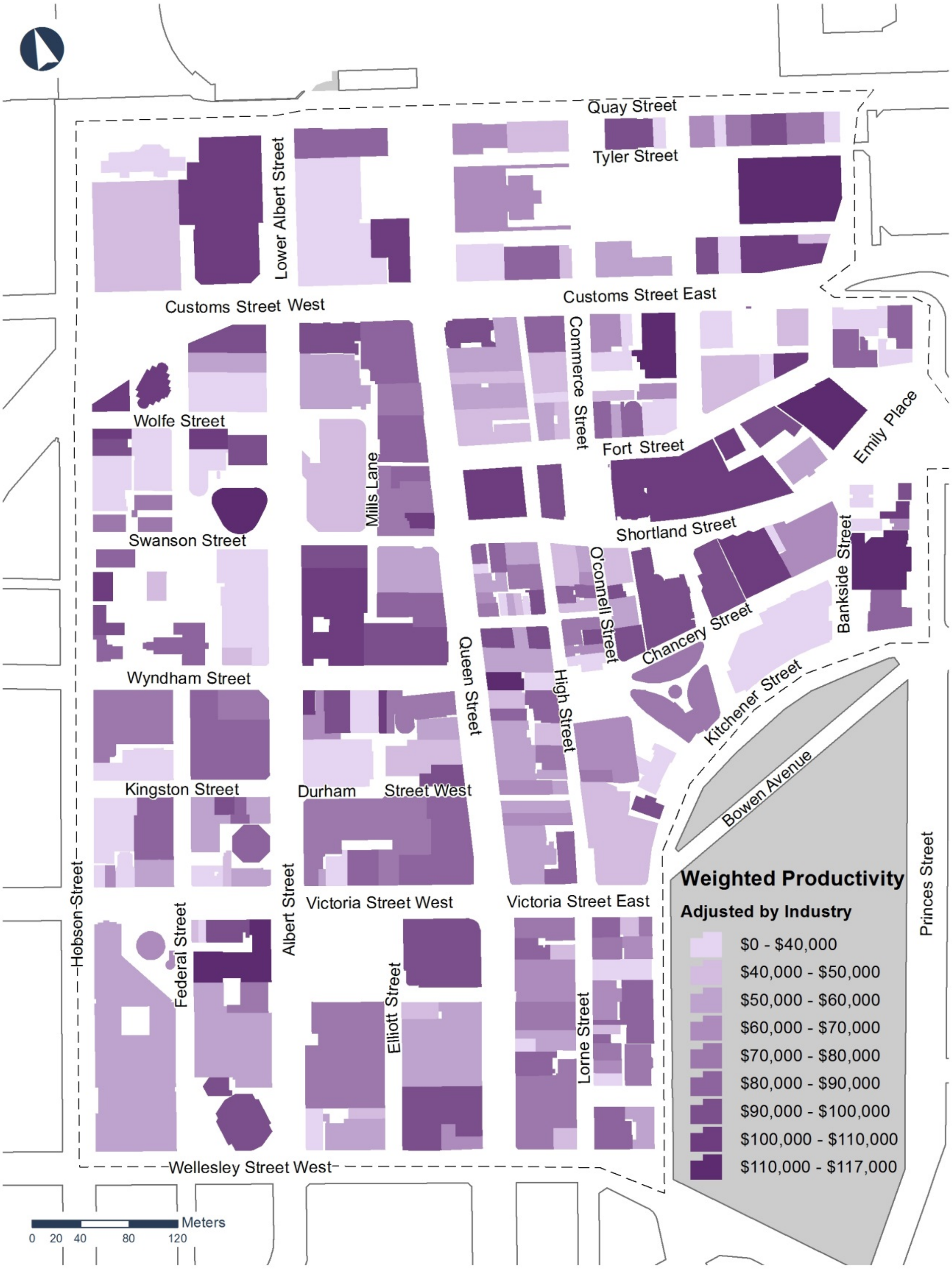
Table 4: Average annual earning by industry, study area and rest of Auckland

Industry	Study area	Study area adjusted for industry	Rest of Auckland
Agriculture and Mining	$146,950	$80,760	$60,440*
Manufacturing	$68,760	$86,266	$64,560
Electricity, gas, water, and waste services	$121,366**	$108,219	$80,990
Construction	$60,580	$86,787	$64,950
Wholesale trade	$108,620	$91,196	$68,250
Retail trade	$38,420	$53,622	$40,130
Accommodation and food services	$36,260	$39,391	$29,480
Transport, postal, and warehousing	$86,300	$86,466	$64,710
Information media and telecommunications	$90,600	$105,467	$78,930
Financial and insurance services	$116,050	$116,170	$86,940
Rental, hiring, and real estate services	$104,880	$83,713	$62,650
Professional, scientific, and technical services	$91,400	$103,249	$77,270
Administrative and support services	$58,280	$63,243	$47,330
Public administration and safety	$75,870	$89,005	$66,610
Education and training	$51,900	$78,369	$58,650
Health care and social assistance	$46,250	$75,362	$56,400
Arts and recreation services	$63,189**	$55,653	$41,650
Other services	$53,500	$82,428	$61,688
Total industries	**$82,428**	**$82,428**	**$77,164**

Source: Statistics New Zealand customised LEED quarterly data, average earning based on full quarter jobs for 4 quarters to June 2015.
* Average of wages in agriculture ($41,700) and mining ($79,180) sectors provided by Statistics NZ.
** The numbers have not been provided by Statistics NZ because of confidentiality matters. They have been estimated by the authors based on the HLFS average annual earning data 2015.

Figure 17 shows high productivity firms are dispersed throughout the study area. Shortland Street (located at the eastern part of the area) is the only street with relatively higher concentration of high productivity buildings.

Figure 17: Study area building footprint labour productivity



Source: Authors' estimates

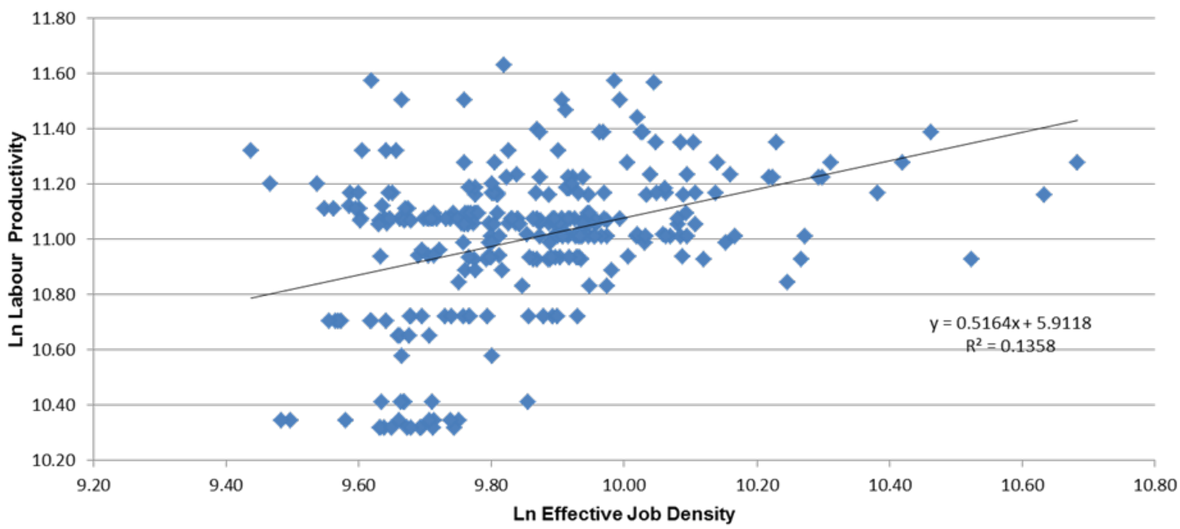
3.0 The relationship between walking effective job density and productivity

Agglomeration economics literature suggests that there is a positive and causal relationship between EJD and productivity. Several studies have found that better walking connectivity and/or accessibility to jobs within close proximity within city centre environments is associated with higher productivity (Rosenthal and Strange, 2003; Arzaghi and Henderson, 2008; SGS, 2014). Furthermore, some studies found that density of jobs, rather than city size, is a primary driver of agglomeration economies (Ciccone and Hall, 1996 and Cervero, 2001). However, these relationships have not been investigated in Auckland or even in New Zealand. This study is the first research in New Zealand that investigates the correlation between walking connectivity and labour productivity.

The association between EJD and labour productivity is reassessed in this version of the report using the updated EJD estimates.[24]

Figure 18 shows a positive association between walking EJD and productivity in the Auckland city centre.

Figure 18: The association between walking EJD and labour productivity



Source: Authors' estimates

Walking EJD 'explains' around 14 per cent of the variation in estimated labour productivity in the Auckland city centre, which is likely to reflect the influence of other

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[24] As the result the association between pedestrian connectivity and productivity has slightly changed compared to the previous version of the report.

factors such as variations in industry composition between different parts of the city centre and proximity to other transport facilities, such as the Britomart train station. [25]

The point estimate suggests that a 10 per cent increase in walking EJD is associated with a 5.2 per cent increase in productivity. This compares to the SGS (2014) results of 0.66 per cent. This means that a one per cent increase in walking EJD within each travel zone will increase the value of economy of the study area by 0.52 per cent or approximately $41 million based on the authors' estimate of $8.01 billion GDP for the study area.

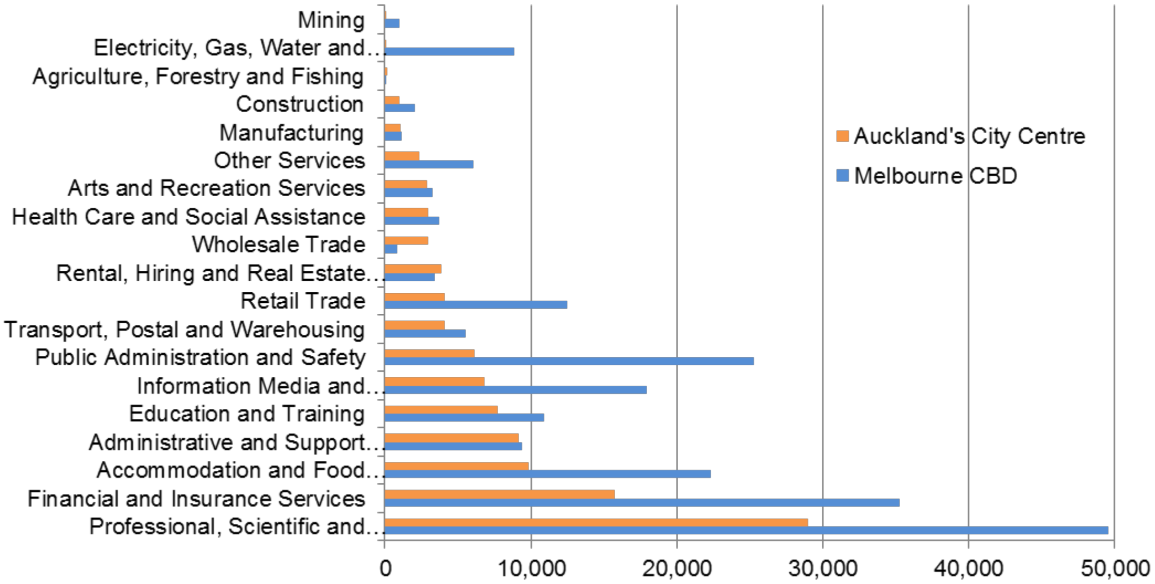
The estimated elasticity of productivity with respect to walking EJD was high compared with other estimates of agglomeration elasticities. Most estimates of agglomeration elasticities at a regional level are an order of magnitude lower. This may reflect the fact that there are other variables, such as proximity to major transport facilities that have not been controlled for by the SGS (2014) model. Nonetheless, this result is consistent with the hypothesis that better walking accessibility raises economic productivity.

This research is the first empirical study on the relationship between connectivity (specifically walking connectivity) and productivity in a fine scale for Auckland city centre. The relationship between EJD and productivity is positive but not as strong as the Melbourne CBD study by SGS (2014). This could be the result of differences in the size and scale of the two city centres. In 2015, the employment density of Melbourne city centre was 353.29 employees per hectare, 24 percent higher than Auckland city centre's employment density (284.47).

Figure 19 shows the employment by industry in Auckland's city centre compared to Melbourne CBD. Three main industries in Auckland's city centre; professional, scientific and technical services, financial and insurance services and accommodation and food services are also three of four main industries in Melbourne CBD with 70 per cent, 123 per cent and 126 per cent higher employment respectively, compared to Auckland's city centre.

[25] By comparison, SGS (2014) finds that EJD 'explains' around 40% of variation in labour productivity in the Melbourne CBD.

Figure 19: Employment by industry in Auckland's city centre and Melbourne CBD



Source: City of Melbourne Census of Land Use and Employment (2002-2016) and Infometrics employment data 2015

This report could be a starting point for more studies on agglomeration economics in fine geographic units in New Zealand. Future studies could consider the following based on the empirical results of this research.

- The SGS (2014) model used in this study designed a single variable correlation method. There are a range of other unobserved factors that may affect productivity, including proximity to other transport facilities and a range of unobserved factors that may arise at the local level.
- The model also does not include the reverse causality between urban agglomeration, human capital and labour productivity.[26] The choice of firms to locate near suppliers, customers and other like-minded businesses is in part because that co-location generates improved productivity through connectivity and associated knowledge. This raises the question of the direction of causality in the effective density-productivity equation. More robust evidence that better walkability increases productivity could be obtained by applying econometric techniques such as instrumental variables estimation that can address causality.
- Location of a highly productive firm may not be chosen for walkability reasons but rather for other amenity factors such as waterfront location.

[26] Reverse causality means agglomeration effects can raise productivity; but an entrepreneur may also seek the most productive locations turning it into an agglomerated area.

- Other proxies for productivity and walkability might have different results compared to the method used in this study. For example, ground floor rents could be a proxy for walkability for retail located in areas with high pedestrian traffic. Real estate prices also could be used as a proxy for productivity.

4.0 Scenario analysis

This section of the report examines the impact of the real life scenarios based on the Auckland council's design plans to further demonstrate the value of connectivity through the walkable network in Auckland's city centre. The results illustrate the potential value added through increasing the physical connectivity (proximity) of firms and workers associated with labour productivity (agglomeration effects) measured by means of the pedestrian network. The agglomeration effect was measured using Walking Effective Job Density (EJD) for each scenario compared to the base case.

Two high connectivity scenarios were tested to examine the impact of changes in pedestrian connectivity on Auckland's city centre economy. The first scenario (one) was broken down into components to better understand the influencing factors. The scenarios were developed by the Auckland Design Office within Auckland Council and depict potential interventions to improve walking accessibility.

4.1 Scenario 1

Scenario one is a high connectivity scenario consisting of three subsets, each representing a different type of intervention to the pedestrian network, in different parts of the study area. The three sub scenarios – additional through blocks links, a complete laneway network and improving permeability along Shortland Street - are described as follows:

Scenario 1.1: Through block links

Six through block links were added in scenario one as follows; link between Lower Albert St and Queen St (East to West orientation), Swanson St to Wyndham St (N/S), Wyndham St to Durham Lane (N/S), Durham Lane to Victoria St West (N/S), Albert St to Elliot St (E/W) and an additional through block link from Queen St to High St (E/W).

Scenario 1.2: Completed laneway network

Four laneways were tested to complement the already existing Fort St, O'Connell St, and Elliot St laneway shared spaces and to extend the shared space on the southern end of Federal St.

The test laneways were added Federal St, from Victoria St West to Wyndham St joining up to St Patricks Cathedral Sq. and continuing along Federal from Swanson St to Fanshawe St. Two more sections were added, along Lorne St and High St, from Wellesley St to Victoria St East, and from Victoria St East to Shortland St respectively. Both Federal St laneways cross one intersection, Kingston St and Wolfe St respectively. Additional zebra crossings were applied to the northern ends of the High St and Federal St (Wyndham St section).

Scenario 1.3: Shortland Street connections

Four pedestrian crossings were added to Shortland St. to improve permeability and to support the current one. Each of the uncontrolled crossings was assigned minimal delays through a reduced walking speed of 4km/hr to account for potential interactions between vehicles and pedestrians, and wait times.

Each of the scenario one subsets was mapped and built into the updated base pedestrian network and EJD was recalculated for each building. This was then tested against the updated base case to measure change in EJD. Figure 20 shows the changes in EJD as the result of the scenario one subsets.

Figure 20 New EJD index scenario one subsets compared to the base case EJD index. Left to right; 1.1 through block links, 1.2 completed laneway network and 1.3 Shortland St connections

The impact of the additional through block links (scenario 1.1) shows widespread increase in EJD with the largest gains in locations directly next to the interventions. The overall impact of the lane way network (scenario 1.2) is more significant and widespread throughout with higher impacts at buildings adjacent to the laneway improvements. All building within the study experience increased EJD as a results of the completed laneway network. The Shortland Street connections (scenario 1.3) improve the connectivity of the eastern quarter. However, the changes are not as significant as other scenarios.

Figure 21 shows the changes in each building EJD as the result of the combined scenario one.

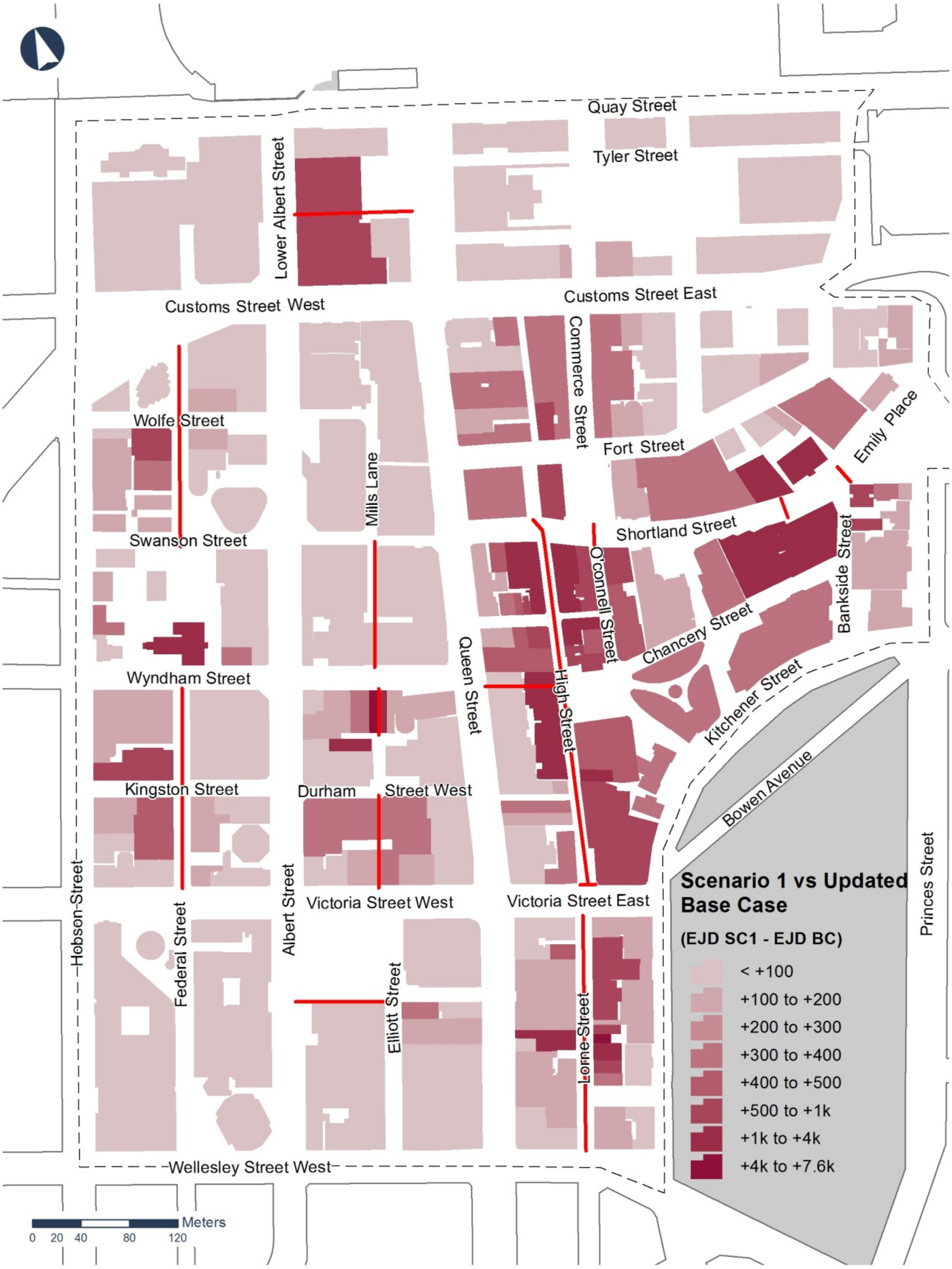
The combined scenario one, which includes all of the aforementioned interventions in a single pedestrian network, was overall more effective than each of the subsets alone at improving EJD across the study area. The addition of laneways along Federal Street and High St/Lorne St (scenario 1.2) contributed the most to increasing EJD while two other sub scenarios impact was more confined. The combined changes to EJD for scenario one is greater than the total of each individual subset scenario due to cumulative interactions.

4.2 Scenario 2

Scenario two is positioned along Queen Street, the main Street at the middle of the study area where a shared space has been proposed in conjunction with a light rail network (not tested). The shared space runs the length of Queen Street from Wellesley St to Quay Street. The shared space is interrupted at two major arterial intersections, Customs St and Victoria St, to maintain bus and private vehicle movement. Other minor changes to the network included reduced intersection pedestrian delay times to account for reduced distance. Figure 22 shows the changes in EJD as a result of scenario 2.

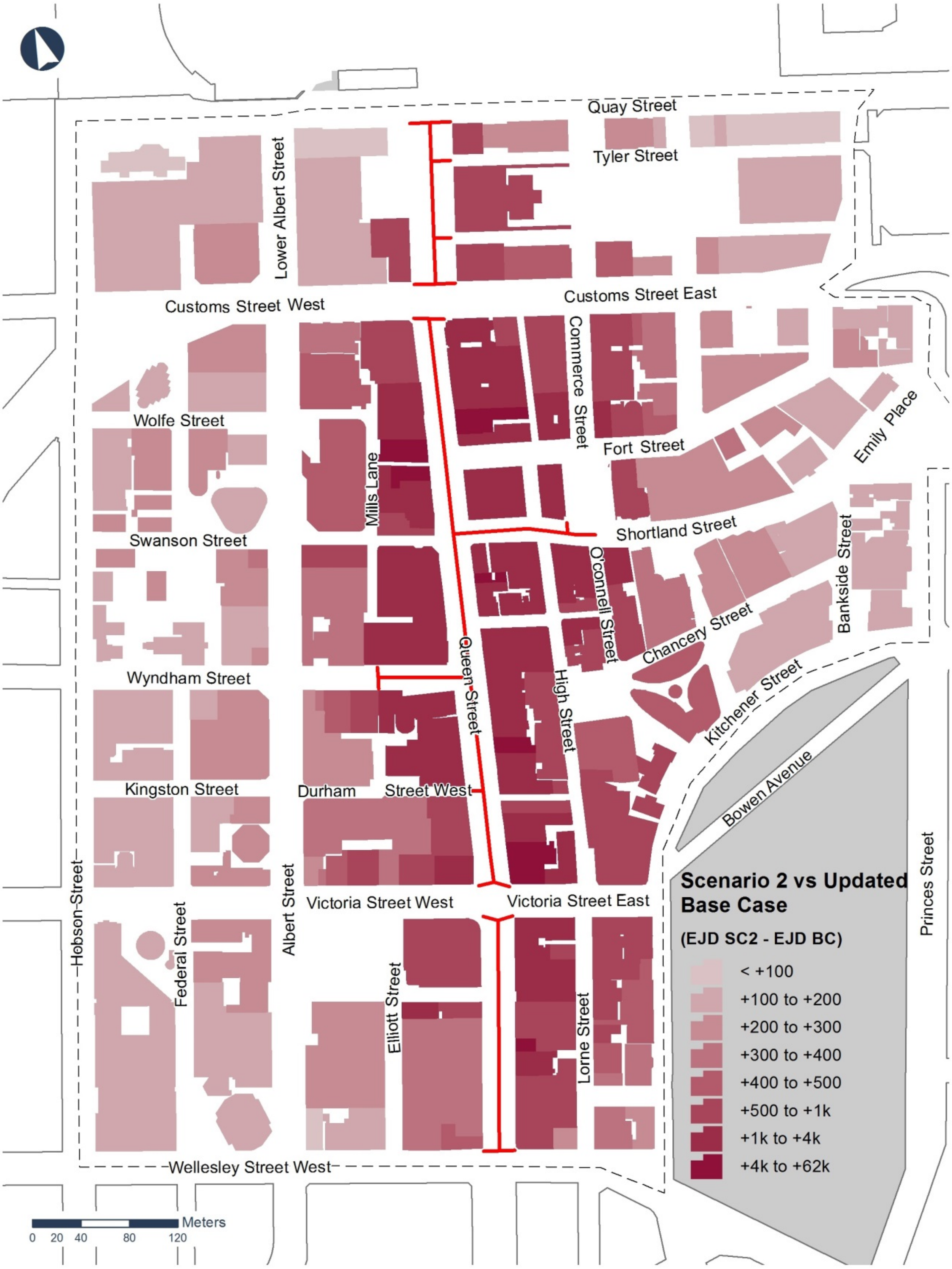
The results of scenario two on walking EJD for a shared space in the centre of the network show a positive impact throughout the entire study area. Its impact is most significant for the buildings adjacent to Queen Street and reduces with increasing distance.

Figure 21 New EJD index combined scenario one compared to updated base EJD index



Source: Authors' estimates

Figure 22 New EJD index scenario 2 compared to updated base EJD index



Source: Authors' estimates

4.3 Scenario analysis results

The potential impact of each of the scenarios on the area's economy was estimated using the changes on the EJD index under each scenario compared to the base case.

Table 5 shows the estimated changes in EJD and its impact on the city centre's economy.

Table 5: Estimated impact of each scenario on EJD and economy's value[27]

Scenario	Changes in total EJD	Percentage change in total EJD	Impact on the area's economy (million)
Scenario 1.1	15,920	0.27%	$11.13
Scenario 1.2	71,581	1.21%	$50.04
Scenario 1.3	1,712	0.029%	$1.20
Scenario 1 combined[28]	**98,678**	**1.67%**	**$68.99**
Scenario 2	**348,926**	**5.90%**	**$243.94**

The results show that shared space (scenarios 1.2 and 2) would add higher value to the city centre's economy compared to other changes in the network. This impact is more significant when the street has higher connectivity.

[27] Based on GDP estimate for the study area $8 billion, see section 1.3

[28] The results of combined scenario 1 are not equal to the total of three sub scenarios because three interventions have some overlap impacts.

5.0 Conclusion and recommendations

This report examines the dynamics of agglomeration economies in Auckland's city centre by replicating and improving on a pedestrian analysis methodology developed by SGS (2014) for the Melbourne city centre. The method has provided a more detailed understanding of Auckland city centre's walking connectivity and economy.

The value of pedestrian connectivity to agglomeration economies was measured using the relationship between walking Effective Job Density (EJD), and labour productivity. The EJD estimated for buildings located in the defined study area included the meshblocks with the highest employment density within the Auckland city centre.

Two real life high connectivity scenarios were tested to examine the impact of changes in pedestrian connectivity on Auckland's city centre economy. Scenario one is a high connectivity scenario consisting of three subsets, each representing a different type of intervention to the pedestrian network, in different parts of the study area. The three sub scenarios include, additional through blocks links, a complete laneway network and improving permeability along Shortland Street.

Scenario two is positioned along Queen Street, the main Street at the middle of the study area where a shared space has been proposed in conjunction with a light rail network (not tested). The shared space runs the length of Queen Street from Wellesley St to Quay Street.

The results of the research are summarised as follows:

- The 2015 GDP for Auckland's city centre is estimated to equal more than $\$_{2010}$16 billion, 20 per cent and 7.4 per cent of Auckland and New Zealand's GDP respectively.
- A census of businesses was undertaken within the study area collecting information on business name, address, activity and type for more than 3220 firms. Employment number and industry (based on Level 1 ANZSIC) was allocated to each building from Statistics NZ Census data available at meshblock level.
- The result of the employment data analysis shows that retail is concentrated in the core of the study area along Queen Street with high walking connectivity and low productivity compared to other industries.
- The high productivity industries in the study area, financial and insurance services, administrative and support services and professional and scientific services are more dispersed throughout the area. This dispersion is the

highest for larger professional services firms (i.e. those with higher employment). Large financial services companies are located in the northern half of the study area and administration services with higher employment are largely located in the south-eastern quarter of the area.

- Walking EJD in Queen Street is high while it is one of the lowest productivity areas. It is because the main industries in most of the buildings are retail with relatively lower productivity in general compared to other industries.
- Shortland Street shows a high and positive relationship between connectivity and productivity as both of them are high in this part of the study area.
- Consistent with previous research, there is a positive and statistically significant association between walking EJD and estimated labour productivity within the Auckland's city centre. Locations that are more walkable tend to have higher productivity. This relationship is robust with the inclusion of controls for (estimated) industry composition at a building level, suggesting that it does not simply reflect the fact that higher-productivity industries choose to locate in more walkable places.
- The estimated elasticity of productivity with respect to walking EJD is high compared with other estimates of agglomeration elasticities. Most estimates of agglomeration elasticities at a regional level are an order of magnitude lower. This may reflect the fact that there are other variables, such as proximity to major transport facilities that have not been controlled for by the SGS (2014) model. Nonetheless, this result is consistent with the hypothesis that better walking accessibility raises economic productivity.
- Improving pedestrian connectivity through changes to light phasing and/or changes to the physical network and consequently EJD improvement means decreases in time spent walking in the study area enhanced face-to-face interactions and knowledge exchange. This causes agglomeration effects to occur and potentially increases labour productivity and economic outcomes.
- The results of network scenarios assessments show that shared spaces would add higher value to the city centre's economy compared to other changes in the network. This impact is more significant when the shared space is centrally located which would allow for higher connectivity and greater impact on surrounding network.

This study, as the first research in New Zealand investigating the relationship between walking connectivity and agglomeration economics, could be a starting point for more studies on agglomeration economics in fine geographic units in New

Zealand. Future studies could consider the following based on the empirical results of this research:

- The SGS (2014) model used in this study designed a single variable correlation method. There are a range of other unobserved factors that may affect productivity, including proximity to other transport facilities and a range of unobserved factors that may arise at the local level.
- The model also does not include the reverse causality between urban agglomeration, human capital and labour productivity.[29] The choice of firms to locate near suppliers, customers and other like-minded businesses is in part because that co-location generates improved productivity through connectivity and associated knowledge. This raises the question of the direction of causality in the effective density-productivity equation. More robust evidence that better walkability increases productivity could be obtained by applying econometric techniques such as instrumental variables estimation that can address causality.
- Location of a highly productive firm may not be chosen for walkability reasons but rather for other amenity factors such as waterfront location.
- Other proxies for productivity and walkability might have different results compared to the method used in this study. For example, ground floor rents could be a proxy for walkability for retail located in areas with high pedestrian traffic. Real estate prices also could be used as a proxy for productivity.

[29] Reverse causality means agglomeration effects can raise productivity; but an entrepreneur may also seek the most productive locations turning it into an agglomerated area.

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Glossary of terms

Centroid is the geometric centre of a feature such as polygons or lines. In network analysis centroids were used to define the network locations (origin and destination) of a pedestrian route.

Deep labour market is a labour market that only includes short-term unemployment

Distance decay is "a quantitative conception of the phenomena that things being further away are less likely to be used. It is used as one of the base assumptions when modelling human spatial behaviour, including assessment of accessibility of resources and mobility of the users". (Skov-Petersen, unknown)

Distance matrix is a square matrix (two-dimensional array) containing the distances, taken pairwise, between the elements of a set.

Elasticity is a measure of a variable's sensitivity to a change in another variable. For example the sensitivity of effective job density to changes in productivity.

Impedances is a measure of the amount of resistance, or cost, necessary to traverse through elements of a network. Resistance is typically measured by travel distance or speed – in this study the optimum (lowest cost) route was based on travel speed. Both accumulative travel speed and distance were derived from the lowest cost route.

Knowledge diffusion is the process by which science knowledge is spread.

Knowledge intensive industries are services and business operations heavily reliant on professional knowledge.

Travel zone is a geographic area that is defined specifically and covered in the study.

Appendix A: ANZSIC Level 1 industries

Agriculture, forestry, and fishing	A
Mining	B
Manufacturing	C
Electricity, gas, water, and waste services	D
Construction	E
Wholesale trade	F
Retail trade	G
Accommodation and food services	H
Transport, postal, and warehousing	I
Information media and telecommunications	J
Financial and insurance services	K
Rental, hiring, and real estate services	L
Professional, scientific, and technical services	M
Administrative and support services	N
Public administration and safety	O
Education and training	P
Health care and social assistance	Q
Arts and recreation services	R
Other services	S
Not elsewhere classified	T

Appendix B: Pedestrian crossing timing

Crossing	Walk	Clearance	Int Cycle	Total Walk Time	Red Time	Average Delay	Cycle
Albert Street / Wyndham Street	6	23	70	17.5	52.5	19.7	Short
Albert Street / Swanson Street	6	19	70	15.5	54.5	21.2	Short
Victoria Street / Queen Street	8	27	90	21.5	68.5	26.1	Short
Victoria Street / High Street	6	21	90	16.5	73.5	30.0	Short
Victoria Street / Kitchener Street	6	20	90	16	74	30.4	Short
Sturdee Street / Lower Hobson Street	6	13	100	12.5	87.5	38.3	Short
Wellesley Street / Queen Street	12	31	119	27.5	91.5	35.2	Short
Customs Street / Lower Albert Street	12	30	120	27	93	36.0	Medium
Customs Street / Queen Street	12	30	120	27	93	36.0	Medium
Quay Street / Lower Queen Street	12	27	120	25.5	94.5	37.2	Medium
Quay Street / Lower Albert Street	12	21	120	22.5	97.5	39.6	Medium
Queen Street / Shortland Street	12	19	120	21.5	98.5	40.4	Medium
Customs Street / Commerce Street	6	29	120	20.5	99.5	41.3	Medium
Wellesley Street / Elliot Street	12	15	119	19.5	99.5	41.6	Medium
Customs Street / Britomart Place	6	26	120	19	101	42.5	Medium
Customs Street / Gore Street	6	25	120	18.5	101.5	42.9	Medium
Queen Street / Wyndham Street	12	13	120	18.5	101.5	42.9	Medium
Wellesley Street / Kitchener Street	6	23	120	17.5	102.5	43.8	Medium
Queen Street / Fort Street	9	14	120	16	104	45.1	Medium
Quay Street / Britomart Place	6	19	120	15.5	104.5	45.5	Medium
Wellesley Street / Hobson Street	6	19	120	15.5	104.5	45.5	Medium
Victoria Street / Hobson Street	6	18	120	15	105	45.9	Medium
Quay Street / Commerce Street	6	16	120	14	106	46.8	Long
Quay Street / Gore Street	6	15	120	13.5	106.5	47.3	Long
Hobson Street / Wyndham Street	6	14	120	13	107	47.7	Long
Fanshawe Street / Lower Hobson Street	6	13	120	12.5	107.5	48.2	Long
Wellesley Street / Albert Street	12	31	135	27.5	107.5	42.8	Long
Victoria Street / Albert Street	6	25	135	18.5	116.5	50.3	Long
Victoria Street / Federal Street	6	18	135	15	120	53.3	Long
Victoria Street / Elliot Street	6	16	135	14	121	54.2	Long
Wellesley Street / Federal Street	6	16	135	14	121	54.2	Long

Appendix C: Census of businesses

Employment data is available for meshblocks (MB) as the finest geographic unit. In order to estimate the employment in a finer geographic unit for this study, a census of businesses in the study area was undertaken as part of this study. Information on the business name, address, location and main specialty of more than 3220 firms in 33 meshblocks was collected. Based on the location and the industry that was identified for each firm (based on its main activity), a proportion of employment of that industry in the respective MB was allocated to the firm.

The latest employment data is 2015 therefore we did not include firms that were established after 2015.

The industries we identified through the census were not always consistent with the MB employment data and we had to allocate employment to the closest building footprint with the similar industry, in the case of major employment. For example, one of the MB data showed more than 250 employment in the public administration and safety industry (specifically Auckland Council), but there was no council building located in that MB. Instead, employment for the main Auckland Council planning building was just around 300.

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