Enhancing Transportation Corridors to Support Southern Ontario Innovation Ecosystems

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McMASTER INSTITUTE FOR
TRANSPORTATION
& LOGISTICS

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Mark Ferguson

Carly Harrison

Joelle Pang

Chris Higgins

Pavlos Kanaroglou

McMaster Institute for Transportation and Logistics
McMaster University
Hamilton, Ontario

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EXECUTIVE SUMMARY

The research has clearly shown that the even the most exceptional of metropolitan innovation ecosystems suffer from rather mundane transportation problems. Intra-metropolitan highway corridors in such metros are some of the busiest and most congested seen anywhere. The 50-75km driving commute from the heart of San Francisco to the campuses of Silicon Valley can easily take two or three hours on a bad day. The risk of congestion is high but the options to avoid the highway remain limited as the well-known Bay Area Rapid Transit System (BART) is not well integrated with Silicon Valley. There is substantial traffic congestion risk on the 115km downtown Toronto to Waterloo corridor but there are, as of yet, no private “Google-style” shuttles to dampen the negative impacts.

While most big metros have transportation problems, many of these metros have given rise to, or have enabled, transportation innovations of recent years and decades. These include electronic tolling, HOV and HOT lanes, modern inter-city bus services, high-speed rail, suburban bus rapid transit systems, advanced commuter rail systems and regional rapid transit, managed lanes and expressways and others. Many of the largest and most successful feature considerable transportation diversity: there can be multiple transit systems in place (e.g. heavy, light, and commuter rail and others). When the likes of ridesharing, taxis or short term car rentals are taken into account, there can be multiple transport providers also. These transport alternatives are important to help minimize automobile dependence, including on inter-city corridors.

Much has been written in transportation circles about topics such as complete streets, active modes of travel, and real estate value uplift from investments in rail transit. A review of this literature gives a real sense of renewed appreciation for downtown living and reduction of one’s transportation footprint. This same trait is evident in observable patterns of highly focused downtown start-up activity. At the same time that more and more people are placing a higher value on central city living, there are many high-tech business investments taking place that offer nearby residents a place to work. The pattern has been very strong in San Francisco, New York, Boston and in less prominent cases like Denver. In the lower population success cases, such as Ann Arbor, Boulder or New Haven, the presence of top-flight universities is very important. In these cases, corridors to nearby large metros are very relevant as is the case for Waterloo.

Metropolitan innovation ecosystems come in different sizes and densities and this can lead to wide variations in how *intra-metropolitan* corridors function. The average setting in which the typical household in the New York metro area lives is about 15 times denser than is the case in Atlanta. It is no surprise then that Atlanta is much more dependent on the automobile than New York and helps to explain why the Atlanta region is currently working on some of North America’s largest metropolitan highway projects. This very basic metropolitan land use measure goes a long way to explaining what mobility options beyond the private automobile are even realistic on a day-to-day basis.

In the context of joining two or more metropolitan areas over distances of 75 to 150 km, the possibilities associated with *inter-metropolitan* corridors are affected by these same intra-metropolitan densities. Such corridors are lengthier and less intensely developed than their intra-metropolitan counterparts. Ground modes other than the automobile are much more dependent on high spatial concentrations of travelers so that originating trips can be consolidated; the destination context will ideally share similar characteristics.

Corridors of this length have challenges. While there are a small group of people known as "super-commuters" who travel great distances to work, driving commutes of over 100km are actually on the very outer limits of what is considered viable. The risk of serious congestion, which is shown to be quite real along built-up areas of Southern Ontario corridors, further reduces viability. To a point, people will tolerate more time for rail travel but commuter rail systems are not express-services. An important innovation metro such as Region of Waterloo is at the "end of the line" in commuter rail terms rather than being a focal destination.

Ann Arbor, Michigan is one of the leading U.S. innovation ecosystems and especially so in the context of smaller metropolitan areas. Its connection with nearby Detroit is clearly very important but the latter is a low-density metro especially lacking a densely populated core. Despite recent efforts to the contrary, the lack of a viable rail connection between Ann Arbor and Detroit stands in stark contrast to the U.K. pairing of Cambridge and London. This corridor is about 50% longer than the Michigan example but rail is the commuting mode of choice. For about $10,000 per year spent on inter-city rail, a person can live in London and work in Cambridge and the daily trip over 105km can be completed in as little as 50 minutes not including ingress and egress times. This is express-oriented travel as opposed to a multiple stop commuter rail trip and it is conventional as opposed to high-speed rail.

The conclusions of this research, which are discussed in more detail in the final chapter, are as follows:

- Leading metropolitan innovation ecosystems feature serious transportation problems mixed with innovative transportation solutions
- There are varied transportation models for metropolitan innovation ecosystems
- The corridor between the cores of Toronto and Waterloo, at 115 km, is a relatively long one for daily travel

- Metropolitan population density, when measured properly, is one of the most important transportation metrics
- All signs point to rail as an important means to draw innovation clusters within our region closer together
- There is an imbalance between inter-city highway infrastructure and inter-city passenger rail infrastructure in this region that ideally would be corrected over time
- Solutions less oriented to infrastructure are needed for local highways
- Targeted road infrastructure improvements are appropriate
- For the objective of joining innovation clusters at least, “two-tier” thinking is preferable to egalitarian thinking
- Dislodging truck freight from important regional highway innovation corridors to speed traffic flows would not be easy and is probably not wise
- A balanced transportation approach to innovation corridors seems prudent for this region

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Introduction and Background

1.1 Rationale and Objectives

The need for this report has arisen from the observation that Southern Ontario hosts prominent innovation clusters and metropolitan ecosystems that are world class. These clusters host thriving startup ecosystems as well. It has long been recognized that transportation is one of the most important economic enablers and yet the corridors that join important nodes in Toronto, Waterloo and Hamilton feature apparent possibilities for improvement. There is an opportunity to effectively pull innovation clusters in Southern Ontario closer together via efficient, multi-modal transportation corridors to maximize the potential for economic integration and innovation synergies.

With that brief background in mind, the primary objectives of this report are to:

- Assess the transportation character of other important innovation corridors with an emphasis on cases from the United States

- Consider some of the important quantitative metrics which can be used to characterize metropolitan ecosystems and the transportation corridors that link them
- Assess whether there are obvious constraints which hamper the performance of the corridors that join regional innovation clusters and to do so in the Southern Ontario cases as well.
- Assess some of the transportation “best practices” from other jurisdictions which seem to offer the most support for efficient innovation corridors
- Characterize traffic congestion patterns on the important highway corridors in Southern Ontario through the analysis of data from INRIX corporation
- Synthesize available insights from elsewhere, and the current situation locally, to suggest means by which these important local transportation corridors might be enhanced

1.2 An Overview of Innovation Clusters

It has been documented that innovation tends to manifest itself via some specific geographic patterns. In particular, innovation tends often to occur in a spatially concentrated manner known as clusters (Porter M. , 2000). A cluster is a “geographically proximate group of interconnected companies and associated institutions in particular field, linked by commonalities and complementarities.” While Porter notes that clusters can be associated with particular nations or regions, metropolitan areas in practice are almost always an important driving force in their generation and support.

There are a variety of reasons why innovation clusters are more likely to appear in metropolitan areas and most have to do with the vibrancy and intensity of such areas. The importance of metropolitan areas in the innovation context is further reinforced by some prominent applied work on what makes for a successful business start-up (Compass, 2015). Compass clearly makes the point that certain metropolitan areas provide the right “ecosystem” for startups to thrive. Their ranking of some of the top ecosystems in the world is, in fact, a listing of world metropolitan areas. This approach dovetails nicely with the findings of other research linking metropolitan areas and innovation. In many ways, the metropolitan area is a fundamental unit of analysis in this paper.

The types of progressive firms and sectors that together give rise to innovation may be software-oriented firms (Compass, 2015) or related to the life sciences (JLL, 2014) among others. They are important sources of future job growth and the innovative outputs of these industries are already in the process of profoundly affecting daily life for millions of people. Many important innovations emerge from large and established firms but some of the most important essentially come from start-up firms with disruptive new ideas for products or services. New patents, venture capital deals and ultimately a culture/ecosystem of innovation are associated with the firms and their metropolitan areas that drive innovation.

It is worth mentioning that innovation clusters are but one type of spatial cluster. For example, Sheffi (2012) dedicates a book to the exploration of logistics clusters. Such a cluster forms because participant firms in the logistics sector benefit in various ways from agglomeration and being in close spatial proximity. A logistics cluster would not be defined as an innovation cluster per se which is not to imply that logistics firms are not innovative. Most firms that seek to be competitive are constantly looking to improve their operations, cut their costs and operate more efficiently. Often the effective use of new technologies is an effective means to accomplish this.

If there is one distinguishing feature about firms in innovation clusters relative to other firms, it is a focus on the development of new technologies as opposed to the leveraging of existing technologies. Certainly firms in innovation clusters can do both but the emphasis is on the former. If occurring in a cluster with sufficient scale, this focus can lead to a surrounding environment or culture which features venture capital and angel investors who seek to guide and benefit from early stages of company growth. Entrepreneurs go to such places in much the same way that actors will flock to Hollywood. The associated culture is typically most developed in larger metropolitan areas or in University centres not far from larger metropolitan areas. The culture is most strongly associated with San Francisco/Silicon Valley where there is anecdotal evidence, for example, that local gyms will offer free services in exchange for equity in a start-up (Compass, 2015).

The earlier example of a logistics cluster would not feature this type of environment and neither would the typical general employment cluster which would contain representation across a much wider range of industrial sectors or from the public sector. General employment clusters can be quite large. They can occupy a significant portion of a city and they can be responsible for generating significant traffic and congestion. Their externalities can certainly impact the operation of innovation clusters.

Innovation is not just synonymous with business start-ups. Firms that are already large and well-established account for a significant share of the patents that are issued every year. Sometimes these larger firms are interspersed with the start-up culture and in other cases they may be housed in relatively isolated suburbs. Nowadays, when people are thinking of innovation clusters though, these are focused a lot on the intersection of start-ups and central cities. As it turns out, central cities have received much attention in transportation circles as well as the following section indicates.

1.3 Innovation Clusters and Transportation

Transportation is a lifeblood of metropolitan areas and is one of the most critical economic enablers. Transportation means to a metropolitan area what running water means to a household. What goes for metropolitan areas also goes for innovation – good transportation networks and infrastructure are needed for both to thrive. It is not an exaggeration to say that almost any interaction that involves even relatively small distances depends on the availability of good transportation infrastructure.

Complicating the analysis of the relationship between transportation and innovation clusters, especially looking into the future, is that transportation itself is experiencing a period of rapid innovation. Dan Ammann, the president of GM, has recently said that transportation will change more in the next five years than it has in the past fifty. Disruptive technologies such as smartphones, and electric, autonomous and connected vehicles are making it more difficult to make plans and forecasts about required transportation infrastructure.

One thing that transportation and innovation clusters are sharing in common is an increasing emphasis on the urban core as a place for people to live, work and play. In transportation circles there has been great emphasis on the possibilities for light rail transit and complete streets to greatly enhance the livability of urban corridors (Higgins & Ferguson, 2012; Ferguson, Higgins, Lavery, & Abotalebi, 2015) and in the process reduce dependence on the automobile. Active forms of travel such as walking and cycling are being emphasized more and more in urban planning documents. Meanwhile, the urbanization of innovation is being seen as a powerful trend (Florida & Mellander, 2014; Clark & Moonen, 2015). In the heart of San Francisco, no fewer than 34 startup software companies have achieved billion dollar valuations within the past decade or so (Atomico, 2015), and each is located in the most urbanized of environments. This level of recent urbanized and successful startup intensity has not been matched in the more suburbanized Silicon Valley nearby. The fact that thousands of Silicon Valley employees are choosing to live in the heart of San Francisco also testifies to the power of this trend.

1.4 Transportation Improvements and Economic Development Impacts

One difficulty with transportation improvements is specifically linking them to economic outcomes. This is a very challenging area of study. In many cases, transportation improvements are not assessed through economic metrics but rather through measures that relate more specifically to transportation. For example, the impact of measures to reduce highway bottlenecks might be measured primarily through traffic flow impacts. Also there are economic impact studies that focus as much or more on the economic benefits associated with construction more so than what happens when construction is complete e.g. (InterVISTAS Consulting Inc., 2015).

While there can be little doubt that transportation infrastructure taken as a whole is a very good thing for development, one of the dominant themes that emerges from the literature is that incremental transportation improvements have a reallocative effect. From an economic impact perspective, this means that there can be "winners and losers" from corridor improvements. Since some locations may end up relatively worse off, it becomes more complicated to assess net economic benefits. Another issue is that as transportation infrastructure becomes more developed in a region, there is a greater possibility that some improvement will be subject to diminishing returns which would dampen economic benefits. Some useful sources that highlight these themes as it relates to highways are Ewing (2008) and also Boarnet (1995). In the context of high-speed rail see Givoni (2006) and in the context of light rail transit see Higgins and Kanaroglou (2014). Munroe et al. (2006) analyze cases in California to assess economic impacts of toll roads.

To the extent that economic or financial impacts have been reported upon in the material that has been reviewed for this report, these results are mentioned. For example, in Section 2.2.5 economic costs associated with traffic congestion in U.S. metros are reported upon. The methodology to do so is based on some very straightforward assumptions. Some results emerge from case-studies in the report. For example, it is estimated that Denver's multiple FasTracks projects have injected more than $5 billion into the local economy and have created 13,000 full-time jobs (Whaley, 2015) even as work on these projects continues.

1.5 The Importance of Transportation Corridors

Transportation corridors are plentiful within metropolitan areas and, as will be shown below, many of these are very heavily travelled. Among other purposes, such corridors are very useful for connecting innovation clusters. While it is possible for multiple innovation clusters to reside within the same metropolitan ecosystem it is also possible for two clusters to span over multiple, relatively nearby metropolitan areas and potentially to be seen as participating in two distinct ecosystems. Of particular interest for this report is the case where two or more apparent ecosystems teeter on the borderline of being considered as one; they are far enough apart that simultaneous transport options may exist for private, inter-city transport, and also for commuter forms of public transit.

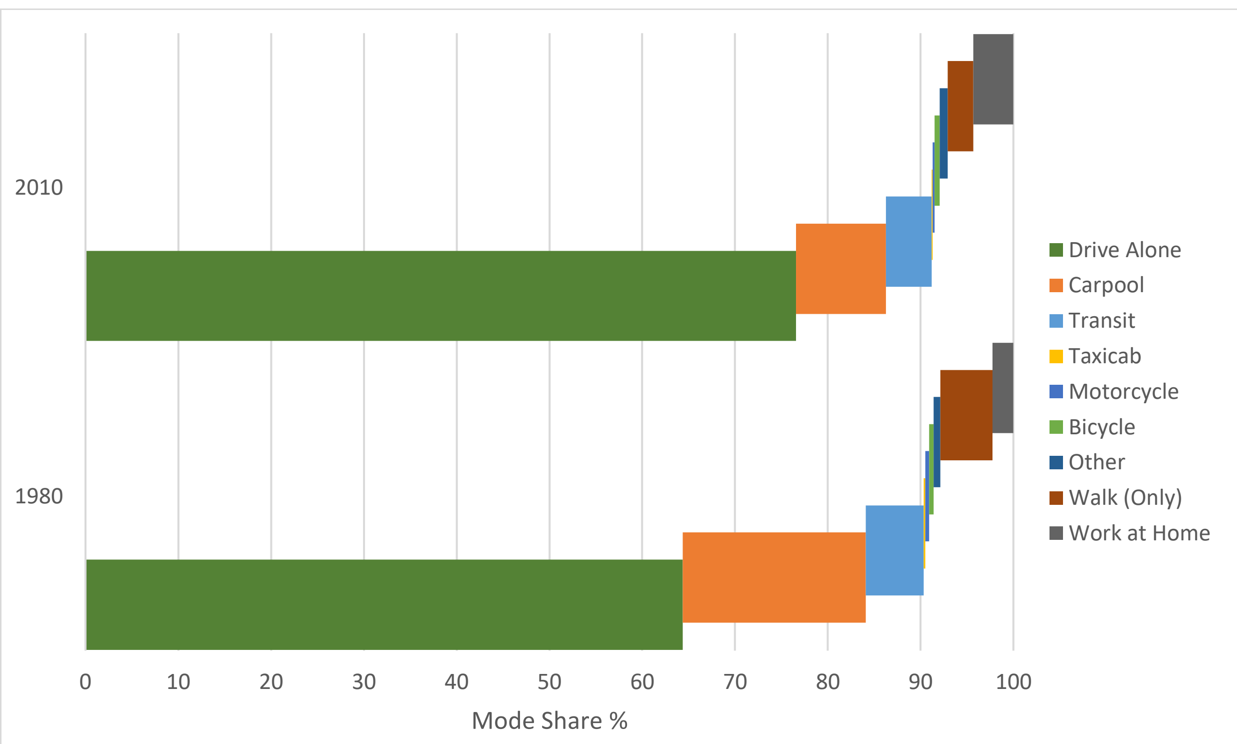
Clearly, the concept of a corridor is central in this context as well but the corridor will tend to be longer and less densely populated than its metropolitan counterpart. Moreover, there is the possibility that shorter, multimodal urban corridors are combined with inter-metropolitan corridors to compose an end-to-end trip solution. In other cases, lower density, suburban origins or destinations may be involved and there will be few apparent mode options to traverse the distance that do not involve the automobile. Overall, the lower-density and longer corridors still have their challenges.

1.6 Commuting Behaviour and "Super-Commuting"

Of all the forms of trip-making, commuting behaviour is one of the most important to consider. AASHTO (2013) provides a good overview of the topic for the United States and offers some of the basic insights discussed here.

Commuting captures the fundamental geographic realities of where to live and where to generate a living and the associated travel behaviour occurs most every work day. A metropolitan area is sufficiently large and dense to permit a wide range of live and work possibilities for the working members of a household. Living and working in entirely separate metropolitan entities is relatively rare for a given person but becomes more likely when we consider multiple worker households. The flow of workers is intimately related to the labour pools to which firms have access and which ultimately affect economic performance. Smaller, somewhat isolated metro ecosystems can be particularly challenged in this respect.

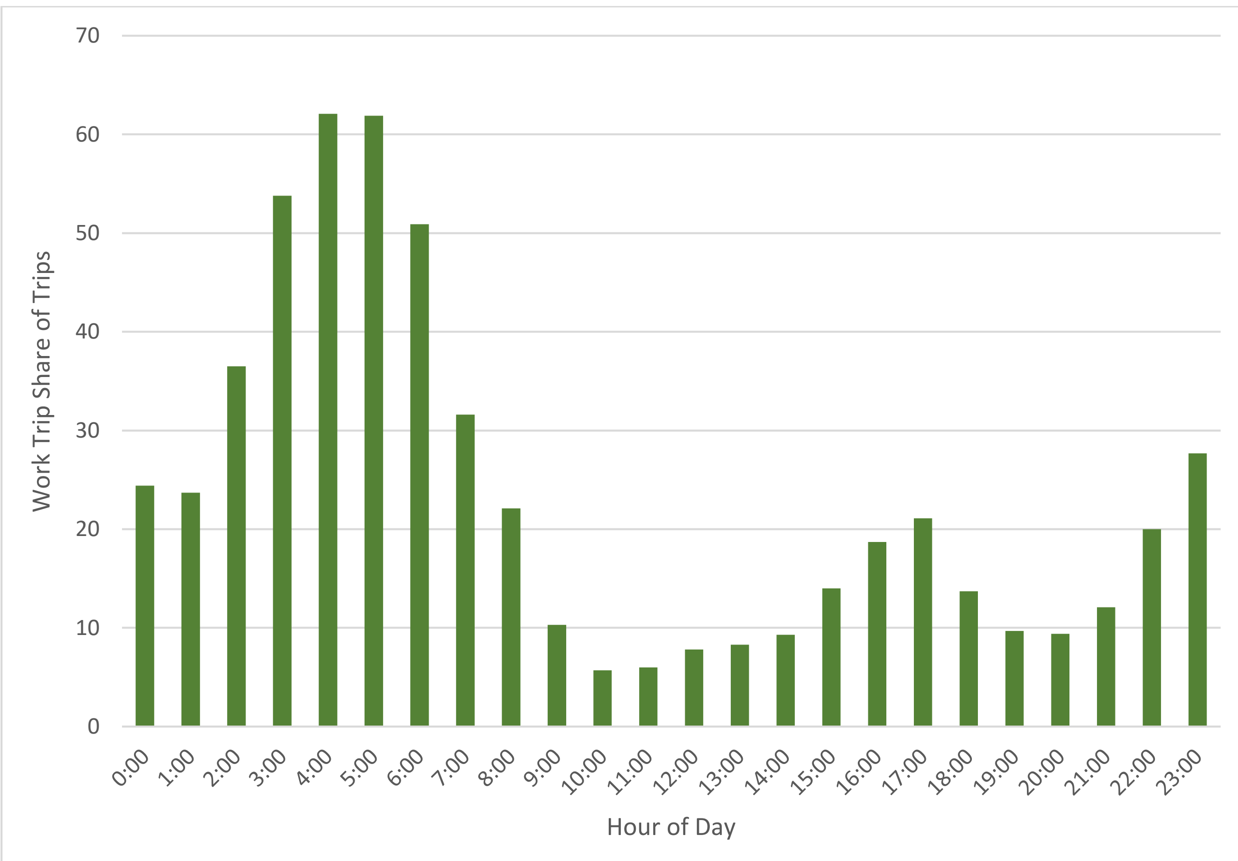
Figure 1-1: Differences in U.S. Commuting Modes: 1980 versus 2010



Source: Adapted from AASHTO (2013)

Figure 1-1, which does not focus on any particular corridor length, offers some current and long term perspective on how U.S. commutes are made. The importance of car travel as of 2010 was similar to its status in 1980 but driving alone has gained importance relative to carpooling. Transit shares have actually declined since 1980, although the absolute number of transit trips has increased, and active modes of travel (walking, cycling) are not too consequential. Working at home has increased but is at less than five percent as of 2010.

Figure 1-2: U.S. Commuting Trips as a Share of Total Trips by Hour of Day



Source: Adapted from AASHTO (2013)

Commuting trips to and from work are but one of several types of trips that people make. There are also trips related to shopping, appointments, and social and recreational activities which are generally more discretionary in nature. Of considerable relevance for this study is the U.S. National Household Travel Survey estimate that 21.6% of actual trips to work (i.e. the final leg) do not actually originate at home and 41% of trips from work (i.e. the initial leg) do not end at home (AASHTO, 2013). In both cases, trips to other destinations are involved. It could be because of household chauffeuring activity, meals or shopping/errands among other possibilities. Living and working in separate metropolitan areas can make the co-ordination of such complex travel patterns more challenging. These latter factors are likely to have a profound impact on the modes that people choose as well. There are generally more options/possibilities when driving.

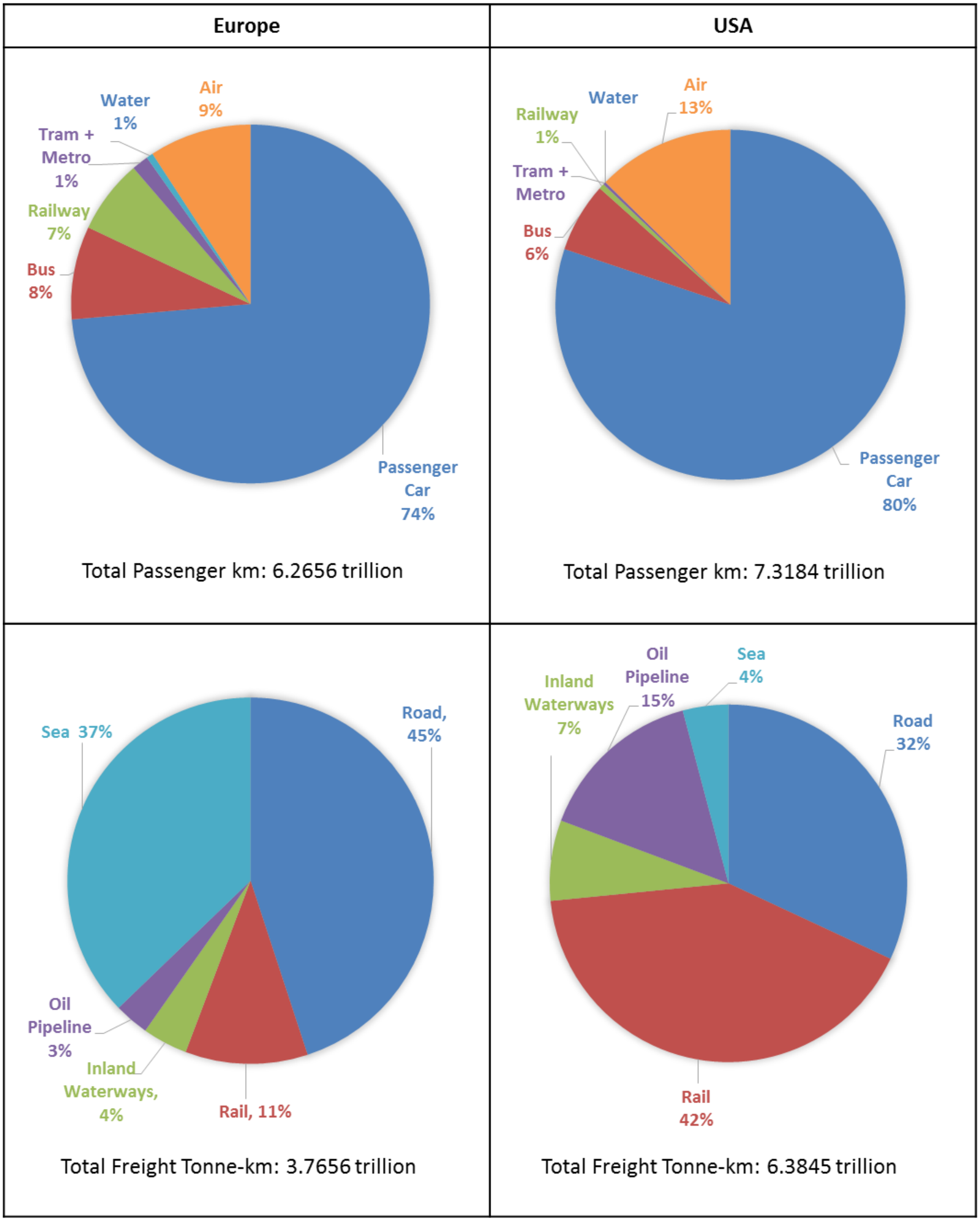
Another very relevant fact for this study is that work trips actually compose a smaller share of trips than one might think. This share has actually declined significantly over time as personal travel patterns have become more complicated. Figure 1-2 shows that by 8AM, the time most associated with peak AM traffic, the share of trips that are actual commuting trips are little more than 20%. At that time many people are driving around for many different purposes but only a fairly small minority are commuting. These somewhat surprising inter-city oriented results could have policy implications for how important travel corridors are treated.

This section on commuting would not be complete without acknowledging the growing trend of super-commuting. There are full-time workers, who can be professionals or more middle-class oriented, and who commute what would seem to be unrealistic distances to get to work (Van Praet, 2012; Moss & Qing, 2012). It was estimated that Manhattan alone has 59,000 super-commuters (Dawson, 2014). Some of these commutes are of the week-long variety and often involve flying. Many are due to perceived economic and job instability that has middle class Americans commuting a long distance rather than relocating (Torrieri, 2013). There has been a similar phenomenon in Europe (Mount, 2015). Prominent super-commuting corridors in Canada are Edmonton-Calgary, Ottawa-Toronto and Quebec City - Montreal, among others (Van Praet, 2012). Traversing the Toronto-Waterloo corridor does not constitute a super-commute per se but under present circumstances, it is an uncomfortable commute if done on a daily basis.

1.7 Comparisons of Freight and Rail between North America and Europe

In terms of understanding the modes that can move people within and between innovation clusters, Figure 1-3 is useful. Passenger cars are extremely important in both Europe and North America for moving people for all purposes. In Europe, passenger cars are somewhat less important than in the United States, but any stereotype that suggests driving is not important in Europe is in error. The other noteworthy difference is the much greater prominence of passenger rail in Europe. As a share of total passenger-km movement, rail is not strongly prominent in Europe, but it is very relevant and useful at peak times of travel and in certain metropolitan contexts. The fact that air travel is less prominent in Europe is partly related to the greater role seen there for high-speed rail.

Figure 1-3: Importance of the Modes in Moving People and Freight (Europe vs. United States)



Source: (European Union , 2014)

The lower two pie charts focus on total tonne-km moved in the freight context. On a relative basis, freight by rail is almost four times more important in the U.S. than it is in Europe. Road is proportionally more important for freight in Europe than it is in the U.S. and waterborne movements of freight are much more significant for Europe. Overall, movement of freight in the U.S. is more land-based than it is in Europe and there is no doubt that the heavy use of rail and pipelines is helping to keep a lot of trucks off the road in North America. Joining innovation clusters is not really a “freight story” per se. Moving people is much more relevant. Accordingly, an important theme in North America could be that the dominance of freight by rail is crowding out possibilities for moving people by rail, with inter-city rail suffering the most. Further evidence is offered in that regard in subsequent chapters.

1.8 Scope

- This report is covering many different aspects associated with the travel corridors that draw innovation clusters together. It is quite possible that detailed reports could be written on many of the individual topics highlighted within this document. This report should be seen as a high level overview and assimilation of many topics that are associated with streamlining inter-metropolitan travel corridors in support of innovation clusters.

- The report does not deal in an in-depth manner with the financial or engineering feasibility of specific measures that could be implemented to improve movements along innovation corridors. For example, if observations are made about the potential to improve road infrastructure, they do not take into account the potential high costs of doing so.

- This report focuses on forms of ground travel that have been implemented somewhere in the world or will be in the near future. Accordingly, there is no focus on prospective technologies such as the hyperloop that are years or decades from implementation. Even if hyperloop were developed somewhere in the world within the next decade, It is worth noting that high-speed rail was first developed in the early 1960’s but has never been implemented in North America.

- This report touches on economic development aspects associated with transportation corridor improvements and offers some empirical evidence but a detailed analytical treatment is beyond the scope of this report.

Overview and Metrics for Metropolitan and Corridor Cases

The purpose of this chapter is to compare important transportation metrics from U.S. metropolitan areas that host the largest innovation ecosystems. To facilitate this analysis, a database of the top 100 U.S. metropolitan innovation ecosystems was compiled from a variety of metropolitan data sources. Upon reviewing the larger list of metropolitan areas, a handful of the metropolitan areas will then be discussed in further detail in Chapter 4. This latter analysis will also include a review of the U.K. corridor of London-Cambridge. Overall, the results should offer a useful frame of reference and some good analogies for cases in Canada. Underlying the whole analysis is a focus on the concept of the transportation corridor which joins innovation clusters together at the intra-metropolitan and inter-metropolitan levels.

2.1 Overview

A database of the top 100 most significant and innovative U.S. metropolitan areas was compiled. The ranking of these 100 was based on two aspects: the number of utility patents granted to recipients in these metros from 2000 to 2013 and the number of Venture Capital deals associated with these metros in 2015. Both of these aspects were weighted equally in deriving the ranking. The precise ranking of a given metro is perhaps less important than the idea that we have chosen the best set of 100. Data sources that were used to develop the database are shown in Table 2-1 while some of the most important variables within the final data set are shown in Table 2-2.

Table 2-1: Important U.S. Metropolitan Data Sources

Data Source	Data Description
United States Census Bureau: 2010-2014 American Community Survey (5 Year Estimates)	The American Community Survey (ACS) is an ongoing survey that provides annual information on the United States of America. It provides information on people, housing, jobs, occupations, and mode choice travel habits to name a few.
Federal Transit Administration's 2013 National Transit Database	The National Transit Database (NTD) is the nation's primary source for transit systems data and information that are found within the United States. As of 2013, over 750 transit providers in urbanized areas report to the NTD.
United States Patent and Trademark Office – Patent Technology Monitoring Team	The United States Patent and Trademark Office (USPTO) is the federal agency for granting U.S. patents and registering trademarks.
PricewaterhouseCoopers National Venture Capital Association	The MoneyTree™ Report is a collaboration between PricewaterhouseCoopers and the National Venture Capital Association. The Report is a source of information on emerging companies that receive financing and the venture capital firms that provide this financing.
US Department of Transportation – Federal Highway Administration	Federal Highway Administration is an agency within the U.S. Department of Transportation that supports State and local governments in the design, construction and maintenance of the Nation's highway system.
2015 Texas Transportation Institute Urban Mobility Report	The Texas Transportation Institute since 1982 has assessed metropolitan traffic congestion in the United States and has developed several metrics to characterize it.
United States Census Bureau: Metropolitan and Micropolitan Population Data	Metropolitan/micropolitan statistical areas are geographic regions outlined by the Office of Management and Budget. Federal Statistical Agencies collect and tabulate federal statistics.

Table 2-2: Important Variables to Compare Metropolitan Ecosystems

Variable	Description
Total Population	Total number of people living within the metropolitan area
Weighted Population Density	Measured in people/square mile – derived from the census tracts' population densities that are found within the boundary of the metropolitan area. This provides a more accurate characterization of the typical environment the average person lives in
Metropolitan Delay per Auto Commuter	A measure of metropolitan traffic congestion showing annual hours of delay per auto commuter
Average Annual Traffic Volumes	A measure of traffic congestion illustrating the volumes within metropolitan areas on key freeways
Commuting Mode Choice Share	Identifies the mode of transport people use within the metropolitan areas to travel to work
% of Commutes Greater than 60 Minutes	The percentage of people who have commutes to work longer than 60 minutes, distinguished by mode choice
Freeway Planning Time Index	A measure of metropolitan traffic congestion which assesses extra time that must be added to reach a destination by a certain time depending on the time of day
Travel Time Index	A measure of metropolitan traffic congestion. It is the ratio between the peak-period travel time to the free-flow travel time
Congestion Cost	Average cost of congestion for a given metropolitan area, often in billions of dollars per year
Walkable Urbanism Index	A highly walkable urban area is an area with a much higher density, a mix of real estate types and efficient transportation systems connecting the surrounding areas including cycling, rail and motor vehicle routes
Freeway Lane Miles	Provides an indication of the length of freeway lane miles each metropolitan area has
Number of Transit Stations	Illustrates the size and connectivity of the metropolitan area's transit systems
Total Daily Transit Trips	Illustrates the total number of rail or bus trips per metropolitan area on a typical day. Total annual trips divided by 365 days, therefore underestimates typical weekday travel
Patent Counts	A patent is a government license that gives the holder exclusive rights to a process, design or new invention. Provides an indication of the level of innovation within metropolitan area
Venture Capital Deals	The number of startup deals within a given metropolitan area. Venture capital is money provided by investors to start-up firms and small businesses with perceived long-term growth potential

Initially, an overview of some key metropolitan variables is offered. Figure 2-1 provides patent counts by metropolitan statistical area (MSA) for 2012 while Table 2-3 provides a tabular ranking to help put the metropolitan ecosystems into context.

Figure 2-1: Patent Counts by MSA, 2013

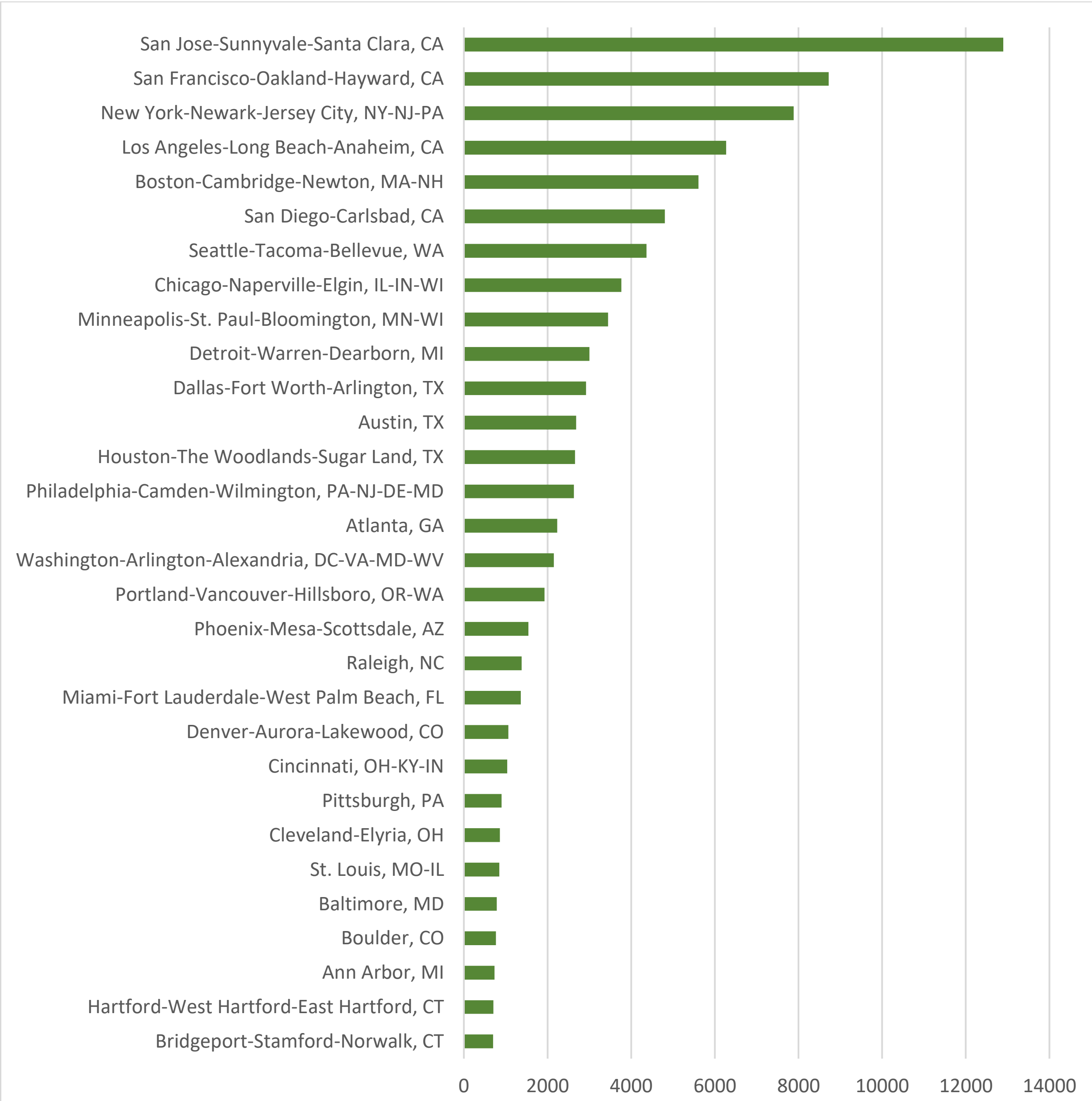


Table 2-3: Overview Table for U.S. Top 50 Innovation Ecosystems

	Metropolitan Area	Population	Pop. Density per sq-mile	Drive Share (%)	2015 Venture Capital Deals
1	New York-Newark-Jersey City, NY-NJ-PA	19,865,045	31,251	56.64	478
2	San Francisco-Oakland-Hayward, CA	4,466,251	12,145	68.60	942
3	San Jose-Sunnyvale-Santa Clara, CA	1,898,457	8,418	86.61	379
4	Boston-Cambridge-Newton, MA-NH	4,650,876	7,980	74.45	428
5	Los Angeles-Long Beach-Anaheim, CA	13,060,534	12,114	84.30	293
6	Seattle-Tacoma-Bellevue, WA	3,557,037	4,722	78.79	110
7	Chicago-Naperville-Elgin, IL-IN-WI	9,516,448	8,613	78.61	87
8	San Diego-Carlsbad, CA	3,183,143	6,921	84.70	100
9	Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	6,015,336	7,773	80.84	115
10	Austin, TX	1,835,016	3,131	86.64	99
11	Washington-Arlington-Alexandria, DC-VA-MD-WV	5,863,608	6,388	75.74	111
12	Minneapolis-St. Paul-Bloomington, MN-WI	3,424,786	3,383	85.85	29
13	Atlanta, GA	5,455,053	2,173	87.84	70
14	Portland-Vancouver-Hillsboro, OR-WA	2,288,796	4,373	80.10	41
15	Dallas-Fort Worth-Arlington, TX	6,703,020	3,909	90.67	28
16	Houston-The Woodlands-Sugar Land, TX	6,204,141	4,110	91.03	29
17	Pittsburgh, PA	2,358,793	2,991	85.66	93
18	Miami-Fort Lauderdale-West Palm Beach, FL	5,775,204	7,395	87.65	32
19	Denver-Aurora-Lakewood, CO	2,651,392	4,804	85.14	51
20	Baltimore, MD	2,753,396	5,436	85.36	41
21	St. Louis, MO-IL	2,797,737	2,742	90.06	41
22	Phoenix-Mesa-Scottsdale, AZ	4,337,542	4,395	87.56	24
23	Detroit-Warren-Dearborn, MI	4,292,647	3,800	92.91	16
24	Cincinnati, OH-KY-IN	2,131,793	2,564	90.70	26
25	Boulder, CO	305,166	3,650	74.96	29
26	Raleigh, NC	1,189,579	1,850	88.98	21
27	Cleveland-Elyria, OH	2,067,490	3,808	89.07	21
28	Ann Arbor, MI	351,454	3,363	79.63	25
29	Bridgeport-Stamford-Norwalk, CT	934,215	5,122	79.80	15
30	Hartford-West Hartford-East Hartford, CT	1,215,159	3,251	89.22	18
31	Rochester, NY	1,082,578	2,909	89.38	8
32	Durham-Chapel Hill, NC	525,050	1,860	84.65	22
33	Indianapolis-Carmel-Anderson, IN	1,931,182	2,286	92.65	15
34	Salt Lake City, UT	1,123,643	4,564	87.15	25
35	Sacramento--Roseville--Arden-Arcade, CA	2,197,422	4,538	86.68	12
36	Columbus, OH	1,948,188	3,186	90.63	24
37	New Haven-Milford, CT	863,148	4,007	86.32	21
38	Providence-Warwick, RI-MA	1,604,317	4,764	88.98	12
39	Albany-Schenectady-Troy, NY	875,567	2,945	87.45	5
40	Provo-Orem, UT	550,774	4,270	86.33	28
41	Madison, WI	620,368	3,502	81.46	20
42	Tampa-St. Petersburg-Clearwater, FL	2,851,235	3,323	88.49	9
43	Oxnard-Thousand Oaks-Ventura, CA	835,790	5,542	89.45	5
44	Memphis, TN-MS-AR	1,337,014	2,372	93.51	27
45	Boise City, ID	639,616	2,310	88.00	3
46	Nashville-Davidson--Murfreesboro--Franklin, TN	1,730,515	1,695	91.51	41
47	Santa Rosa, CA	491,790	3,254	85.38	20
48	Kansas City, MO-KS	2,040,869	2,326	91.83	4
49	Albuquerque, NM	899,137	3,519	88.92	14
50	Burlington-South Burlington, VT	213,891	2,054	84.48	5

Table 2-3 supports the notion that scale has a lot to do with successful innovation ecosystems[1]. The top 25 contains all of the most heavily populated MSAs and within that list there is only one small metro: Boulder, Colorado which is located in close proximity to Denver. High population combined with high population density appear to work together in fueling an ecosystem. The top ecosystems have the lowest drive shares, which translates into more reliance on public transit, but there are several metros outside the top 10 with drive shares of over 90%. Few places outside the top 10 have population densities in excess of 5,000 persons per square mile. There is remarkable variation in population density across metros. New York is on the order of 15 times more dense than Atlanta.

It is important to note that transportation and land use are intimately connected. More transportation options are possible when land is used more intensively. For example, public modes of transport such as heavy rail subways or light rail systems are most effective when population densities are relatively high. On this basis, it is not hard to see why New York offers a more favourable environment for public transit than Atlanta. The transport corridors formed by transit modes can also be a tool to support population intensification. Population density is thus a good land use metric that has implications for transportation.

In recent years, more attention has been paid to population-weighted population density (Wilson, Plane, Mackun, Fischetti, & Goworowska, 2012). The goal of this approach is to derive a better understanding of the density of the environment in which the average person lives. For a given metropolitan area, this is done by calculating the population density for each census tract and then calculating a weighted average of each result by tract where the weight for each tract is its population[2]. This is the approach used in Table 2-3.

Of interest for this research is the concept of the smaller metro that hosts a significant innovation eco-system. Table 2-4 presents a list of those smaller U.S. metros derived from the Top 100 list. The smaller metros generally seem to share two things in common. One is that a major university is associated with the smaller metro and secondly is the fact that a major U.S. metro is generally within little more than an hour's driving time. Four small U.S. metros rank within the top 50 out of the Top 100 indicating that from an innovation perspective, it is possible for small metros to have a higher profile than many places that are much larger.

[1] Note that the "drive share" column is the sum of drive alone and carpooling

[2] For example, the unweighted population density for the U.S. as a whole is 87.4 (total U.S. population divided by total U.S. land area) but the population-weighted result is 5369. The latter is a far more accurate characterization of the environment in which the average person lives. This same weighted approach for metropolitan areas shows that the New York MSA tops the list at 31,251 people per square mile.

Table 2-4: Corridors Associated with Small, Innovative U.S. Metros

RANK	SMALL METRO AREA	UNIVERSITY IN SMALL METRO	POPULATION OF SMALL METRO	NEARBY LARGE METRO	CAR TRAVEL TIME	DISTANCE
25	Boulder, Colorado	University of Colorado Boulder	305,166	Denver, Colorado	35min – 55min	45.6km
28	Ann Arbor, Michigan	University of Michigan	351,454	Detroit, Michigan	45min – 1h10min	69.9km
37	New Haven, Connecticut	Yale University	863,148	New York City, New York	1h40min – 2h20min	130km
40	Provo, Utah	Brigham Young University	550,774	Salt Lake City, Utah	50min – 1h15min	70.7km
52	Tucson, Arizona	University of Arizona	993,144	Phoenix, Arizona	1h40min – 2h10min	183km
58	Worcester, Massachusetts	Worcester Polytechnic Institute	924,722	Boston, Massachusetts	55min – 1h20min	78.1km
66	Ithaca, New York	Cornell University	103,179	Syracuse, New York	1h – 1h10min	83.3km
69	Champaign-Urbana, Illinois	University of Illinois Urbana-Champaign	234,672	Chicago, Illinois	2h – 2h40min	217km
70	Reno, Nevada	University of Nevada Reno	433,919	Sacramento, California	2h – 2h40min	212km
73	Huntsville, Alabama	University of Alabama Huntsville	430,396	Birmingham, Alabama	1h25min – 1h50min	159km
74	Charlottesville, Virginia	University of Virginia	223,063	Richmond, Virginia	1h10min – 1h25min	122km
79	San Luis Obispo, CA	California Polytechnic State University	274,184	San Jose, California	2h40min – 3h10min	297km
84	Gainesville, FL	University of Florida	268,707	Jacksonville, Florida	1h15min – 1h40min	114km
94	Baton Rouge, Louisiana	Louisiana State University	814,805	New Orleans	1h15min – 1h40min	129km

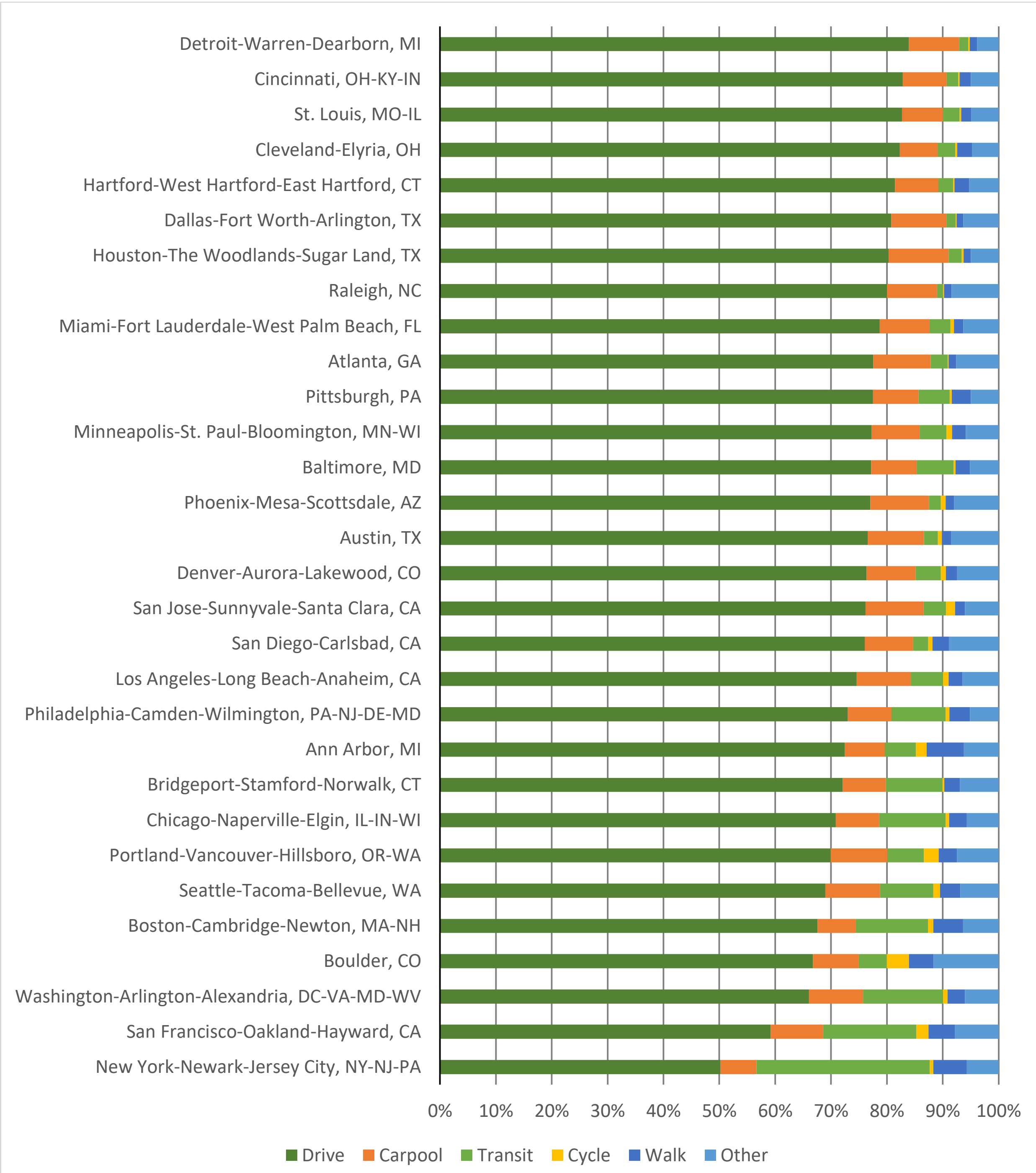
2.2 Transportation-Oriented Metrics

In this section, some useful metrics or indicators are used to compare the largest U.S. ecosystems. The results are primarily focused on U.S. cases but some selected data for Canadian cases are considered.

2.2.1 Commuting Modal Splits

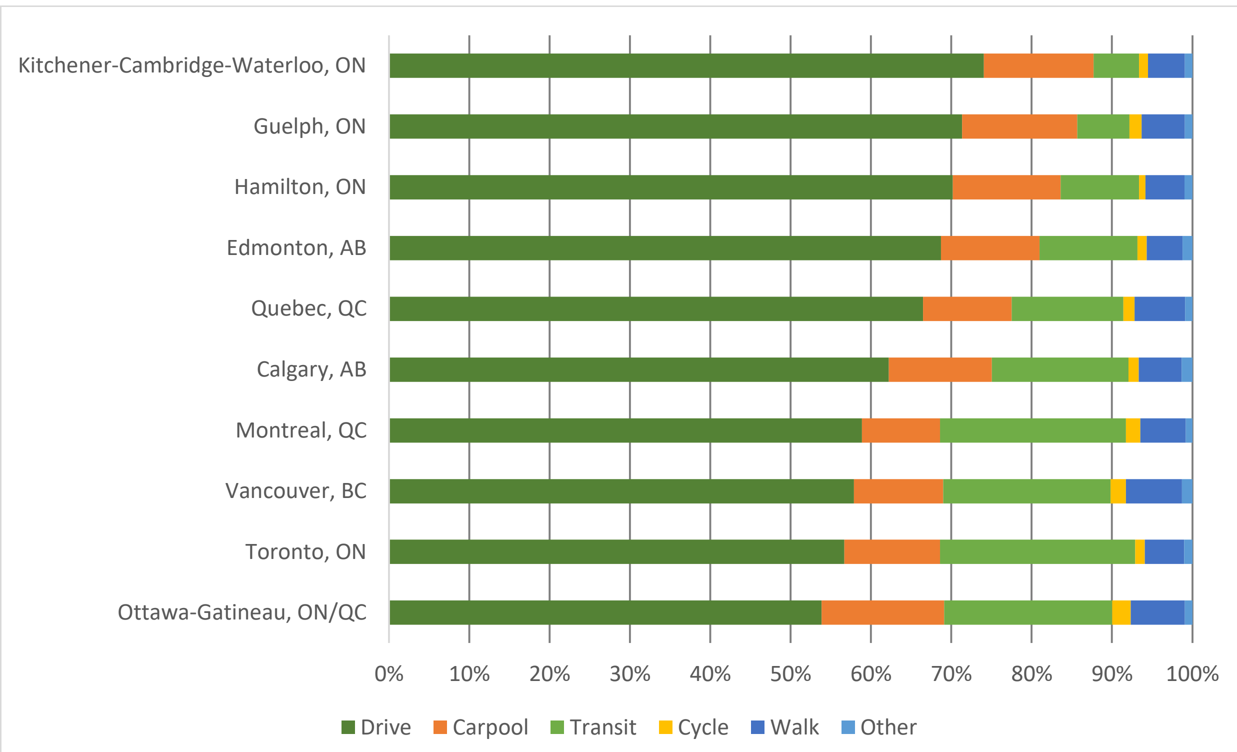
In Figure 2-2, the two components of driving (drive alone and carpooling) are broken down in more detail along with other modal possibilities. The table is sorted based on the drive alone share. The "other" category includes aspects such as working from home, taxis and more.

Figure 2-2: Commuting Mode Share Across Top 30 USA Innovation Metros



Driving alone represents the majority of trips in every MSA except New York. In most every MSA, in fact, the drive alone share represents a very comfortable majority. It is interesting that sorting the top 30 on drive alone almost seems to lead to a reversal of the top 30 that was based on the innovation ranking. Other aspects that stand out are the general prominence of the carpooling mode and the fact that there are some metros where cycling has no discernable share. Figure 2-3 offers a similar chart for top Canadian metros also sorted based on drive alone. It can be seen that Canada's three largest metros, Toronto, Montreal and Vancouver each have drive alone shares of less than 60%. There are only two such metros that meet this criterion in the U.S. out of a much larger list of metros. From a transit perspective, Canada does not have any metropolitan area with a transit commuting share as high as New York's but has several metro areas with a higher share than San Francisco which ranks second in the U.S. in this regard. Carpooling has a robust share in each Canadian metro.

Figure 2-3: Commuting Mode Share Across Top 10 Canadian Innovation Metros[3]



[3] There are differences in how commuting data are set up in Canada and the U.S. One implication is that the "other" category has some differences between these sets of charts.

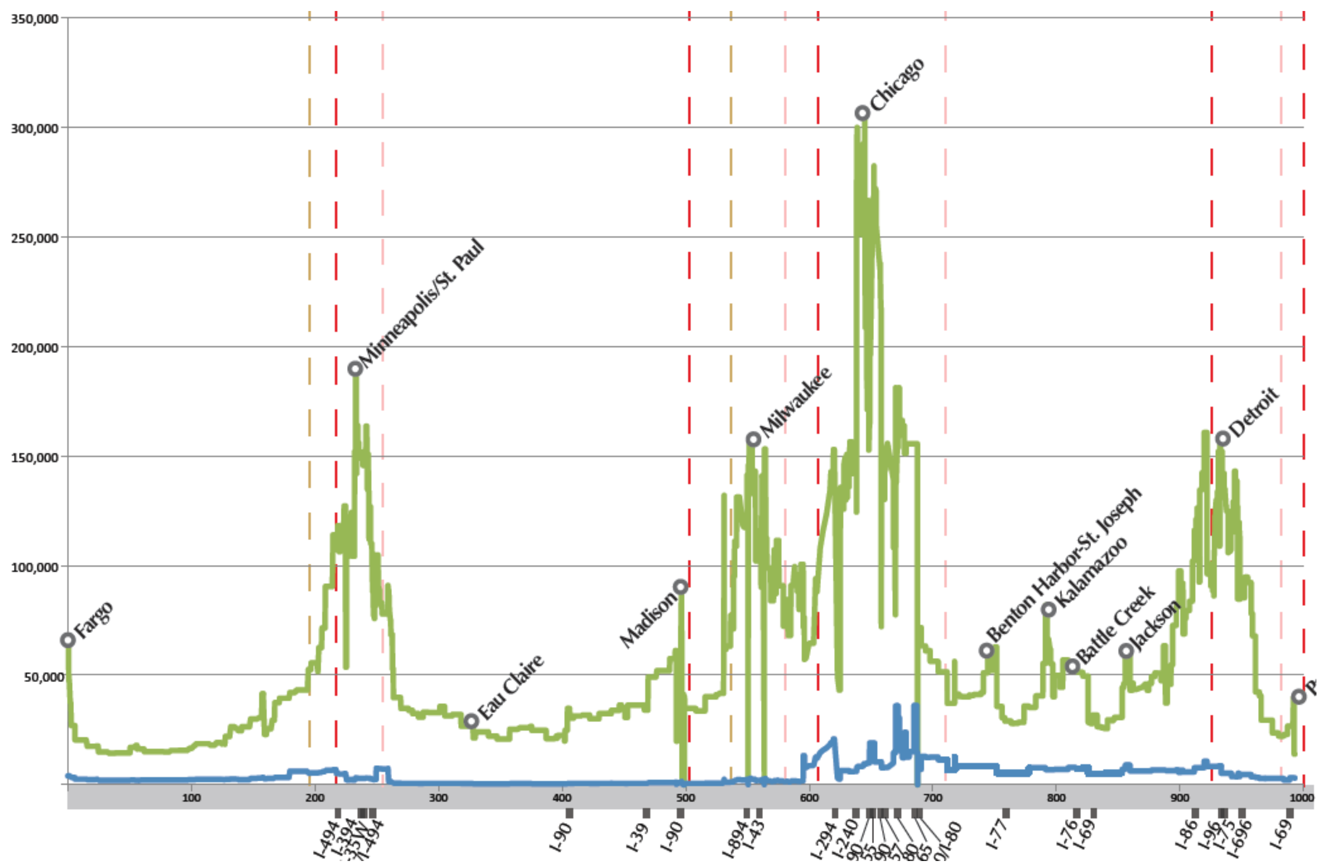
Table 2-5: Relative Importance of Carpooling versus Transit for U.S./Canada Metros

Metropolitan Area	Carpool Share (%)	Transit Share (%)	Index
New York-Newark-Jersey City, NY-NJ-PA	6.43	31.07	4.83
Boston-Cambridge-Newton, MA-NH	6.85	12.89	1.88
San Francisco-Oakland-Hayward, CA	9.41	16.70	1.77
Chicago-Naperville-Elgin, IL-IN-WI	7.74	11.90	1.54
Washington-Arlington-Alexandria, DC-VA-MD-WV	9.67	14.28	1.48
Bridgeport-Stamford-Norwalk, CT	7.70	10.13	1.32
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	7.83	9.70	1.24
Seattle-Tacoma-Bellevue, WA	9.80	9.55	0.97
Baltimore, MD	8.19	6.59	0.80
Ann Arbor, MI	7.13	5.56	0.78
Pittsburgh, PA	8.13	5.59	0.69
Portland-Vancouver-Hillsboro, OR-WA	10.15	6.54	0.64
Boulder, CO	8.19	5.00	0.61
Los Angeles-Long Beach-Anaheim, CA	9.70	5.75	0.59
Minneapolis-St. Paul-Bloomington, MN-WI	8.56	4.82	0.56
Denver-Aurora-Lakewood, CO	8.80	4.52	0.51
Cleveland-Elyria, OH	6.76	3.20	0.47
Miami-Fort Lauderdale-West Palm Beach, FL	8.90	3.74	0.42
St. Louis, MO-IL	7.35	2.94	0.40
San Jose-Sunnyvale-Santa Clara, CA	10.42	3.97	0.38
Hartford-West Hartford-East Hartford, CT	7.77	2.66	0.34
San Diego-Carlsbad, CA	8.65	2.71	0.31
Atlanta, GA	10.25	3.06	0.30
Cincinnati, OH-KY-IN	7.85	2.07	0.26
Austin, TX	10.06	2.50	0.25
Houston-The Woodlands-Sugar Land, TX	10.72	2.37	0.22
Phoenix-Mesa-Scottsdale, AZ	10.53	2.08	0.20
Detroit-Warren-Dearborn, MI	8.96	1.64	0.18
Dallas-Fort Worth-Arlington, TX	9.90	1.62	0.16
Raleigh, NC	8.98	1.05	0.12
Montreal, QC	9.72	23.13	2.38
Toronto, ON	11.93	24.30	2.04
Vancouver, BC	11.09	20.84	1.88
Ottawa-Gatineau, ON/QC	15.23	20.92	1.37
Calgary, AB	12.83	17.00	1.33
Quebec, QC	11.01	13.91	1.26
Edmonton, AB	12.26	12.17	0.99
Hamilton, ON	13.42	9.76	0.73
Guelph, ON	14.33	6.50	0.45
Kitchener-Cambridge-Waterloo, ON	13.66	5.64	0.41

It is an interesting exercise to study the relative importance of carpooling versus transit across metros in terms of which is more important for commuting. Generally speaking, there is more discussion surrounding the concept of public transit. To see that in many metros carpooling actually moves many more people, this could be an unexpected result to some. One thing that is striking about Table 2-5 is that carpooling shares are much more stable across metros than transit shares which are quite volatile. Transit shares are less volatile in Canada and seem to be related more to the size of the city than anything else. In general, transit is more prominent in the older, denser and northern metros of the U.S. Detroit, with its automobile heritage, is an exception to this rule. It is one of three MSAs with a transit share below 2%.

2.2.2 Corridor Travel Characteristics

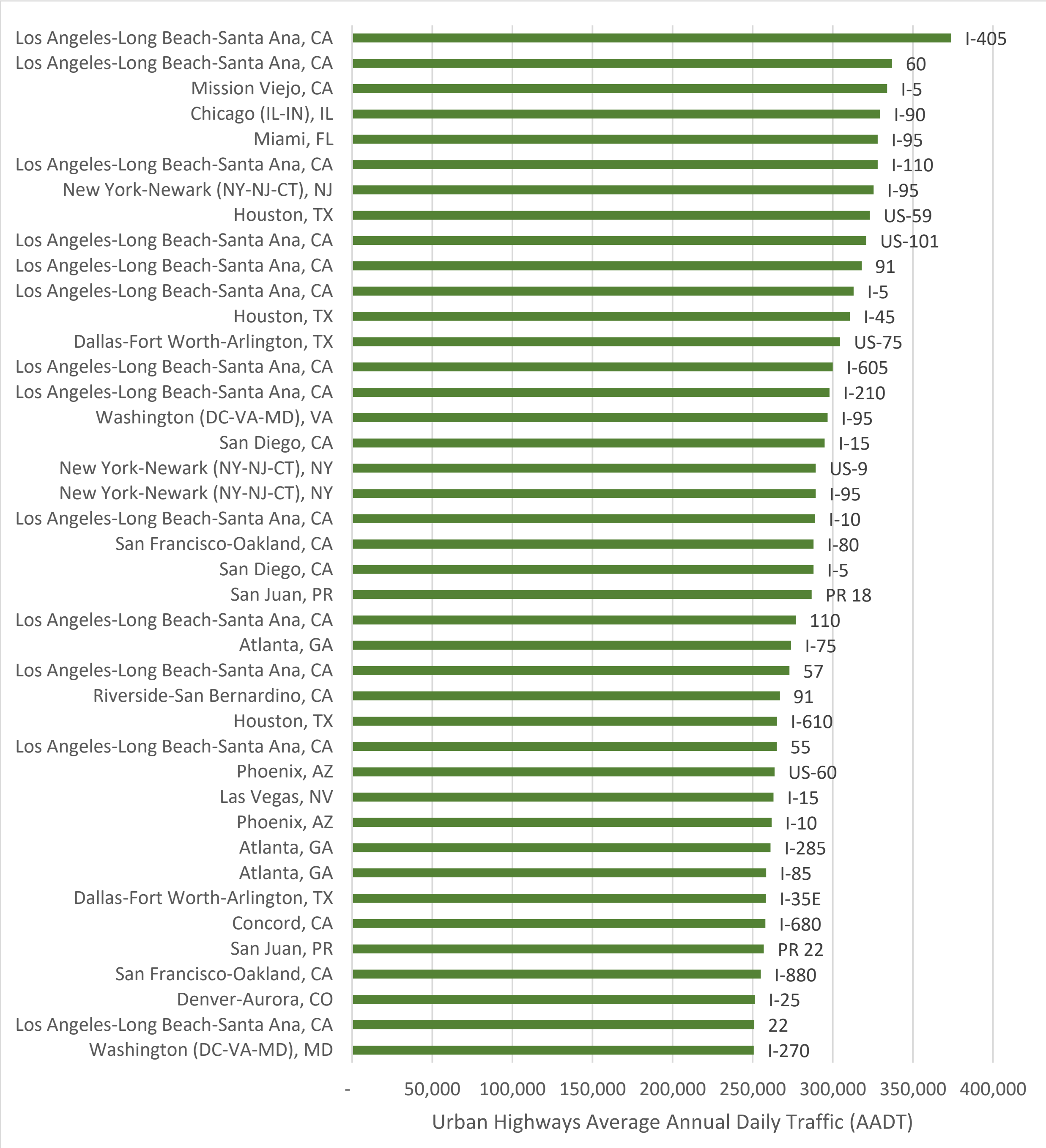
Figure 2-4: Average Annual Daily Traffic Profile for Interstate 94



Source: Highway Traffic Performance Monitoring System

The concept of the travel corridor is central to this paper. Travel corridors within metropolitan areas tend to be very heavily travelled (Figure 2-5). Travel corridors between metropolitan areas, since the distances involved are larger and less populated, are typically less heavily travelled. Intra-metropolitan corridors will often carry a large number of commuters who will make the trip between home and work every day. The larger distances involved with inter-metropolitan corridors assures that smaller numbers of commuters will be carried and ultimately lower overall traffic volumes. In Figure 2-4 the Average Annual Daily Traffic totals along Interstate 94 illustrate this point. Intra-metropolitan volumes are clearly the largest and in the case of Chicago are reaching nearly 300,000 vehicles per day. There are shorter localized spikes for other urbanized areas along the route.

Figure 2-5: Heavily Travelled U.S. Urban Corridors – Average Annual Daily Traffic Volumes



Source: U.S. Federal Highway Administration (2008)

Figure 2-5 illustrates the heaviest travelled corridors in the United States. The Chicago case shown in the prior figure ranks fourth at 329,542[4]. The cases shown on this chart represent realistic upper limits for what a multi-lane expressway can possibly carry in a single day. Massive investments in highway infrastructure have been required to facilitate these volumes. A review of the urban areas associated with this table yields the result that nearly all relate to the leading metropolitan innovation ecosystems. It is also striking how certain metros, such as Los Angeles, show up repeatedly for different corridors. Los Angeles shows up 13 times while the more heavily populated and denser New York metro shows up only 3 times. Upcoming results show that New York is nevertheless very congested in traffic terms indicating that New York likely has fewer high capacity freeways than Los Angeles.

In contrast, Table 2-6 focuses on corridors associated with linking small innovative metros to larger, generally nearby metros and these are ranked by the length of the corridor. Typical traffic volumes over the length of the corridor are added and these are much lighter than the most heavily travelled of urban corridors.

Table 2-6: Representative Traffic Volumes between Ecosystem Clusters in the U.S.

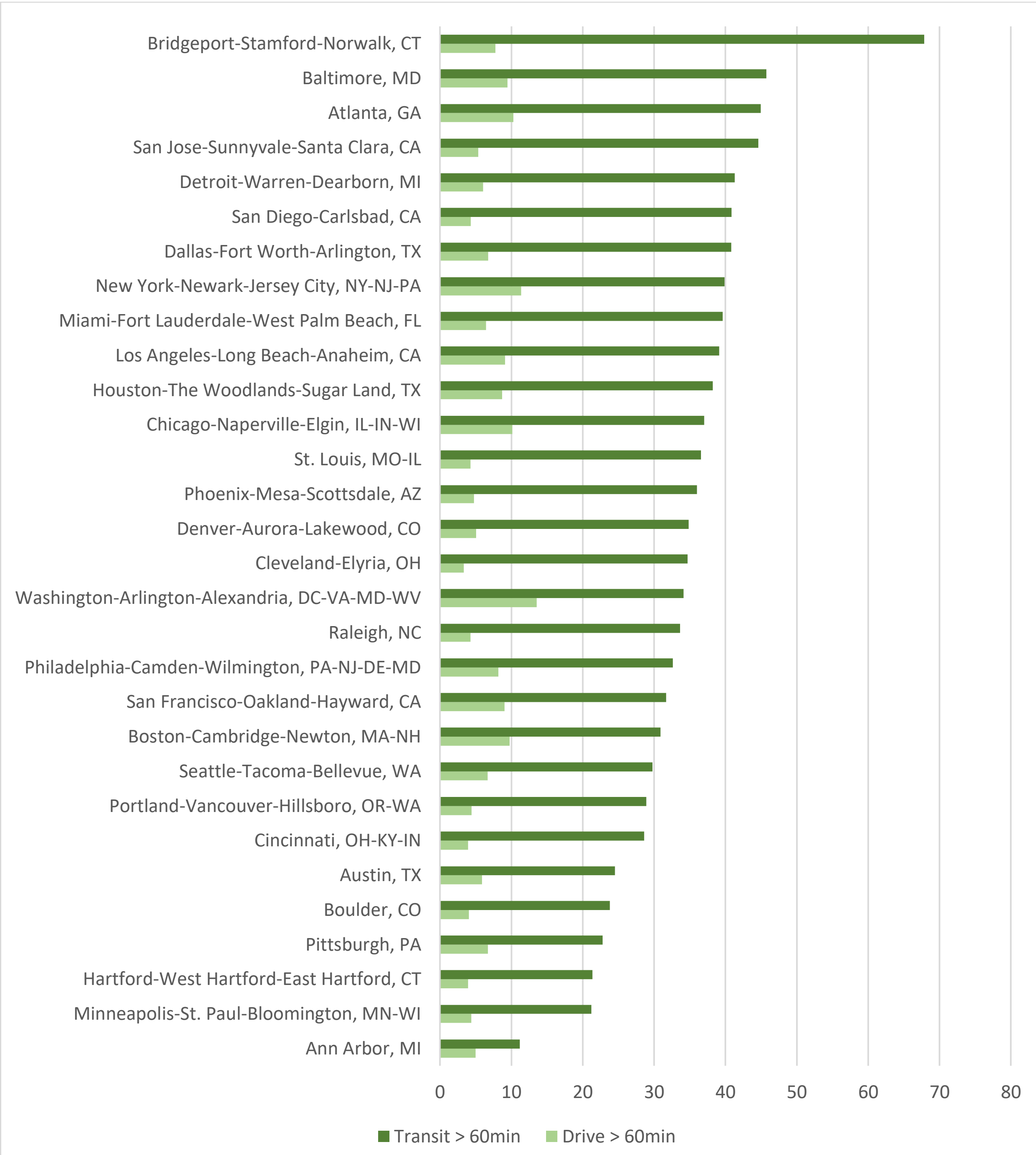
DISTANCE (KM)	SMALL METRO AREA	TRAFFIC VOLUME (AADT)	NEARBY LARGE METRO
45.6	Boulder, Colorado	43,000	Denver, Colorado
69.9	Ann Arbor, Michigan	85,200	Detroit, Michigan
70.7	Provo, Utah	116,075	Salt Lake City, Utah
78.1	Worcester, Massachusetts	84,422	Boston, Massachusetts
83.3	Ithaca, New York	16,283	Syracuse, New York
114	Gainesville, Florida	50,000	Jacksonville, Florida
122	Charlottesville, Virginia	61,470	Richmond, Virginia
129	Baton Rouge, Louisiana	170,912	New Orleans, Louisiana
130	New Haven, Connecticut	130,500	New York City, New York
159	Huntsville, Alabama	99,340	Birmingham, Alabama
183	Tucson, Arizona	151,160	Phoenix, Arizona
212	Reno, Nevada	111,430	Sacramento, California
217	Champaign- Urbana, Illinois	79,700	Chicago, Illinois

[4] Note that I-90 and I-94 share the same right-of-way in Chicago

2.2.3 Commuting Time and Distance

In assessing the connectivity of two innovation ecosystems, both commuting time and commuting distance are important considerations. Taken together, it is possible to understand the extent to which there can be a high rate of daily connectivity between two ecosystems.

Figure 2-6: Share of Commutes in Excess of 60 Minutes by U.S. Metro (Transit vs. Drive Alone)



For the U.S. as a whole, Van Haaren (2016) has utilized the 2009 National Household Travel Survey to assess the distances of U.S. drive commutes. Results suggest that 80% of one-way drive commutes are 20 miles or less and about 95% are less than 40 miles. Only a tiny share of commutes extend beyond 65 miles drive. In heavy traffic we would expect even fewer at such long distances.

Figure 2-7: Modal Splits of Commutes by Distance

The main reason that so many prefer to drive in the U.S., despite ongoing problems with traffic congestion, is that people are typically able to get to their destination more quickly when they drive. Some evidence of this simple fact is provided in Figure 2-6 which compares the share of each travel mode by metropolitan area that exceeds one hour. In each metro, transit is associated with a much higher share of trips that exceed this time frame.

In Figure 2-7, information given by Canada's 2011 National Household Survey is used to assess how modal splits for commutes over 35km in length are compared to shorter distance commutes by census metropolitan area. In general, longer trips mean a greater share of driving. It is interesting to note that a long commute from Hamilton most likely means a commute to Toronto. In this case, use of public transit becomes much more likely.

2.2.4 Measures of Active Travel

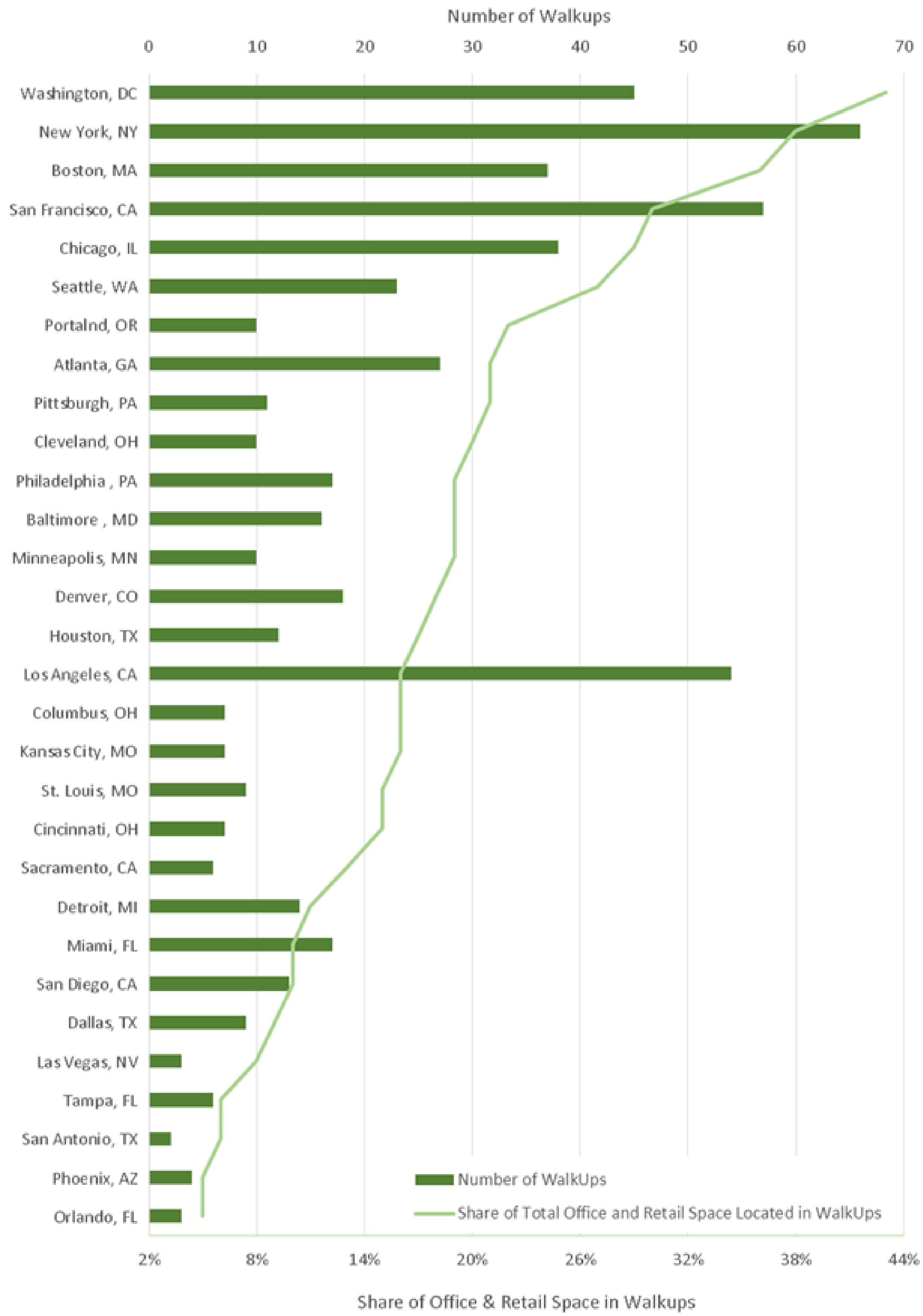
In considering a pairing of two innovation ecosystems, and the centralization of innovation activity to downtowns, it is becoming increasingly possible that travelers between the two ecosystems will walk on both ends of their trip. Ideally, high speed rail would tie into high-end walkable urban places but results in the U.S. suggests that this can be difficult in some metros.

There are 558 regionally significant and walkable urban places in the 30 largest metropolitan areas in the United States (Leinberger & Lynch, 2014). These 558 areas account for only a very small percentage of metropolitan land area (perhaps less than 1%). These rather small areas have become quite important for real estate development. In Washington, D.C., 45 walkable urban places have accounted for 48% of the metro area's new office, hotel and rental apartment square footage developed since 2009. As it turns out, quite a high share of walkable urban places are located in the top innovation ecosystems.

U.S. Metropolitan areas were ranked for walkable urbanism by assessing how well metropolitan area office and retail space linked to walkable urban places. Figure 2-8 illustrates an estimated count of the actual number of walkable urban places in each metro and secondly, the share of metropolitan office and retail space that is associated with such metropolitan areas. Trips for working and shopping account for a high share of all trips so it can be very significant when these types of destinations can be reached easily on foot or by public transit. With respect to the number of walkable urban places, the most prominent result is that some very large U.S. metros have really very few significant places to walk at all.

There is an approximate relationship that those metros with a high number of walkable urban places also have a high share of metropolitan office and retail space located in walkups. Approximately 43% of the office and retail space in Washington, D.C. is located in a walkable urban place compared to only 9% in Dallas. One interesting divergence is that Los Angeles has a large number of walkable urban places but they seem to be somewhat poorly matched to the locations of office and retail space.

Figure 2-8: Walkable Urban Places in Leading U.S. Metros



Source: Adapted from Leinberger and Lynch, 2014

2.2.5 Measures of Metropolitan Traffic Congestion

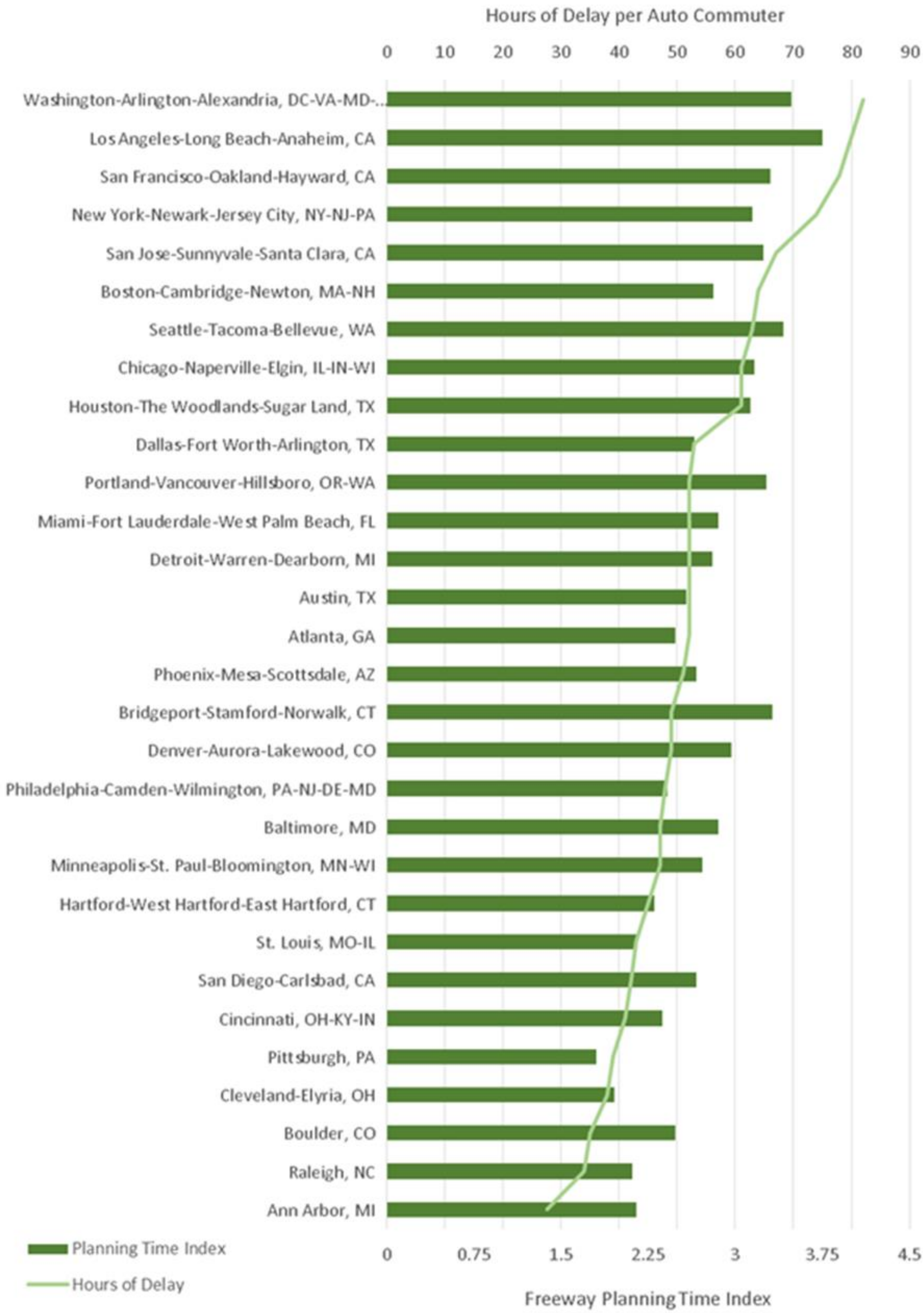
Metropolitan traffic congestion is a problem that draws increasing attention and is certainly a matter of interest for innovation ecosystems. New sources of data are becoming available which are permitting improved ability to characterize traffic congestion in precise geographic and temporal terms. Commercial vendors such as INRIX Corporation are leading in this regard.

Whether at the intra or inter-metropolitan level, measuring traffic congestion gets to the heart of how well freeway-based corridors are functioning. One important point is that it is quite misleading to measure congestion against unrealistic benchmarks such as the posted speed limit on the highway. In peak-time dense urban contexts, speeds much slower than the speed limit are more realistic and remain competitive with other modes. Freeways are actually capable to carry the most vehicles at slower speeds, though beyond a certain level of slowness, vehicle throughput plummets. Along with generally competitive speeds, travel by the automobile offers unmatched point-to-point access and this is a critical factor that boosts the ability to tolerate traffic congestion.

Historically, the leading authority on Metropolitan traffic congestion in the United States has been the Texas Transportation Institute (TTI) (Schrank, Eisele, Lomax, & Bak, 2015). Nationally, since 1982, TTI estimates that the annual cost of U.S. metropolitan congestion has nearly quadrupled to $160 billion. The annual grand total is derived as a simple tabulation of the wasted fuel and the wasted time associated with both passenger and commercial vehicles. These calculations are based on assumed constants such as 1.25 occupancy per vehicle, $17.67 per person*hour as a value of occupant time and $94.04 per hour for operation of a commercial vehicle.

In Figure 2-9 some of the important analytical results are displayed at the metropolitan level. What becomes immediately obvious is that many of the most important ecosystems are also having some of the worst performance on traffic congestion performance benchmarks. The big five in terms of annual delay per commuter are Washington D.C., Los Angeles, San Francisco, New York and San Jose. It seems fair to say that generally, the biggest metros are also the ones with the most delay on highway corridors. High levels of public transit do not seem associated with lower levels of delay along the highway corridors. In terms of the planning time index, values of 3.0 and above are noted for the worst metro cases. This means that commuters must budget three times the free flow or low traffic travel time to be reasonably sure of not being late.

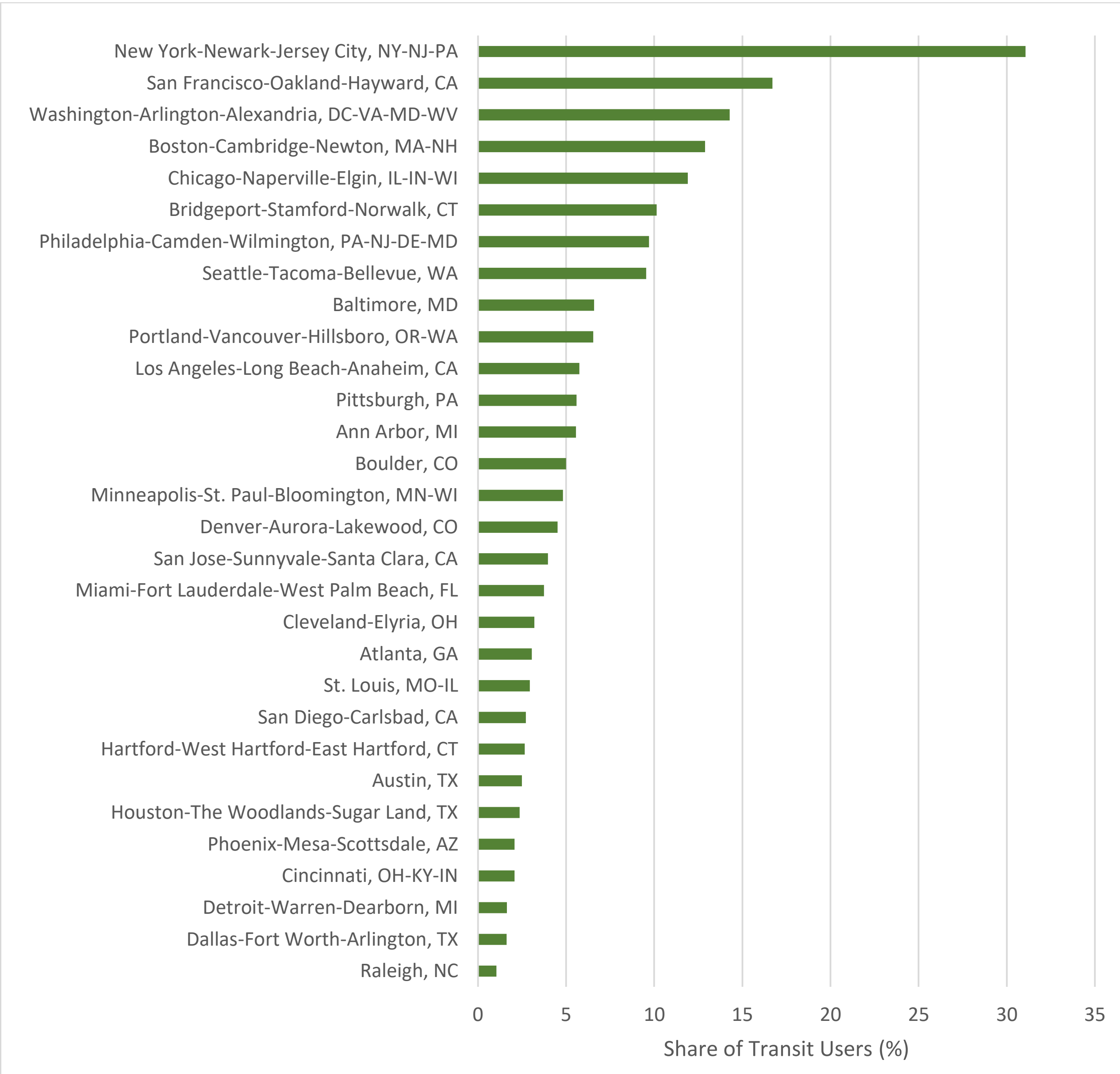
Figure 2-9: Measures of Aggregate Traffic Congestion by Metro



2.2.6 Metropolitan Transit Diversity

There are a range of public transit modes that can be employed within metros and the general rule appears to be that a wider range is applied in the largest and most innovative metros. Figure 2-10 focuses specifically on public transit and is one of the sub-totals from Figure 2-2. Public transit is more than twice as prominent in the New York metro as compared to any other.

Figure 2-10: Public Transit Commuting Share by U.S. Metro



Source: (APTA, 2015)

Table 2-7: Daily Trips[5] by Public Transit Mode for Top U.S. Innovation Metros

Metropolitan Area	Commuter Bus	Commuter Rail	Heavy Rail	Light Rail	City Bus
New York-Newark-Jersey City, NY-NJ-PA	98,033	719,680	7,490,437	49,779	3,148,826
San Francisco-Oakland-Hayward, CA	552	44,889	346,703	124,271	477,429
San Jose-Sunnyvale-Santa Clara, CA	-	-	-	29,431	89,715
Boston-Cambridge-Newton, MA-NH	2,998	96,517	462,249	191,850	333,063
Los Angeles-Long Beach-Anaheim, CA	6,838	36,835	135,662	174,390	1,455,893
Seattle-Tacoma-Bellevue, WA	52,803	8,132	-	26,658	318,834
Chicago-Naperville-Elgin, IL-IN-WI	151	211,534	627,709	-	914,560
San Diego-Carlsbad, CA	842	4,464	-	81,368	172,921
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	-	103,501	305,694	-	535,033
Austin, TX	1,758	-	-	-	93,408
Washington-Arlington-Alexandria, DC-VA-MD-WV	9,189	12,466	750,215	-	518,577
Minneapolis-St. Paul-Bloomington, MN-WI	-	2,157	-	27,844	223,887
Atlanta, GA	8,219	-	190,767	-	175,497
Portland-Vancouver-Hillsboro, OR-WA	2,012	-	-	107,327	176,584
Dallas-Fort Worth-Arlington, TX	39	5,734	-	80,745	124,590
Houston-The Woodlands-Sugar Land, TX	22,504	-	-	31,016	166,771
Pittsburgh, PA	-	-	-	22,006	149,657
Miami-Fort Lauderdale-West Palm Beach, FL	-	11,510	58,079	-	363,517
Denver-Aurora-Lakewood, CO	-	-	-	65,134	209,174
Baltimore, MD	11,509	24,740	41,667	23,692	188,839
St. Louis, MO-IL	-	-	-	46,725	87,501
Phoenix-Mesa-Scottsdale, AZ	-	-	-	39,140	165,423
Detroit-Warren-Dearborn, MI	-	-	-	-	110,585
Cincinnati, OH-KY-IN	139	-	-	-	56,481
Raleigh, NC	-	-	-	-	26,185
Cleveland-Elyria, OH	471	-	17,598	7,940	95,102
Ann Arbor, MI	263	-	-	-	37,512
Bridgeport-Stamford-Norwalk, CT	-	-	-	-	32,057
Hartford-West Hartford-East Hartford, CT	1,143	2,388	-	-	43,313

Source: (APTA, 2015)

In Table 2-7, a better idea is given about what transit modes are used to reach overall transit shares by metro. The New York metro has representation from the main modes of public transit

[5] Daily trips are obtained by dividing annual trip totals by 365 days. As such, these are likely to be underestimates of totals on a typical weekday.

and daily trip totals for heavy rail/subway and city bus are particularly impressive. San Francisco is better rounded than nearby San Jose and both Boston and Chicago utilize a range of modes. While Los Angeles has the reputation of a driving city, many of its public transit totals are quite substantial. The roots of high density areas in Los Angeles were put down by rail decades ago. Results were suburban town centres like Pasadena, Glendale, Santa Monica and Long Beach all of which were walkable (Leingberger & Lynch, 2014) and which offer some of the high density clusters that are supportive of transit.

The lower half of the table has many fewer empty entries, with the main constant being city bus services. It is interesting that several metros in the lower tier have representation from light rail. Trip totals in this context do not approach city bus totals but are substantial in certain cases such as Portland, Oregon.

In Appendix 7.2, transit-mode specific graphs are presented that provide further details on how transit is deployed among the leading U.S. metros.

3

Streamlining Inter-Metropolitan Travel Corridors

This chapter is an exploration of some of the best possibilities to streamline travel between relatively nearby metropolitan areas. The objective, in the context of this report, is to support innovative capacity between and within the distinct urban areas. The chapter will consider ideas that have been tried elsewhere along with concepts that have been considered though not yet implemented. There is an emphasis on the North American experience but ideas from elsewhere are considered. The organization of the chapter is by conceptual themes.

3.1 Highway Tolls and HOT Lanes

One of the most obvious best practices to increase speeds along highway corridors is to charge for the privilege of using the road. While Americans are generally comfortable with this concept, the general prevailing approach in Canada has been to not charge directly for road usage at all. At present, there are only two significant highway stretches that are tolled in Canada: Hwy 407 and the Cobequid Pass Toll Highway in Nova Scotia. For the latter, a flat fee is charged to traverse the 45km section of the Trans-Canada Highway. While there are few implemented cases, interest in the concept of charging to use highways is increasing in Canada, especially as a way to defeat metropolitan traffic congestion (Ecofiscal Commission, 2015).

Tolling is implemented in the United States as applying to the entire right-of-way or on a "managed lane" basis where only certain lanes of the right-of-way are tolled. The former applies largely on longer stretches of mostly non-metropolitan interstate highway and in cases of specialized infrastructure such as bridges. The latter case applies mostly to the intra-metropolitan context and is associated with high-occupancy toll lanes (HOT) which were first implemented in California in the 1990's.

Table 3-1 provides a useful overview of how important tolling is in the United States. Nearly 6,000 miles of road are covered by tolls in the U.S. and this generated about $13 billion in revenue in 2013 (IBTTA, 2015). These amounts tend to be reinvested back into maintaining the associated infrastructure. While there are 6,000 miles of toll roads in the U.S. there are 722 corridor-miles of high-occupancy vehicle lanes (HOV) and just under 500 miles of HOT or express lanes that exist or are under development (ULI, 2013). Under new federal laws, existing HOV lanes can be converted to HOT lanes.

Table 3-1: Important Tolling Facts from the United States

Number of US States and territories with at least one tolled highway, bridge or tunnel	35
Toll revenues collected by US toll agencies in 2013	$13 billion
Number of trips per year on tolled roads and crossings in the US	$5.7 billion
Miles of US toll roads	5,932 miles
Capital investment over three years by the top 40 US toll facilities operators	$14 billion
Fatality rate on all US roads (1.47 per 100 million vehicle miles traveled) versus all toll facilities (0.50)	3x higher
Number of transponders being used for electronic tolling in the US	$27 million
Percentage of Americans who feel tolls should be considered as a primary source of transportation revenue or on a project by project basis	84%
Total share of highway revenue from tolls	5%

Source: Adapted from IBTTA, 2015

To a large extent, the modern-day story on highway tolling is really a technological one. The idea of charging to travel on roads is hardly new, but new technologies are creating possibilities that would not have been possible little more than a generation ago. These technologies have permitted "free flow tolling" where high average speeds can be maintained even as tolls are administered by electronic tag-and-beacon systems (Barnes, 2011). The world`s first electronic toll system was implemented surprisingly quite recently in Norway in 1987. Ontario's Highway

407, which opened in 1997, was the world's first all-electronic, barrier-free system. Some other prominent systems include the 22km CityLink in Melbourne and the e-470 system in Denver. Needless to say, manned toll booths are becoming less and less common. The possibilities for realizing the benefits of tolling technologies in Canada remain relatively untapped and there are calls for this opportunity to be pursued more vigorously (Ecofiscal Commission, 2015; Lindsay, 2007).

With respect to tolls, the biggest technological question going forward is that of inter-operability (Barnes, 2011). Different jurisdictions have their unique technologies that do not translate well to other places. In the case of long-distance trucking, this can lead to windshields that are filled with an array of transponders/electronic tags.

With the rise of automated tolling, a natural outcome is the identification of more nuanced ways to implement the technology. Options emerge to charge for a subset of lanes from a right-of-way, by certain vehicle types, by the time-of-day or even dynamically based on prevailing levels of congestion. HOV or carpooling lanes have been around in the United States since approximately 1970 and since these provided pre-defined separated lanes, there has been a natural inclination to convert to HOT lanes. In the typical scenario, these lanes remain free for carpoolers but low occupancy vehicles can be automatically billed to use the lanes.

The question of revenue is an important one in the sense that its maximization is likely not the best way to promote optimal utilization of the road. Research has confirmed that increasing toll rates leads to increased revenue (Beaty, Burris, & Geiselbrecht, 2013). Toll rates have elasticities of approximately -0.35 which means that a 100% increase in price would be expected to reduce the volume of users by 35%. Rates must be carefully calibrated to reflect whether the goal is revenue maximization or optimal utilization of the toll road.

With many existing HOT lanes there is dynamic pricing technology where tolls can vary from cents to $10 or more depending on circumstances and this permits some ability to manage congestion. It is not uncommon for HOT lanes to be under-utilized as drivers get used to the idea of the new system but generally results suggest that drivers will pay even relatively large amounts to save time in their travels. By and large though, HOT lanes have struggled to generate profits in the U.S. (Jaffe, 2013) which clearly hinders their ability to fund infrastructure.

Experiences in other jurisdictions suggest that modifying an existing highway to accommodate a HOT lane is more controversial than alternatives such as constructing a new road that is defined at the outset to be a toll road. Some form of retrofit will cause changes in the status quo and there will always be perceptions of winners and losers in such contexts. HOV lanes already introduce some level of resentment since carpoolers are clearly seen to be travelling faster than those who must stick to the general purpose lanes. HOT lanes spark greater resentment because motorists can avoid general purpose lanes by simply paying for the privilege. This leads to charges that HOT lanes are for the rich. Moreover, HOT lanes can generate resentment from carpoolers if HOV lanes are already used nearly to capacity or if occupancy requirements are raised from 2+ to 3+ (Marchese, 2013).

Malone (2014) addresses the commonly held perception that HOT lanes are really “Lexus Lanes.” Research done on the I-85 express lane system in Atlanta found that the makes and models of the top four car types were the same on both the pay and free lanes although the HOT lanes had versions of these models that were, on average, a year newer. This result provides at least some evidence that HOT lanes in the U.S. are used by a wide cross-section of travelers.

Conversions from HOV to HOT lanes are clearly cheaper than building entirely new infrastructure to accommodate road pricing (Ecofiscal Commission, 2015) but there are examples where the expensive course of action is taken to relieve traffic congestion. One of the better examples is the Atlanta Northwest Corridor toll lane project which is turning out to be a monumental undertaking (Simmons, 2015). The new construction features approximately 50 km of reversible toll lanes and incudes 39 new bridges. The project is largely elevated because it runs in close proximity to existing interstate infrastructure. Reversible lanes will run inbound to Atlanta in the morning, close at mid-day and open in the afternoon to accommodate the reverse commute. The new infrastructure is being implemented via a public-private partnership and the lanes are expected to open in 2018. The charging of tolls is to be integrated with the Peach Pass which is already utilized for the nearby I-85 HOT lanes.

In Table 3-2 some prominent U.S. examples of HOV/HOT lanes implementations are highlighted with some descriptive information about each and associated outcomes.

Table 3-2: Prominent U.S. HOV/HOT Lane Implementations

Location	Description	Outcomes
SR-91 Orange County, California	- 4 lanes, 2 in each direction - 10 miles in length - Requires a FasTrak transponder - Toll prices adjusted every 3 months	- During congested periods, HOT lanes have speeds of 60-65mph while free lanes have speeds of 15-20mph
I-15 Salt Lake City, Utah	- 2 lanes, 1 in each direction - 38 miles in length - Requires an Express Pass transponder - Dynamic toll pricing with an algorithm that calculates rates every 5 mins	- Twice as many people throughput in express lanes than general free lanes
I-85 Atlanta, Georgia	- 2 lanes, 1 in each direction - 16 miles in length - Requires a Peach Pass transponder - Dynamic toll pricing with an algorithm that calculates rates every 5 mins	- About 23,000 trips are taken on the express lanes daily - Trips have tripled since 2011
I-10 Katy Freeway Houston, Texas	- 4 lanes, 2 in each direction - 12 miles in length - Free for carpoolers during HOV hours - Toll pricing is fixed depending on the time of day	- Over 20,000 vehicles and 36,800 transit passengers daily
SR-167 Seattle, Washington	- 2 lanes, 1 in each direction - 26 miles in length - Carpooling with two or more and a Good To Go! Pass means free travel - Dynamic toll pricing charges vehicles once they enter from an access point	- 3,400 tolled trips every weekday in April 2012 - Reliable travel times averaging 12 mins northbound and 8 mins southbound compared to the general purpose lanes of 19 mins in both directions
I-25 Denver, Colorado	- 2 reversible lanes - Southbound from 5am to 10am - Northbound from 12pm to 3am - 7 miles in length - Requires a transponder or new sticker tag pass and an Express Toll account - Fixed variable toll rate based on time	- 20 min time savings by travelling in the express lanes - 4 min time savings by travelling in the general purpose lanes
I-15 San Diego	- 4 lanes in between northbound and southbound - 20 miles in length - Requires a FasTrak transponder - Moveable barriers allow for 3 lanes in one direction when needed - Dynamic toll pricing	- Generates $2 million in revenue annually where half is used to finance transit improvements - Up to 20 min time savings compared to the general purpose lanes

One of the most recent HOT lane implementations has been in the Seattle vicinity. New express lanes on Interstate 405 were opened near the end of September 2015. Usage of the lanes has thus far exceeded expectations Lindblom (2016) finds. About 17% of peak-time toll payers spent more than four dollars and prices can spike as high as ten dollars. Proceeds are to be invested back into I-405 by law. A promising option for reinvestment is to retrofit a shoulder so that peak time traffic could use it as a general lane. INRIX corporation has been analyzing the traffic implications of the I-405 conversions and has been finding that travelers on the general purpose lanes have suffered increased travel times (Swaby & Whittenberg, 2016). Table 3-3 illustrates the costs associated with using other examples of tolled infrastructure throughout the United States. It is evident that cost is heavily influenced by time of day and direction of travel, particularly during the peak periods. The costs can be quite expensive during this time.

To conclude this section, it is worth noting that trends such as greatly improved fuel efficiency are reducing revenues from fuel taxes. This suggests that other means to fund infrastructure will need to be identified. Despite the prominence of different forms of tolling in the U.S., fuel taxes are actually six times more important than tolls in generating revenue to support road infrastructure (IBTTA, 2015). A pilot project in Oregon (Oregon Department of Transportation, 2013) is testing out a potentially bold solution in this respect. At present, citizens can sign up voluntarily for the OreGo program which substitutes a distance-based fee for state fuel taxes. Tracking technology on a household vehicle exactly measures mileage travelled within the state and the owner is billed accordingly with any fuel taxes being refunded. An approach like this has potential to reduce congestion because distance-based fees could be varied by time of day. Meanwhile an important source of government revenue is protected, for example, against the rise of battery electric vehicles which would produce zero revenue from fuel taxes.

Table 3-3: Sample U.S. Tolls by Infrastructure Context

	Route	Cost for passenger vehicles (2 axles)
Bridges and Tunnels	New York – New Jersey Lincoln, Holland Tunnels; George Washington, Bayonne and Goethals Bridge	Cash Toll: $15 E-ZPass Peak: $12.50 E-ZPass Off-Peak: $10.50
	San Francisco (California) San Francisco Oakland Bay Bridge	Mon-Fri AM and PM Peak: $6 Weekends: $5 All other times: $4
HOT/HOV Lanes	Atlanta (Georgia) I-85 Express Lanes (HOT Lanes) Distance: ~25.7km	Toll Range: 0.01 cent to 0.90 cents per mile (0.02 cents - $1.45 per km) Rates based on user demand
	Denver (Colorado) I-25 HOV/Tolled Express Lanes Distance: 11.27km	Toll Range: $0.50 - $5 E.g. 6-6:45am - $1.75-$2.25 Variable rates based on the time of day
	Orange County (California) SR-91 Express Lane Distance: 16km	Toll Range: $1.50 - $9.95 E.g. Monday 7am = $2.30 (Eastbound) and $5.20 (Westbound); Thursday 4pm - $9.80 (Eastbound) and $2.30 (Westbound) Variable rates based on the time of day
Turnpikes / Thruways / Highways	Pennsylvania Turnpike Distance: 579.5km	Toll Range: $2.15 – $45.95 depending on distance travelled E.g. Exit 30 (Warrendale) to Exit 110 (Somerset) = $10.20 Distance: 139km
	Massachusetts Turnpike Distance: 222.25km	Toll range: max. Eastbound ($7.10), max. Westbound ($10.60) E.g. Exit 26 (Boston) to Exit 6 (Chicopee) = $8.60 Distance: 138.5km
	New York State Thruway Distance: 798.2km	Toll Range: $1.40 - $18.35 E.g. Exit 23 (Albany Downtown) to Exit 50 (Buffalo I-290) = $13.10 Distance: 453km
	Highway 407 (Ontario) Distance: 107.3km	Toll Range: $0.2162 - $0.3697 per km E.g. Highway 403 to Mississauga Road $5.92 (with transponder) or $9.97 (without transponder) Distance: 83.6km

3.2 Car Pooling and Ride Sharing

There is certainly nothing new about the idea of sharing a ride on a commute but the concept is being re-invigorated through the rise of smartphone technology. Chan and Shaheen (2012) provide a good overview of the overall concept. Recent work by Fishman et al. (2014) has focused on identifying untapped potential to share rides based on where commuters live and work and at what time they travel and analytical results suggest that many more rides could be shared. There is certainly considerable ride sharing infrastructure in place. It is estimated that California has 327 park and ride facilities which contain about 34,000 spaces. The Ontario Ministry of Transportation runs 80 carpool lots with nearly 6000 spaces. Nevertheless, carpooling in the U.S has actually been in a long-term decline: in 1970, 20.4% of American workers commuted to work by carpool but this had declined to 10.7% in 2008. Interestingly, this decline has coincided with the rise of HOV lanes but likely has more to do with factors like rising vehicle ownership over that time span.

HOV lanes are clearly a motivator of ridesharing as the concept offers an option for people to essentially bypass congestion and save time and money. Individuals are more likely to carpool when there are time incentives for drivers, monetary savings for passengers and convenient pick up and drop off locations (Shaheen, Chan, & Gaynor, 2016). Drivers are motivated to share in order to gain access to the HOV lanes. This reality has led to an informal but efficient form of carpooling called "slugging" where no money typically changes hands (Lu, 2015; Peterson, 2016). A driver pulls up to a location where potential passengers congregate, such as a carpool lot, and shouts out his destination. Passengers get in if they are going in this direction. Ultimately, the fact that there is no payment is central to what separates Slugging from Uber-related apps. Slugging has been prominent in recent decades in Houston, Washington, D.C. and the Bay Area and other locations that make liberal use of HOV lanes. It is estimated that between 8,000 and 10,000 people are slugging in the Bay Area.

While slugging participants are clearly not shy, in general there are barriers to the use of shared rides. Chan and Shaheen (2012) note that carpooling is associated with a loss of flexibility and convenience, social awkwardness, security concerns and a general loss of personal space. Organization-based forms of Van or Carpooling have typically required a group of individuals committed to travelling together with a planned schedule. Acquaintance-based forms are similar though smaller scale and less complex.

Apart from all of its other capabilities, the smartphone has been identified as one the most important transport innovations in recent memory (Goldwyn, 2014). Smartphones and the internet enable dynamic ridesharing which provides carpoolers with the flexibility to travel with different individuals on a given day. It provides time savings since little planning and no itinerary over a time period is needed (Agatz, Erera, Savelsbergh, & Wang, 2011). Slugging is a non-tech form of dynamic ridesharing. With smartphones becoming ubiquitous, carpooling seems poised to reverse its long-term decline and this may have implications for trips along longer commuting corridors. Uber has recently introduced "UberCommute" in China which uses smartphones to pair commuters who are travelling over longer distances. UberCommute drivers do not need to be registered as Uber drivers in order to participate in the service. UberPool and Lyft Line have been more prominent in North American to this point.

In Washington, D.C. a new service called "Split" is showing promise (Matthews, 2015). The service is presently oriented to more dense urban areas but suggests a lot about the potential for ridesharing over longer distances. In using the Split app, customers specify their origin and destination. As such, the software matches up riders whose trips follow similar trajectories. Uber and Lyft have been working with a similar approach via Uber Pool and Lyft Line but at present these are costlier services than Split. The basic services of Uber and Lyft have focused on one passenger or group of passengers at a time whereas the philosophy of Split is to fill up vehicles with people going in similar directions. Four or five rides per hour per driver is apparently not unusual and this is much higher than the typical Uber rate. An interesting similarity between Split and traditional carpooling is that there are pre-determined pickup/drop-off points unlike Uber. Traditional carpool lots are few and far between in highly-urbanized environments but a service such as Split has numerous locations to minimize ingress/egress time.

In terms of low-tech approaches, carpooling can be enhanced through employer-based programs. Chan and Shaheen (2012) report on the history of this approach in California. In the 1980s, there were mandatory trip-reduction programs to help reduce smog. Employers with over 100 employees were required to meet standards to reduce the number of single-occupant commute trips and would thus require some ridesharing between employees. Because people who work at the same place share a common destination, these types of efforts by employers, especially large ones, would seem to offer promise in the future. They need not be legislated as they were in California.

3.3 Bus Solutions

3.3.1 Private Shuttles

There are a variety of bus options that could apply in providing transport along an innovation corridor. These range from private shuttles operated by individual firms to commuter and inter-city buses. Each of these options have the benefit that they are likely to remove single-occupancy vehicles from the roads.

The private bus shuttles that ferry high-tech workers between downtown San Francisco and the Silicon Valley campuses of their employers represent a best practice in employing bus within a short inter-metropolitan corridor. It has to be noted that the circumstances supporting the private shuttles are quite unusual in that there are massive numbers of jobs based in campus-like, suburban settings. As of June 2013, for example, Google employed 11,332 at its Mountain View headquarters while Apple employed 16,000 at its Cupertino headquarters. It is estimated that 1/3 of Google employees use the Google Buses. Other firms offering private shuttles in the region include eBay, Yahoo, Electronic Arts, Cisco and Genetech. Accordingly, there is sufficient daily demand across several companies for a San Francisco to company-HQ shuttle. It is estimated that collective daily ridership on the private company shuttles is 35,000 (Dai & Weinzimmer, 2014). The shuttles are not well-regarded by many in San Francisco as they are linked to resentment of "privileged" technology workers who are changing the traditional character of San Francisco (DeKosnik, 2014).

In most other contexts, sufficient demand for such private shuttles could perhaps only be generated by aggregating demand across several firms. In Emeryville, which is located between downtown Oakland and Berkeley, there is an example of a shuttle which is privately operated but not exclusive to a given firm. Emeryville hosts corporate HQ such as Pixar Animation Studios, Leap Frog and others. Local businesses pay for the shuttle which ferries people to the Bay Area Rapid Transit Stop approximately a mile away which runs at least 10 minutes (Gonzales, 2013). Known as the "Emery-Go-Round", the shuttle service caters to 1.7 million riders per year. Admittedly, this is more of a short distance, intra-urban shuttle but the principle could apply to longer distances.

There is evidence in San Francisco that services which cater to expensive tastes in local transit can go too far. Davies (2015) reports on a luxury local transit service called "Leap." The shuttles value comfort over cost and feature leather seats, on-board entertainment, Wi-Fi and refreshments. By the autumn of 2015, this luxury transit service had gone bankrupt.

3.3.2 Inter-City Bus

In a paper that focuses to some extent on inter-metropolitan travel, inter-city rail and bus must be considered. Even for trip lengths up to several hundred miles, ground forms of inter-city travel based on bus and rail can be highly competitive, if not dominant, against air travel. Between bus and rail, O'Toole (2011) contends that inter-city bus is proving to be a formidable competitor against rail options for inter-city travel. The single most heavily travelled rail corridor is between Boston and Washington (especially New York and Washington) (Puentes, Tomer, & Kane, 2013) but O'Toole points out that buses carry 50% more passengers along this corridor than does the Amtrak service.

For joining metropolitan areas that are as little as 100km apart or even less, inter-city bus offers options although there is potential overlap with commuter bus services offered by public agencies. The “sweet spot” for U.S. inter-city bus is for longer distances up to the point where air travel begins to take over. Inter-city bus has been the fastest growing form of transport within the past decade, averaging about 7% per year beginning in 2006 (Schwieterman, Antolin, Largent, & Schultz, 2013). At the root of rapid growth in the U.S. has been aggressive new business models that have prospered in a regulatory environment that has not been restrictive[6]. As of 2013, Megabus serves 130 U.S. cities and six hubs and also maintains a Canadian hub in Toronto. Megabus has expanded particularly quickly in the central south and all of the east. BoltBus is another noteworthy competitor that has a greater presence in the U.S. west.

The new form of bus travel relies much less heavily on bus station infrastructure and personnel and more on dynamic curbside pick-up and drop-off (Collins, 2013). Tickets are now sold over the internet and service is largely express without stops. College/University stops are prominent for these services. To the extent that intermediate cities are being served, they are being served with their own bus routes rather than as stops on larger routes. O’Toole (2011) suggests that the low overhead associated with the new model means that there are many carriers and more competition (e.g. more than a dozen in the Boston-Washington corridor). To be sure, bus travel competes very aggressively on price and, in fact, the first few seats on a bus may sell at extremely low prices, primarily as a marketing ploy, while later seats sell for more. Even so, there is room for many levels of bus service ranging from basic “Chinatown” services to “Limoliner” which connects Hilton Hotels in Boston and New York. Wi-Fi and power outlets are mainstays associated with the new bus value proposition.

Scott et al. (2013) offer a useful overview of what makes the curbside bus industry distinct. They note that about ¾ of passengers are travelling by themselves and that the majority of passengers are women who prefer not to wait around at traditional bus terminals. The typical passenger is young and well-educated. The fact that tickets must generally be purchased on-line using a valid credit card almost seems to serve as a “weeding out” mechanism that gives travelers greater comfort about fellow passengers.

In Alberta, Red Arrow Motorcoach competes aggressively in the 300km Calgary-Edmonton corridor (Klaszus, 2011) and is seen as an alternative to flying or driving. The buses are spacious and seat a maximum of 36 passengers. The seats are comfortable leather and refreshments are available.

[6] Safety has been a major regulatory concern. On March 12, 2011, 15 passengers were killed when a speeding bus overturned on Interstate 95 near New York. Multiple “Chinatown” bus companies with suspect safety practices were closed down in the wake of this incident (Scott, Wicks, & Collins, 2013). Subsequently, Lucky Star and Fung Wah Bus Companies have survived as the best of the Chinatown bus companies. They have prospered via cheap tickets, frequent travel times and flexible departure and arrival location options.

3.3.3 Bus Rapid Transit in Managed Lanes

Internationally, bus rapid transit (BRT) is seen as a cost-effective approach to urban mass transit, particularly in many developing nations where solutions such as light or heavy rail are seen as too expensive (ITDP, 2014). To the extent that BRT has developed in the U.S., or is being planned, freeway corridors are prominent. Generally, these systems play a role somewhat similar to commuter rail in that travelers are moved to and from centralized locations such as the downtown core. Park and Ride facilities can be prominent components of the overall system. Parking may be next to a freeway and the commuter walks to the boarding area. More than a dozen cities in the U.S. have BRT as part of their overall transit picture (Aguilar, 2011).

Expressway-oriented BRT systems, to this point at least, tend to be of medium length and generally shorter than the major commuter rail lines. BRTs in the U.S. are often integrated with HOV lanes to increase average speed. The fact that HOV lanes are often in the middle of the expressway will make it more challenging for buses to enter and exit the freeway across multiple lanes of traffic. For a corridor to be considered BRT, it must have at least 3km of dedicated lanes and meet other minimum requirements such as dedicated right of way, alignment, off board fare collection, intersection treatments and platform level boarding (ITDP, 2014).

In terms of existing and planned BRT services consider the following examples:

- In San Diego, a 20-mile section of the I-15 Express lanes operates a BRT service. It provides commuter service every 10 to 15 minutes during peak hours and every 15 to 30 minutes for off peak hours in mixed traffic lanes. These 4 express lanes have a moveable barrier to separate both directions which can reconfigure the lanes to manage traffic congestion (Tampa Bay Express, 2015).

- The El Monte Busway in Los Angeles is an 11-mile section on I-10 between Downtown Los Angeles and El Monte Station. It is a shared-use bus corridor and HOV lane that carries about 16,000 passengers daily (Metro Digital Resources Librarian , 2013).

- The first BRT in Colorado has been implemented along U.S. 36 from Denver to Boulder (Aguilar, 2011). This example is considered in more detail in the Denver-Boulder case study in Chapter 4.

- A 17 mile BRT along the I-35W in Minnesota is under construction and is to be operating by 2019. Buses will operate in a shared HOV lane with traffic signal priority, express and local services. There will be 12 stations in total and approximately 2,000 park and ride spaces will be created (Minnesota Department of Transportation, 2005). By 2040, this service is forecast to have 26,000 daily riders (Remme, 2016).

- A BRT is being studied for the Tampa Bay-St. Petersburg region. Ultimately, the service would run on sections of the I-275, I-75 and I-4 (Tampa Bay Express, 2015). One interesting aspect that makes this case more comparable and relevant for the Toronto-Waterloo corridor is the considerable length of the proposed route. Two proposed options are suggested to span either 46.5 or 52.3 miles.

3.4 Rail Solutions

3.4.1 Inter-City

With respect to rail, there is no question that a best practice solution is high-speed rail but there are typically questions about whether the high costs justify the benefits. There has been publicity in recent years about maglev technology which is short form for magnetic levitation. Trains that employ this technology are capable of speeds in excess of 500 km/h. However, this technology is in its early days of deployment. One notable real-world implementation is an approximate 30km line from Shanghai Pudong International Airport towards central Shanghai. Groups are also interested to implement high-speed maglev technology in the New York-Washington corridor (Nixon & Soble, 2014). The implementation of such technology could reduce the travel time between the two centres to little more than an hour compared to the current rail trip of two hours and forty five minutes. For the most part, maglev technology has not been the focus of high-speed rail to this point.

Maglev exceptions aside, high speed rail as it has been implemented internationally, shares the same basic engineering principles as conventional rail. Campos and De Rus (2009) suggest that implementation of high speed rail can really be thought of as the removal of technical restrictions that limit commercial speeds to less than 250-300 km/h. Such restrictions include roadway level crossings, frequent stops or sharp curves, and inadequate signaling mechanisms or electrification systems. Implementation of high-speed rail will typically mean exclusive trackways so as not to share with freight trains or slower passenger trains. In the North American context, where freight rail reigns supreme (The Economist, 2010), the obstacles imposed by the focus on rail freight have been virtually impossible for high-speed rail to overcome to this point. Among other factors, freight services are not always scheduled and this can play havoc with fixed passenger rail schedules.

Campos and de Rus (2009) go on to suggest that it is really the relationship of high-speed rail with existing services and how the use of infrastructure is organized that define high-speed services more than the speed per se. Japanese high-speed rail has been characterized by a complete separation from conventional services. Under the more flexible French TGV model, high-speed trains can run on special new lines or upgraded conventional lines. In Spain, there is capability for conventional trains to run on high-speed lines. In a fully mixed model, which applies in Germany and Italy, high-speed and conventional trains can run on both types of infrastructure but with higher maintenance costs.

There are some other interesting differences worth mentioning (Givoni, 2006). The geography of Japan, along with the need to avoid tight curves and steep gradients, has led to about 30% of the Japanese lines running though expensive tunnels. New lines were constructed as well into city centres leading to high costs. France had more favourable geography and conventional tracks were used to get TGV cheaply to the city centres. Povani (2006) notes that tilting of the train has emerged in several jurisdictions as an important solution to permit higher speeds on conventional line with curves. This has been one of the solutions employed by Amtrak for its high-speed Acela service in the U.S. Northeast corridor.

Givoni (2006) suggests that an average speed (not maximum speed) of over 200 kph is a reasonable definition for what constitutes high speed service but he also stresses that high-speed rail is intended to be a high capacity and high frequency service. Vickerman (1997) identifies a requirement for a demand of between 12 and 15 million passengers per year between two urban centres to justify high-speed rail.

Other aspects that are stressed in the literature is the idea that high-speed rail “reshapes” the map to some extent and there can be winners and losers, especially when a city is omitted from a route (Hall, 1999). There is also the basic tension that frequent stops reduce the average speed of the operation. Givoni (2006) notes that the economic development impacts of high-speed rail have been controversial in that they have been difficult to observe and quantify. Sands (1993) suspects that the Japanese implementation has served more to shift growth rather than induce it. Like many transport investments, there is a suspicion that high-speed rail acts as a complement to other, more important, underlying prerequisites that drive economic growth. Feigenbaum (2013) in a review of European and Asian cases concludes that most investments in high-speed rail are not justified and these results are echoed by de Rus and Nash (2007) to a large extent, especially in the case of less dense areas. Work in Europe has suggested that total travel between two major urban centres might increase by 1/3 due to high-speed rail combined with background growth that is occurring anyway, with high-speed trail itself accounting for 2/3 of the total growth.

In North America, the main example for high-speed rail that is highlighted is the Amtrak Acela service between New York and Washington, D.C. This service covers 365km in a little under three hours (Table 3-4). The service reaches peak speeds of over 200km/h but the average speed is clearly not close to reaching the 200km/h threshold. Like other North American cases, conflicts with freight are a big part of the reason why. Even though the service essentially behaves like a conventional one, it has been very successful in taking market share away from air travel between the two centres. Jaffe (2014b) reports that rail travel has captured 75% of the air-rail market between New York and Washington from little over 1/3 share in 2000 around the period where faster rail service was introduced. Clearly, rail service does not have to be high-speed per se to have a strong impact on a market. Even at relatively slow average rail speeds, air cannot compete over this distance. However, the slower average rail speeds do mean that inter-city bus can compete quite well with rail, especially on price.

Table 3-4: Prominent North-East Amtrak Train Services

Route	Amtrak	Car	Distance
Acela Express NY- Washington DC	8:00-10:53 -> 2h53min	8:00 -> 3h30min – 4h30min	365km
Acela Express Washington DC – NY	8:00-10:48 -> 2h48min	8:00 -> 3h30min – 4h30min	365km
Ethan Allen Express Albany-NY	11:10-1:45-> 2h35min	11:10 -> 2h20min – 3h	238km
Keystone NY-Philadelphia	7:25-8:50 -> 1h25min	7:25 -> 1h40min – 2h10min	163km
Northeast Regional NY-Washington DC	8:10-11:35 -> 3h25min	8:10 -> 2h20min – 4h30min	365km
Northeast Regional Stamford-NY	9:30-10:21 -> 51min	9:30 -> 55min – 1h25min	62.5km
Pennsylvanian NY-Philadelphia	10:52-12:15 -> 1h23min	10:52 -> 1h40min – 2h10min	165km

The case for high-speed rail is quite good in the U.S. Northeast considering the high metropolitan populations (Table 2-3) and ideal spacing of cities. High-speed rail was most prominent in recent years soon after Obama's inauguration as he imagined a system that would rival the U.S. Interstate Highway system. $8B that was set aside in his 2009 economic stimulus package was rejected by the states of Ohio, Wisconsin and Florida. Freemark (2014) suggests that the U.S. suffers from a lack of will at the federal level and a loss of faith in the federal system in comparison to how things were as the Interstate system was built.

About $3B in federal funding has been spent in California though construction has not commenced. Recently the California High-Speed Rail Authority has decided to focus on the first 250 mile section from San Jose to Bakersfield, CA and not the southern section near Los Angeles where construction costs are higher and political opposition is greater (Weikel & Vartabedian, 2016). The most recent cost estimate for the whole project between Los Angeles and San

Francisco is $64B but there is a big funding gap and many believe that the project will never get off the ground. More progress appears to be getting made by entirely private high speed initiatives in Texas and Florida (Laing, 2015). The overall situation in the U.S., however, is that there is ample room to increase average rail speeds along major corridors, even in ones that are operating comparatively well at present.

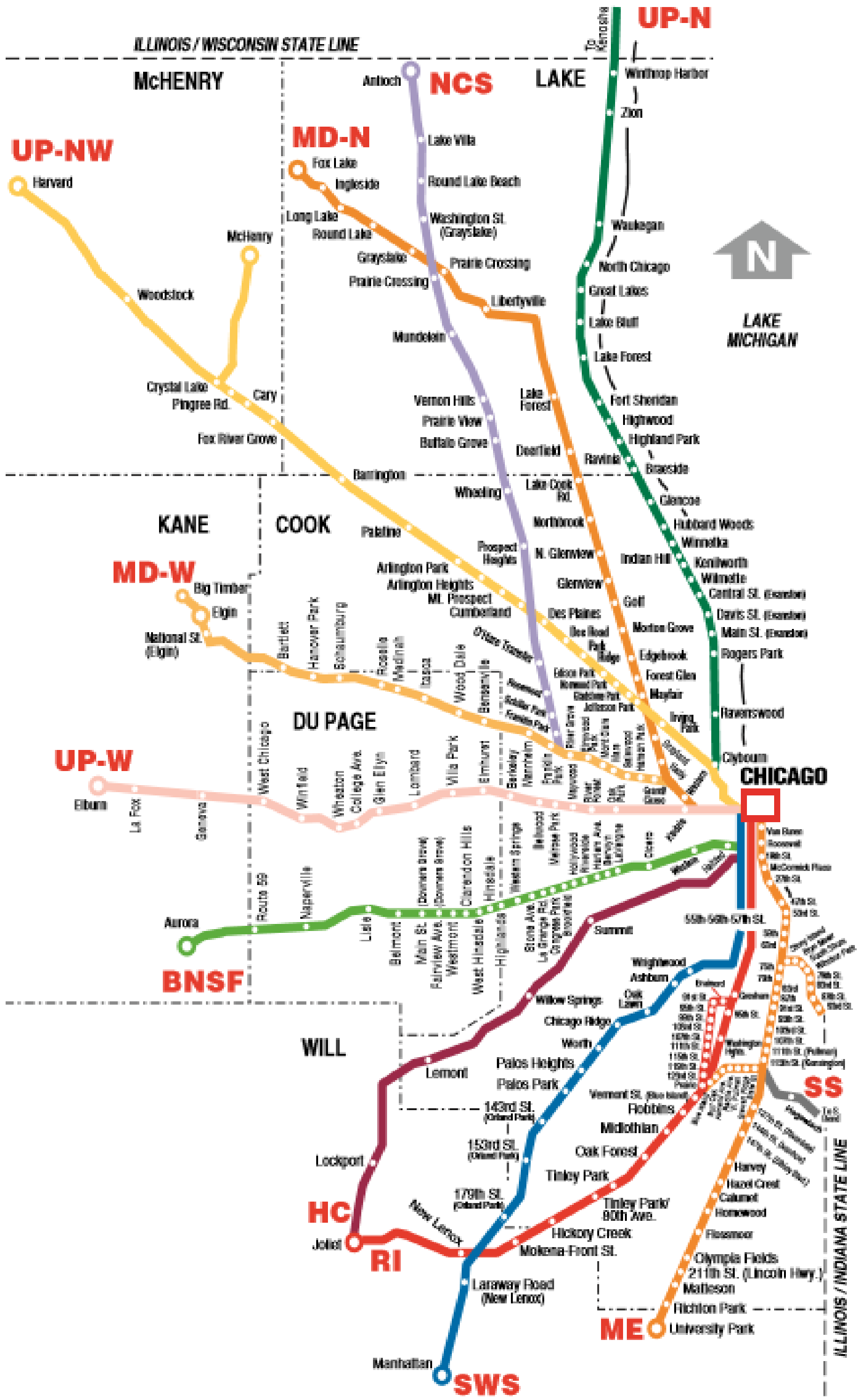
3.4.2 Commuter-Oriented Rail

One possibility for linking two distinct metropolitan areas is an efficient commuter rail service. This section highlights the Chicago Metra commuter rail system (Holle, 2007), which is one of the most extensive in the United States, and the Paris RER system which serves the metropolitan Paris region.

In Figure 3-1, it is interesting to see a representation of required infrastructure in the Chicago metropolitan area to support commuter rail. Chicago ranks second in the U.S. behind the New York metro for commuter rail ridership but it becomes quickly evident that the route infrastructure to accomplish this level of service is quite massive. Like the GO system, the Chicago Metra service has a heavy focus to move suburban commuters to and from the core of the metropolitan area. Getting between two suburban locations by commuter rail proves to be more difficult under such a design.

Table 3-5 provides further detail about individual Chicago Metra lines. Two of the lines are in excess of 100km. A commute from end-to-end on these two lines is long in terms of distance and duration considering that ingress and egress times are required at both ends of the trip. In the context of London-Cambridge (See Chapter 4), these types of distances are covered much more quickly by rail using more of an inter-city express, as opposed to commuter rail, approach.

Figure 3-1: The Extensive Chicago Metra Commuter Rail Service



Graphic courtesy Metra

Table 3-5: Length of Chicago Metra Lines

Rail Line	Start Station	End Station	Distance	Time
Union Pacific/North Line	Kenosha	Ogilvie Transportation Center	102km	1h34min
Milwaukee District/North Line	Fox Lake	Union Station	87.7km	1h33min
North Central Service	Antioch	Union Station	88.9km	1h29min
Union Pacific/Northwest Line	Harvard	Ogilvie Transportation Center	116km	1h33min
Milwaukee District West	Big Timber Road	Union Station	65.6km	1h26min
Union Pacific West	Elburn	Ogilvie Transportation Center	84.7km	1h12min
BNSF Railway	Aurora	Union Station	63.8km	1h19min
Heritage Corridor	Joliet	Union Station	72.2km	1h5min
Southwest Service	Manhattan	Union Station	76.7km	1h30min
Rock Island District	Joliet	LaSalle Street Station	71.3km	1h12min
Metra Electric District	University Park	Millennium Station	57.6km	51min

Table 3-6: Paris RER Representative Trip Times and Distances

Start	End	Distance	Time
CDG Airport Term 2	Paris, Gare du Nord	22.7km	36min
Paris, Chatelet les Halles	Disneyland Paris	44.5km	40min
Paris, Invalides	Versailles Chateau Rive-Gauche	20.6km	29min
Paris, Invalides	Massey Palaiseau	23.2km	48min
Boissy Saint Leger	Saint Germain-en Laye	21.0km	58min
Saint Remy Les Chevreuse	Paris, Gare Du Nord	40.2km	51min
Saint Martin d'Etampes (South)	Pontoise (North)	104km	2h20min
Mitry- Claye(East)	Saint Remy Les Chevreuse (West)	77.4km	1h30min

Commuter Rail is very significant in a handful of North American cities but an alternative concept is the Rapid Express Rail service that is prominent in Paris, shown in Figure 3-2. The RER somewhat blurs the lines between commuter rail and a metro/subway. In Paris, the metro and the RER are well-integrated at several locations and various RER stops are rather like subway stations except the associated trains run faster and stops are less frequent. The RER service has 257 stations, 5 lines and 587 track-km. The service is high-frequency at as little as 3-5 minutes between trains in some central locations.

Figure 3-2: Extensive RER Network in Paris Metropolitan Area

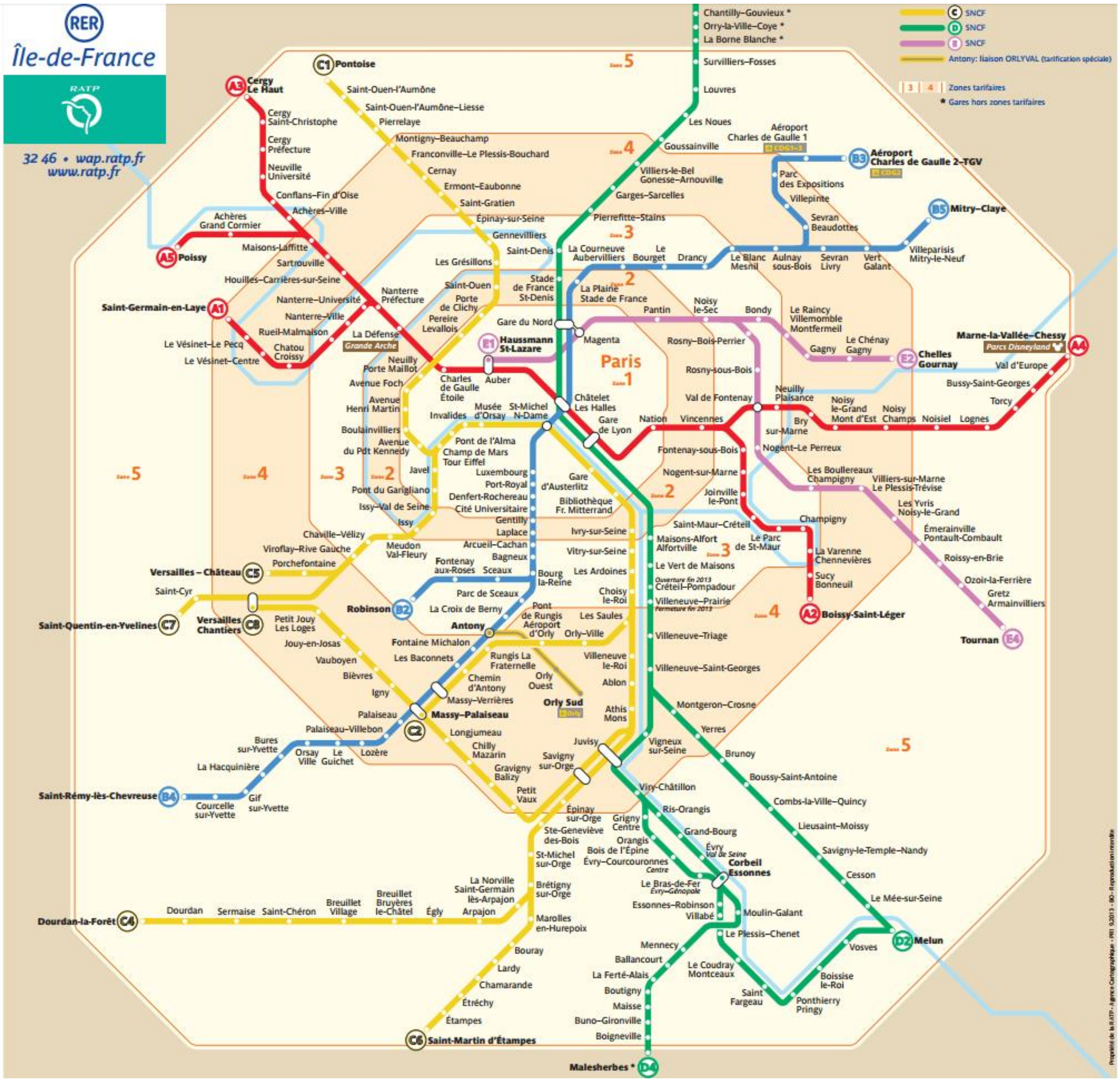


Table 3-6 provides an overview of travel distances and times is given for various origin-destination combinations within the RER system. Many of the trips shown link central Paris to suburban terminal points and the latter two cases show north-south and east-west trips that travel the extent of the system in those directions. The results indicate that the system as a whole is considerably more compact than the Chicago Metra system. Also, the system is very much intra-, rather than inter-metropolitan in nature.

3.5 Managed Expressways

The UK Department for Transport (2013) makes a bold statement in its strategic plan "Action for Roads: A Network for the 21st Century." It proclaims that the UK has become a world leader in the use of technology and traffic management to improve the flow of traffic on its motorways. What is proposed in the plan is portrayed as the most radical change in the UK management of highways in nearly half a century and it aggressively focuses on the efficient use of road space and technology to maximize the potential of motorways. Accordingly, this section on managed expressways focuses primarily on recent events in the UK as a best practice.

In the plan, there is a particular emphasis on what is known as the "strategic road network." This is made up of 1850 miles of motorway and 2580 miles of A-series highways. This mileage accounts for only 2% of British roads but the strategic network carries 1/3 of road traffic and 2/3 of road freight. And while traffic has dropped[7] on local roads, it has increased by more than a billion vehicle-miles on strategic roads. There is a sense in the plan of making up for lost time in that motorway investments in the UK lagged badly in recent years. Only 46 miles of new motorway opened between 2000 and 2009 which was far behind other European countries. The first motorway link between England and Scotland opened only in 2009. Nevertheless, the roots of the current strategy go back to 2004 and soon after when an advanced trial of the new approach focused on the M42 near Birmingham, England. The economic stakes are seen as quite high. In the UK it is estimated that there is a two billion pound cost to the economy of congestion on the strategic road network. A single incident that closes a motorway for a morning or an afternoon can cost several million pounds in lost time.

The intensive use of technology on motorways is particularly targeted at stretches which feature some of the worst congestion bottlenecks – the approach is not necessarily worthwhile on long stretches of motorway in rural areas that don't have the same problems. Interestingly, the premise of the system is more about predicting the onset of congestion rather than waiting for it to happen. It is largely about restraining and smoothing traffic flows so that vehicles that are approaching a hot spot do not simply add to the congestion (Sowman, 2014). Certainly, it is also about managing the motorway optimally in the event of accidents.

An important element of the managed approach is the ability to communicate with drivers and manage the flow characteristics of the motorway. Overhead electronic signs are displayed on "gantries." These are overhead structures that are anchored at the sides of the motorway and allow the display of information to drivers on a lane-specific basis. Information that can be displayed at a particular time include: the current speed limit for the lane and whether the lane is open or if merging has to take place.

Optimal use of constrained space is central to the approach and thus hard shoulder running is allowed and tightly integrated into the overall approach. Whether the shoulder is open to traffic

[7] Reasons for the decline in traffic on local roads include a decline in younger people with licenses and in the number of company cars combined with massive investments in transit and introduction of the central-London congestion charge.

is controlled in real-time. At non-peak times, travel on the hard shoulder can be “turned off” via the overhead messaging but at congested times this space can be used for travel which effectively increases capacity along those stretches by 1200 vehicles per hour.

The prevailing stereotype is that using shoulders for travel is unsafe but outcomes from the UK trials suggest the opposite. Evidence suggests that 90% of people in the UK who stop on the hard shoulder do so for non-emergency reasons and that 10% of deaths that occur on motorways are of people stopped on hard shoulders. When the hard shoulder is “open”, stopping for true emergency purposes is accommodated by periodically spaced “refuge areas” which are carved out at the side of the road adjacent to the hard shoulder.

The results noted from the M42 trial has been quite impressive. Accidents have been halved, the severity of accidents has been reduced and there have been no fatalities during the trial period. More traffic has been handled overall with faster journey times and better reliability. Compared to conventional road widening, improvements are achieved without need for large amounts of land and at an estimated 40% less cost. Two of the UK’s most important motorways will be the focus for roll-out of the managed expressway approach: The M1 and the M6.

As Fontaine and Miller (2012) note, application of these approaches have been slow to take hold in the United States (and in Canada for that matter). One of few examples in the U.S. is northbound Interstate 5 in Seattle where lane-specific, electronic displays are regulating driver behaviour. In the event of accidents, the lanes that have to merge are identified a good distance prior to reaching the site and of course lanes can be closed as well.

Table 3-7: Elements of Managed Expressways

Speed Harmonization / Variable Speed Limits	- Speed limits change depending on the road conditions - Dynamic signs that warn drivers about downstream traffic flow to encourage uniform traffic flow - Allows drivers to have more time to react to road conditions and avoid the need to brake sharply - Germany – Inductive loop detectors are placed on roads and overhead gantries to provide drivers with the speed limit based on a speed-flow density algorithm – speeds on the Autobahn can vary between 60 and 120 km/h. (Mirshahi, et al., 2007) - British Columbia – 50 digital signs will be installed overhead in early 2016 on Highway 1, 5 and 99 – indicates the variable speed zone and changing weather conditions (CBC News , 2015)
Queue Warning Systems	- Provides advanced warning for stopped or slowed traffic indicated by dynamic message signs of downstream traffic - Safety measure that is implemented with other active traffic management solutions - Germany – A8 Autobahn showed improved traffic flow, uniform driving speeds and increased capacity - United Kingdom – installed with variable speed limit systems on the M42 highway (Mirshahi, et al., 2007)
Hard Shoulder Running	- Low cost solution to improve traffic flow - Requires static and dynamic traffic signage and effective monitoring equipment (manpower intensive) (ITS International, 2013) - Netherlands – shoulder lanes become traffic lanes on A15, A27, A28 and A50 during peak hours with cameras every 200 to 250m – no increased accident rates
Movable Medians	- Used for localized stretches to deal with the differences in AM/PM peak - The Zipper truck moves concrete filled barriers along the median of the Golden Gate Bridge in San Francisco to safely reconfigure roadways – cost effective solution
Junction Control/ Dynamic Merge Control	- Regulates or closes specific lanes upstream to an interchange either temporarily or permanently - Allows for smoother traffic merging and higher speeds - Netherlands – reduction of 7-8% of mean travel time and reduced vehicle delay of 4 and 13% for the mainline and merging traffic
Ramp Metering	- Breaks up traffic of vehicles entering and/or limits vehicle entry at entrance ramps - Traffic signals are installed on freeway on-ramps and either local or fixed-time controlled or system controlled - Implemented in Los Angeles since 1966 on Route 5 and 14 and currently in more than 1,000 ramp meters in California
Reversible Lanes	- Lanes made for traffic to travel in either direction depending on displayed overhead signals to accommodate travel patterns - Usually adjusted according to AM/PM peak - Chicago – Kennedy Expressway has 2 reversible lanes that are greatly relied on

3.6 Heavy Trucks and Innovation Corridors

The type of traffic created by innovation clusters is not typically intensive in terms of goods. Outputs are generally of the intellectual variety and have a high value to weight ratio. As such, goods movement may be seen by some as less of a priority. In the case of an innovation corridor, where the objective is to draw separate ecosystems together, heavy trucks may be seen as getting in the way of light vehicle traffic. Heavy trucks have something of an image problem with the general public being pre-occupied with the space being occupied on the road as opposed to the value that is added to the economy (Ferguson, Lavery, & Higgins, 2014).

However, there can be no doubt that truck movements are a critical lifeblood for the economy and an integral component of modern day supply chains. Results from the 2012 U.S. Commodity Flow Survey suggest that movements by truck account for 74% of the value of goods, 70% of the tonnage of goods and 38% of the ton-miles (Ferguson et al., 2014). Though long-distance trucking is important, these results indicate that trucks are especially important for shipments of up to a few hundred kilometers and in metropolitan contexts.

The purpose of this section is to explore what has been done in the context of giving trucks their own transport infrastructure. Apart from potentially speeding up the flow of goods, one of the objectives of this concept would be to remove trucks from “general purpose” expressways, reduce congestion for lighter vehicles and increase safety. Regarding the latter point, collisions involving trucks resulted in 20.3% of all traffic fatalities in Canada from 2001 to 2005 (Roorda, et al., 2010). There are thoughts that segregated trucks could reduce accident rates and severity (Lindsey, 2009). A secondary approach considered below in reducing the impacts of trucks is the concept of shifting truck travel to less congested periods of the day.

As it turns out, efforts to remove trucks from general purpose lanes on freeways and create truck-only road infrastructure have been quite rare. Exclusive truck facilities can be separate facilities or dedicated lanes on existing roads. Most of such facilities extend short distances such as the 3.5 mile Clarence Henry Truckway in New Orleans and the 10 mile I-5 Truck Bypass in Los Angeles. A 35 mile section of the New Jersey Turnpike acts as a long-distance truck facility where trucks are physically restricted to the right lanes while cars and light vehicles are free to travel in all lanes (Poole, 2009). The idea of restricting trucks to certain lanes has the benefit of reducing lane conflicts but there is concern about increased conflict that would reduce safety in highway merging (El-Tantawy, Djavadian, Roorda, & Abdulhai, 2009).

Near Laredo, Texas private investors constructed a tolled freight highway, the Camino-Colombia Toll Road, in anticipation of increasing truck volumes. Unfortunately, forecasts of traffic were far too optimistic and the road was sold to the state. This brings up the related issue of trucks and tolls. Tolling is very unpopular in the trucking industry which is one other factor that drives up the use of general purpose lanes by trucking firms - they find it difficult to pass toll costs on to end-users (Beaty, Burris, & Geiselbrecht, 2013) which in turn makes it difficult to pay for truck infrastructure via its use by the truckers themselves.

When trucking firms are forced to pay tolls they often divert to other routes – and this can be problematic. Rhode Island recently passed a truck-only toll plan for truck movement through the state on Interstate freeways. A majority 77% of members from the Owner-Operator Independent Drivers Association said they would alter their routes away from Interstates to avoid paying tolls (Kilcarr, 2016) or avoid routes through Rhode Island where possible.

The future of exclusive truck facilities may be more interesting than its past. A potential project near Atlanta, which would be the largest of its kind in the U.S., is even more ambitious in the sense that entirely separate, toll-free infrastructure for trucks is proposed to be built over a 40 mile distance on Interstate 75 between Atlanta and Macon Georgia (Simmons, 2016). This is a crucial truck freight corridor that serves the southeast U.S. and moves cargo from the busy Port of Savannah. Truck volumes are expected to increase rapidly in upcoming decades, fueling the urgency. The proposal has generated controversy because this will be a free route for trucks that would at least partly be funded by the proceeds of tolls and HOT lane fees collected from ordinary motorists in the region. Some activists claim that investments in passenger rail between Atlanta and Macon would do a better and less expensive job of unclogging I-75.

In a second proposal, the Virginia Department of Transportation has plans to widen Interstate 81 throughout the entire state from four to eight lanes in each direction where two lanes will be dedicated to trucks in each direction (Kozel, 2008).

With regard to shifting trucks to other times of the day, as opposed to their own infrastructure, the main idea that has generated interest is that of off-peak urban deliveries. However, this approach is most relevant for intra-urban distribution functions that require smaller trucks and vans and is a different form of truck movement than those associated with inter-city corridors.

One interesting example in the time-shifting of trucks is seen at the Ports of Los Angeles and Long Beach. A "Traffic Mitigation Fee" was introduced that does not need to be paid at off-peak times. A 30-35% shift to off-peak hours was seen (Seattle Urban Mobility Plan, 2008). [8] In a pilot project in New York City, freight carriers saw an increase in productivity after shifting to off-peak delivery (Cassidy, 2010). This initiative has forecast potential economic benefits of $150 million to $200 million per year in travel time savings and pollution reductions (Holguin-Veras, Wang, Browne, Hodge, & Wojtowicz, 2014).

[8] The traffic mitigation fee is adjusted annually and is currently at $66.50 per 20-foot-equivalent unit and $133.00 per 40-foot-equivalent unit (Izmirli, 2014).

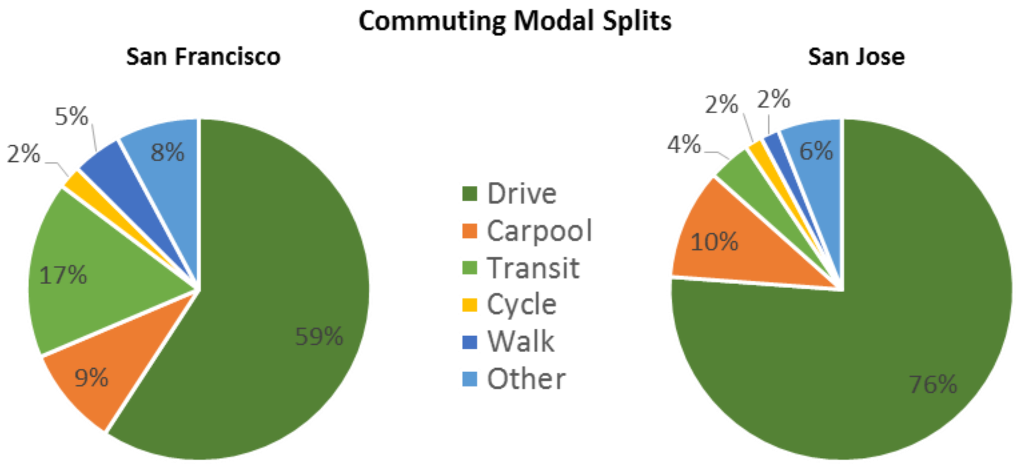
An Overview of Metropolitan and Corridor Cases

The purpose of this chapter is to focus on the important transportation characteristics of particular metropolitan ecosystems and to do so one case at a time. In certain of the cases, there are natural inter-metropolitan corridors that make good comparisons with Southern Ontario. The presentation depends a lot on showing what daily travel is like within each ecosystem. As such it relies on maps and travel tables. A "dashboard" has been created for each ecosystem, or pairing of ecosystems, which highlights some of the important transportation and innovation characteristics of each case.

4.1 Silicon Valley – San Francisco

To begin, Figure 4-1 offers an overview of statistics for the two metros which define the Bay Area: San Francisco and San Jose. Result show clearly that San Francisco is more populated, denser and more transit-oriented. It is striking that San Jose contains almost as much highway mileage as San Francisco despite a much smaller population. Traffic congestion exacts a high toll on the commuters of both places and for trips between.

Figure 4-1: Transportation/Innovation Metrics for San Francisco and San Jose



Population & General Commuting Metrics

	San Francisco	San Jose
Total Population	4,466,251	1,898,457
Weighted Population Density	12,144	8,418
% of Commuters with > 90 Minute Commutes	2.95%	1.85%
Transit/Carpool Ratio	1.77	0.38

Innovation Metrics

Innovation Rank	2	3
2015 Venture Capital Deals	942	379
Patent Counts in 2013	8,721	12,899

Road & Congestion Metrics

Travel Time Index	1.41	1.38
Freeway Planning Time Index – 95th Percentile	3.3	3.24
Annual Congestion Cost	$3.14 billion	$2.23 billion
Share of Driving Commutes > 60 Minutes	9.03%	5.36%
Freeway Lane Miles	1,475	1,338
Hours of Delay per Auto Commuter	78	67

Transit Metrics

Total # Daily Rail Trips (Heavy + Light + Commuter)	515,863	29,431
Total # of Rail Stations (Heavy + Light + Commuter)	85	65
Total # Daily Bus Trips (Commuter + City)	477,981	89,715
% of Transit Commuters with > 60 Minute Commutes	31.67%	44.6%

The Silicon Valley-San Francisco complex is interesting from the geographical and transportation perspectives. It is spread across two MSAs with Silicon Valley itself being more associated with the San Jose MSA. However, the true heart of Silicon Valley, in terms of its prominent corporate headquarters, lies northwest of San Jose and this has the effect of shortening travel times and distances to San Francisco. The distances are sufficiently short that there is a very active daily flow of high-tech commuters.

Figure 4-2: Location Pattern of Important San Francisco/Silicon Valley Innovators

Source: The Economist, October 27 2012 Issue

In Figure 4-2 some of the most important innovation nodes are presented for the San Francisco and Silicon Valley Ecosystems. The contrast in patterns is very pronounced with the San Francisco pattern being highly urbanized while the Silicon Valley pattern is highly suburbanized in comparison. Clearly, the two different patterns have significant implications for what transportation options are viable to serve each cluster. This map is effective in demonstrating that innovation clusters can come in different “shapes and sizes”. Dense downtowns are more conducive to small startups as opposed to sprawling corporate campuses. The highly urbanized San Francisco cluster has been forming rapidly within the last decade and is the most tangible evidence that future innovation clusters are quite likely to locate in dense urban places. Albouy and Lue (2015), for example, have developed a quality of life index for the entire U.S. which illustrates at the micro-level the real estate premiums that people are prepared to pay. Central San Francisco and certain parts of Manhattan score highly on this index. Younger tech workers want to work close to such places.

In Table 4-1, AM peak travel times and distances along the corridor are examined in some detail for some important pairings of origins and destinations. The trips are analyzed using the Google Maps tool and are assessed in terms of drive time and secondly by the use of public transit only. In reality, there may be options to use a mix of driving and public transit (analogous to parking at the GO station) but this possibility is not captured here.

In distance terms, results suggest that even the commute from Mission Bay in downtown San Francisco to eBay HQ is less than 75km. Figure 4-3 shows this particular commute to be one of the longer trips to one of the main corporate campuses. An all-transit trip is basically guaranteed to take two hours one-way and this is not a very attractive option. The results for a car trip show a high degree of variability depending on the conditions of the day but even a worst-case scenario is not expected to take as long as transit. Other combinations of origins and destinations yield similar themes though transit is more competitive over shorter distance pairings. For the relatively lengthy trips involved in moving between San Francisco and Silicon Valley, driving seems to yield a better outcome and this is despite both MSAs being ranked quite highly for delay due to traffic congestion (Figure 2-9). The Economist (2012) offers anecdotal evidence that the AM drive from San Francisco to San Jose can take three hours.

From a transit perspective especially, San Francisco and San Jose really have been functioning as two separate MSAs. The well-known Bay Area Rapid Transit (BART) system is largely responsible for San Francisco ranking second in transit commuter share to New York. But the system is much more oriented to joining San Francisco to Oakland as opposed to joining the former to San Jose (Figure 4-4). The transit connection between San Francisco and San Jose is commuter rail based but is not heavily used. In general, transit in the Silicon Valley area is problematic. Goldman (2015), highlights the difficulties experienced by Silicon Valley janitors who cannot rely on transit to get to their jobs.

Table 4-1: AM Peak Travel Table for San Francisco-Silicon Valley Ecosystem

Start		End		Car	Public Transportation	Distance
A	**Mission Bay (San Francisco)**	**B**	**eBay Inc. (San Jose)**	1h 10min – 1h 50min	**Total: 1 h 56 min** [7min] Walk [1h1min] Commuter Rail [7min] LRT [11min] Walk [20min] Transfer/Wait	72.6km
A	**Mission Bay (San Francisco)**	**C**	**Google Headquarters (Mountain View)**	1h – 1h 40min	**Total: 1h 44min** [7min] Walk [40min] Commuter Rail [22min] Bus [15min] Bus [2min] Walk [18min] Transfer/Wait	56.9km
A	**Mission Bay (San Francisco)**	**D**	**Texas Instruments Inc. (Santa Clara)**	1h 5min – 1h 50min	**Total: 1h 19min** [7min] Walk [1h1min] Commuter Rail [11min] Walk [0min] Transfer/Wait	67.3km
A	**Mission Bay (San Francisco)**	**E**	**Hewlett-Packard Enterprise (Palo Alto)**	1h 8 min	**Total: 1h 17min** [7min] Walk [44min] Commuter Rail [11min] Bus [5min] Walk [10min] Transfer/Wait	63.1km
A	**Mission Bay (San Francisco)**	**F**	**University of California Berkeley**	22min – 40min	**Total: 55min** [6min] Walk [11min] Bus [6min] Subway [12min] Walk [20min] Transfer/Wait	20.2km
F	**University of California Berkeley**	**G**	**Stanford University**	1h 10min – 1h 50min	**Total: 2h 3min** [11min] Walk [50min] Subway [38min] Commuter Rail [12min] Walk [12min] Transfer/Wait	74.9km
H	**Apple Headquarters (Cupertino)**	**C**	**Google Headquarters (Mountain View)**	16min – 30min	**Total: 1h 37min** [4min] Walk [31min] Bus [22min] Bus [6min] Bus [2min] Walk [32min] Transfer/Wait	14.6km
I	**Downtown (San Jose)**	**J**	**South of Market (San Francisco)**	1h 15min – 2h	**Total: 1h 58min** [18min] Walk [1h27min] Commuter Rail [2min] Walk [5min] Bus [2min] Walk [4min] Transfer/Wait	76.3km

Figure 4-3: Map of Silicon Valley- San Francisco Innovation Ecosystem

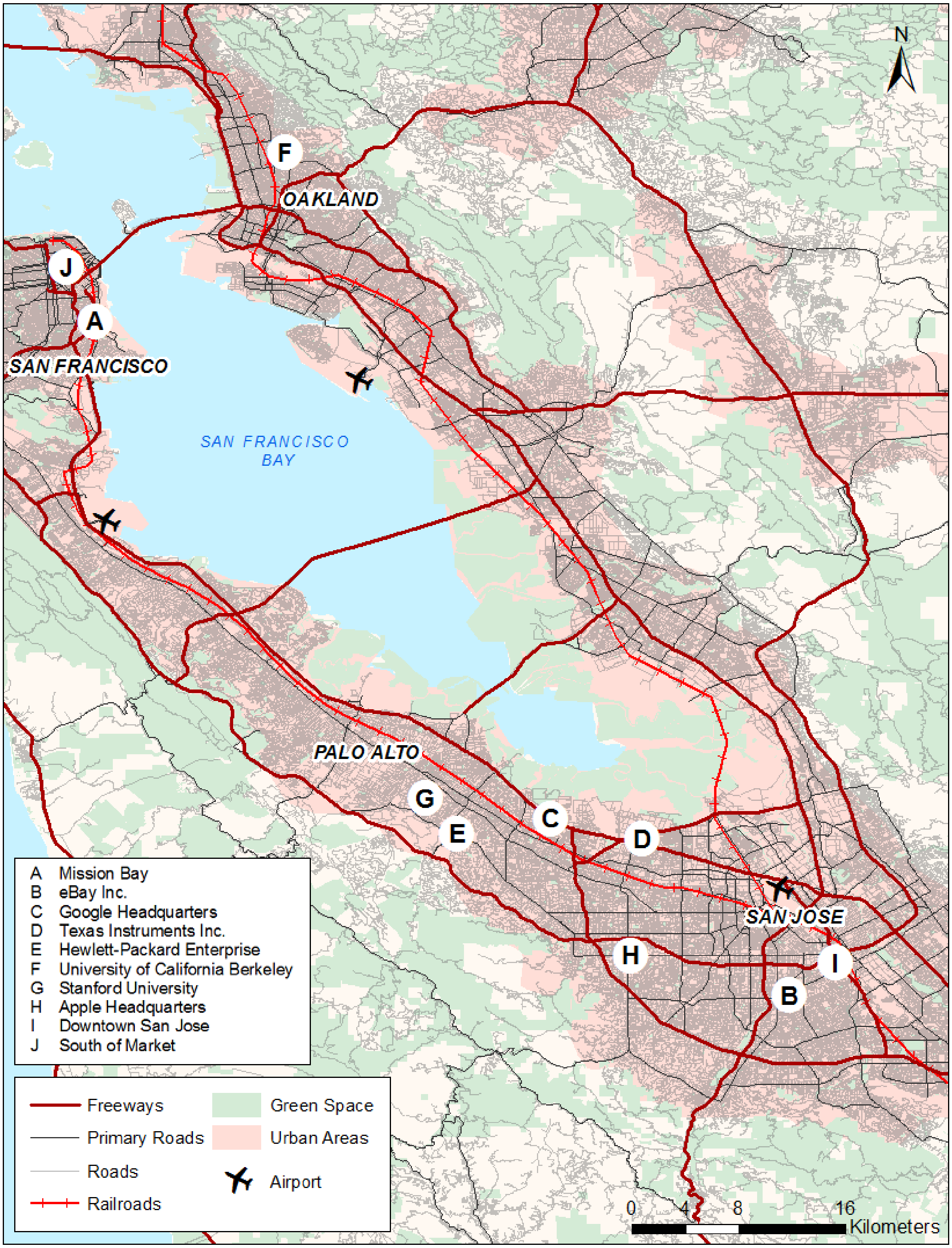


Figure 4-4: BART System Map

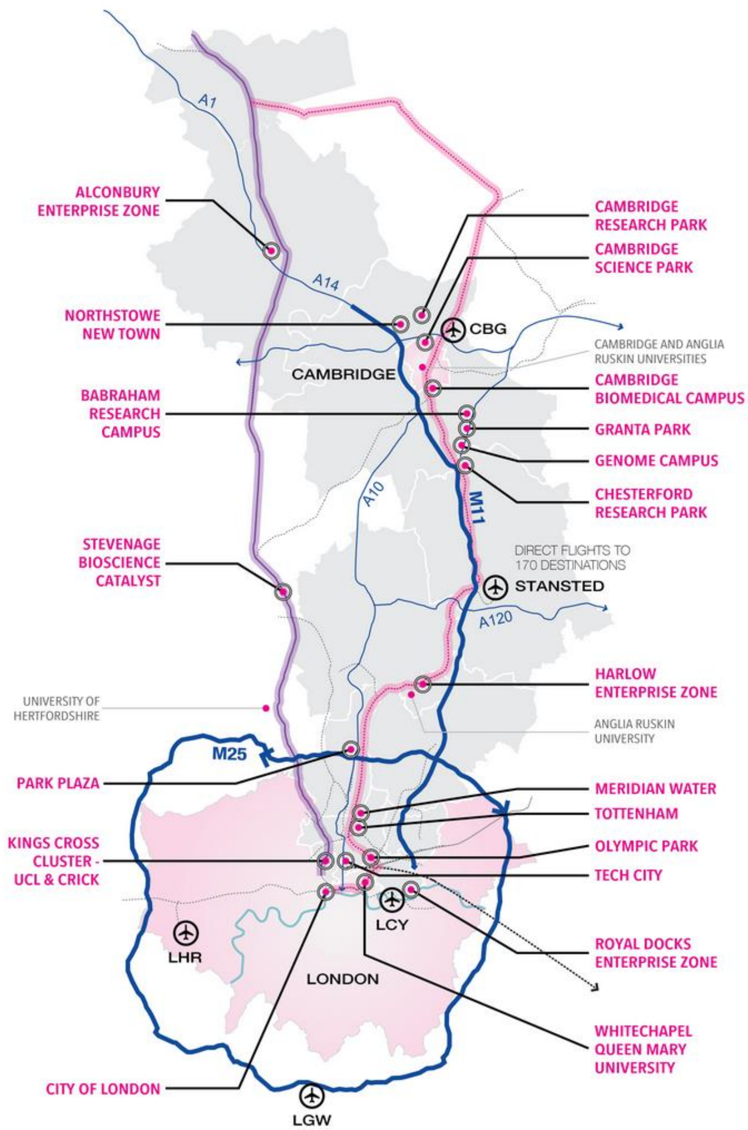
Source: (San Francisco Bay Area Rapid Transit District, 2014)

4.2 Cambridge-London

The Cambridge Cluster, also known as Silicon Fen, is generally perceived as the closest that Europe comes to a Silicon-Valley style start-up culture (Naughton, 2013). Cambridge is Europe's largest technology cluster. 57,000 people are employed by more than 1500 technology-based firms with combined annual revenues of over 13 Billion Pounds (University of Cambridge, 2016). Curiously, Cambridge per se is not specifically mentioned in the Compass (2015) report of start-up ecosystems though London is ranked as #6 in the world. Potentially, Cambridge is seen as part of the same ecosystem. However, the two places are quite distinct and separate. The London-Cambridge travel table gives some indication of the significant travel distances and times that separate the two. An important anchor of the corridor between London and Cambridge is Stansted International Airport which is centrally located between the two centres along the toll-free M11 motorway. This is London's "3rd" airport but it has risen to increasing prominence in recent years. The M11 motorway itself was completed only in 1980.

To provide similar context as for the other cases, consider that London's metropolitan population was 14,032,000 and the metropolitan population of Cambridge was 350,000 as of 2011. London is ranked first in this regard out of all metros in the U.K. and Cambridge ranks only 28th. The City of Cambridge proper has a population of only 158,000 with the metropolitan number being achieved through the population contributions of a series of small, outlying communities. These could hardly be seen as U.S. style suburbs but instead are a series of old, English settlements with their own town centres.

Figure 4-5: The Cambridge-London Corridor



Source: London-Stansted-Cambridge Consortium (2016)

Table 4-2: Travel Times Along the London-Cambridge U.K. Corridor

Start	End	Car	Public Transportation	Distance
University of Cambridge	**Imperial College London**	1h 50min – 3h	**Total: 1h 54min** [7min] Walk [7min] Bus [2min] Walk [55min] Commuter Rail [2min] Walk [15min] Subway [11min] Walk [15min] Transfer/Wait	105km
Tech City (Central and East London)	**Cambridge Research Park**	1h20min – 1h50min	**Total: 1h 58min** [4min] Walk [6min] Subway [3min] Walk [1h7min] Commuter Rail [3min] Walk [17min] Bus [18min] Transfer/Wait	106km
Watford (Suburb in Northwest London)	**Royal Docks Enterprise Zone (East London)**	1h – 1h40min	**Total: 1h 5min** [20min] Commuter Rail [3min] Walk [10min] Subway [21min] LRT [2min] Walk [9min] Transfer/Wait	72.7km
Station Road (Southeast Cambridge)	**Tech City (Central and East London)**	1h 20min – 2h20min	**Total: 1h 16min** [5min] Walk [53min] Commuter Rail [3min] Walk [6min] Subway [2min] Walk [7min] Transfer/Wait	89.2km
Brixton (neighborhood in South London)	**Cambridge Science Park**	1h 30min – 2h20min	**Total: 1h 51min** [3min] Walk [17min] Subway [3min] Walk [46min] Commuter Rail [2min] Walk [25min] Bus [4min] Walk [11min] Transfer/Wait	113km

Three main planning documents have shaped the spatial character of Cambridge in recent history (SQW, 2011). In 1950 the focus was on the preservation of the special character of Cambridge as a university town in a rural setting and thus development was quite restricted and a green belt was subsequently introduced. In 1969, a report suggested that science parks along the lines of the famous Cambridge Science Park should be excepted from restrictions. A report in 2003 helped to relax constraints of the green belt and from “demand pressures” that were building up (The Economist, 2001) and the result has been a dispersed pattern of industrial developments. Lately, there has been increased demand for central Cambridge space, but there are many competing demands. The rise of “coffee shop” culture and the fastest possible access to London (by train) is seen as important in this regard.

The links of Cambridge to London are considered very important for the Cambridge cluster (SQW, 2011). Cambridge is close enough to London that the latter is able to share its enormous labour market. Cambridge benefits from and contributes to the agglomeration effects generated by an enormous metropolitan region. Commuting from Cambridge to London is not seen as desirable, but it is seen as feasible. There are scenarios where two careers can be accommodated within a household and with one of the careers being based in each place. Access to London’s city life is obviously very important for many in the same way that San Francisco is appealing to Silicon Valley workers. There are also strong science and research links between London and Cambridge. Finally, London is an important source of venture capital for Cambridge.

Rail links between Cambridge and London are seen to be very important (SQW, 2011). Commuting by rail between the two centres is attractive because there is serious road congestion in both London and Cambridge and to a lesser extent along the M11. Intra-city road congestion pricing of course has been implemented in central London and discussed, though rejected, for central Cambridge. Frequent trains (i.e. multiple per hour) are available to Cambridge from both King’s Cross and Liverpool Street stations in London. It is possible to buy weekly, monthly or annual tickets that give unlimited rail travel between the two centres. Annual commuting of this type by rail would cost in the vicinity of $10,000 per year. Cambridge is suited to cycling and this is also a good way to get to and from the train station which is somewhat inaccessible to the city centre.

Table 4-3: Primary Modal Split of Commuting/Business Trips in England, 2013

Mode of Transport	Modal Split
Car/Van	69%
Walk	9%
Rail	9%
Local Bus	7%
Other	6%

Source: 2013 National Travel Survey

While commuting between Cambridge and London by car is difficult, and there appears to be more emphasis on rail links, the majority of all commuting to and from Cambridge is done by automobile. Evidence for this is provided in Table 4-3 where results from the 2013 National Travel Survey for England are shown. Nearly 70% of commuting/business trips are done by car or van. Walking is three times more prominent than in the United States and travel by rail alone exceeds the collective U.S. public transit share.

Overall, there is concern that growth of the Cambridge Cluster is outstripping developments in transportation to support this growth. Connections to London are paramount but many of the outlying science parks are not well-connected to the Cambridge rail station and instead are better suited to the automobile. There appears to be increased emphasis on improving connections to rail and ultimately with London. A new station is being built in the north of Cambridge and this is connecting to the Cambridge Guided Busway which opened in 2011 and which connects Cambridge to communities to the north-west nearly parallel to the route of the A14 highway.

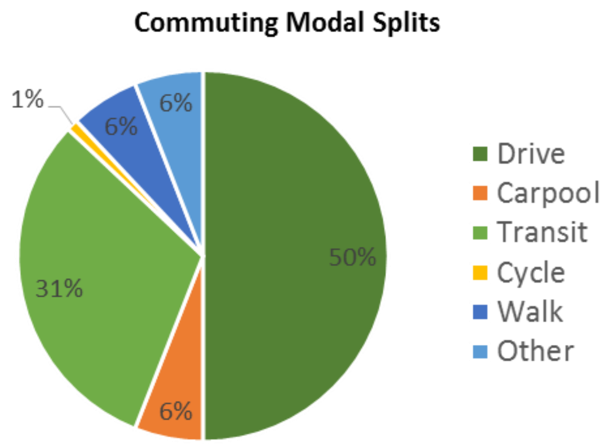
4.3 New York

In terms of a combination of venture capital deals and new patents, the New York Ecosystem ranks highest among all U.S. metropolitan areas though it ranks behind the Bay Area Ecosystem in sectors most associated with innovation. New York is the leading financial and cultural centre in the U.S., among other aspects, and is the largest of the metropolitan areas. There are numerous universities within its boundaries (e.g. Columbia University) and there are short freeway corridors to some of the most famous in the country (Princeton University 90km; Yale University 130km). These corridors offer parallels to the Toronto-Waterloo context.

As Figure 4-6 highlights, two things that stand out about the New York MSA are by far the highest metropolitan population densities in the U.S. in parallel with by far the highest shares in transit commuting. The typical census tract in New York, based on the weighted average calculation, has a population density of about 31,000 people per square mile. In New York, near Central Park on the Upper East Side, there are small census areas where the population density per square mile exceeds 200,000. Almost all of Manhattan and massive areas within the Bronx, Queens and Brooklyn have consistent tract densities of over 50,000 people per square mile. By way of comparison, San Francisco also rates highly in terms of metropolitan population density but hosts only a tiny number of tracts where population densities exceed even 100,000 per square mile. Clearly, public transit and population density have forged a symbiotic relationship in New York which has persisted for the long-term.

One of the implications, which was made apparent in Figure 2-5, is that there are fewer highway corridors in the New York MSA which feature ultra-high traffic volumes. In this respect, the New York system appears to be more balanced. However, annual hours of travel delay per auto commuter rank highly among U.S. metros and due to the sheer size of the metro, annual costs due to traffic congestion are very large (Figure 4-6).

Figure 4-6: Transportation/Innovation Metrics for New York



Population & General Commuting Metrics

Total Population	19,865,045
Weighted Population Density	31,251
% of Commuters with > 90 Minute Commutes	6.17%
Transit/Carpool Ratio	4.83

Innovation Metrics

Innovation Rank	1
2015 Venture Capital Deals	478
Patent Counts in 2013	7886

Road & Congestion Metrics

Travel Time Index	1.34
Freeway Planning Time Index – 95th Percentile	3.15
Annual Congestion Cost	$14.7 billion
Share of Driving Commutes > 60 Minutes	11.35%
Freeway Lane Miles	7,437
Annual Hours of Delay per Auto Commuter	74

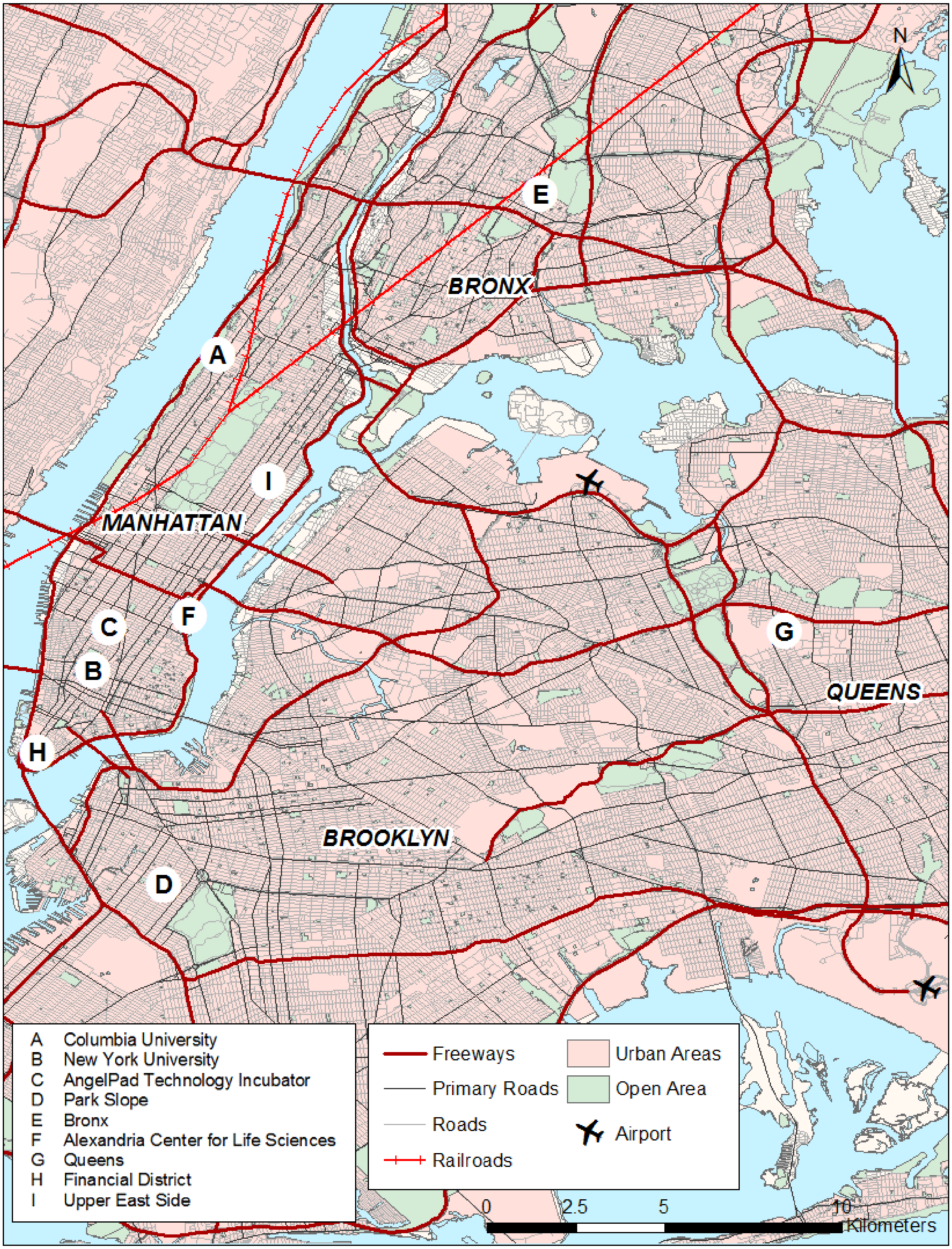
Transit Metrics

Total # Daily Rail Trips (Heavy + Light + Commuter)	8,259,896
Total # of Rail Stations (Heavy + Light + Commuter)	944
Total # Daily Bus Trips (Commuter + City)	3,246,859
% of Transit Commuters with > 60 Minute Commutes	39.87%

Table 4-4: AM Peak Travel Table for New York Innovation Ecosystem

Start		End		Car	Public Transportation	Distance
A	**Columbia University**	B	**New York University**	22min – 45min	**Total: 29 min** [2min] Walk [11min] Subway [12min] Subway [4min] Transfer/Wait	11.4km
C	**AngelPad Technology Incubator**	D	**Park Slope (neighborhood in Brooklyn)**	22min – 40min	**Total: 32 min** [18min] Walk [38min] Subway [12min] Walk [0min] Transfer/Wait	11.1km
E	**Bronx**	F	**Alexandria Center for Life Sciences**	35min – 1h	**Total: 1h 8min** [9min] Walk [44min] Subway [3min] Walk [0min] Transfer/Wait	18km
G	**Queens**	C	**AngelPad Technology Incubator**	40min – 1h15min	**Total: 1h 9min** [3min] Walk [10min] Bus [46min] Subway [4min] Walk [6min] Transfer/Wait	23km
H	**Financial District New York**	I	**Upper East Side New York**	18min – 30min	**Total: 33min** [11min] Walk [22min] Subway [0min] Transfer/Wait	13.2km
J	**Stamford, Connecticut**	B	**New York University**	1h5min – 1h50min	**Total: 1h 10min** [52min] Commuter Rail [2min] Walk [8min] Subway [3min] Walk [5min] Transfer/Wait	61.5km
A	**Columbia University**		**Princeton University**	1h10min – 1h50min	**Total: 1h 50min** [18min] Subway [3min] Walk [1h4min] Commuter Rail [13min] Walk [12min] Transfer/Wait	97.9km
	Yale University	A	**Columbia University**	1h30min – 2h10min	**Total: 2h 39min** [2min] Walk [28min] Bus [5min] Walk [1h49min] Bus (2) [15min] Transfer/Wait	125km

Figure 4-7: Map of New York Innovation Ecosystem



It is not just automobile trips that are time consuming though: 40% of transit-oriented commutes in New York take more than an hour. New York is a major centre for commuter rail also. Figure 2-6 and Table 4-4 capture that there are many transit commuters from Connecticut, for example, who have long commutes into the core of New York City.

Manhattan, the heart of the metro, receives a lot of attention for traffic woes, despite high transit shares, and there has been a long-standing debate about whether a congestion pricing solution, along the lines of London, is the only way to solve the problem (Jaffe, 2014a). The issue in Manhattan is significant from the innovation perspective, among others, because this borough has become a real focus for start-up activity.

4.4 Austin

Austin, Texas is noted as being the fastest growing metropolitan area in the United States and recent reports suggest that it has just passed 2 million in population. A favourable climate in terms of both investment and weather has had much to do with growth and there has been a much publicized large migration pattern from California to Texas with the latter state being perceived as much more business-friendly. Austin has been a main beneficiary.

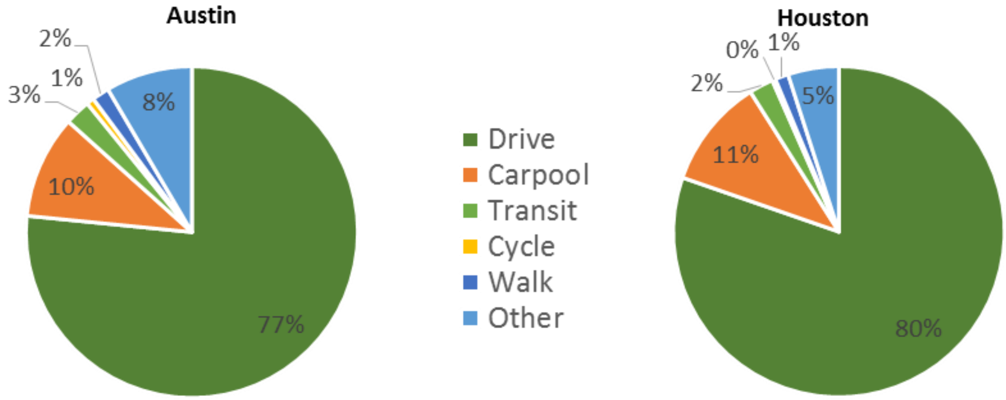
Austin defines the heart of a large Texas innovation triangle which includes the much larger metropolitan areas of Houston and Dallas. Austin outranks both in terms of key innovation criteria and is home to 2,200 technology companies (Powers, 2006). As the smallest metropolitan area of the three, Austin has more in common with the Region of Waterloo than Toronto but Austin is sufficiently remote that it really stands on its own in its region. The University of Texas is the major university in the region.

A new high-speed rail line that is being planned between Dallas and Houston would leave Austin out because it is not close to being on the direct route. Austin is on the Dallas-San Antonio corridor. There is increasing concern about road congestion in the triangle and this is part of the reason that high-speed rail is seen as a profitable possibility for the private entity that is developing it.

The problem of traffic congestion looms large in the Austin region itself and there is considerable local concern that growth in the region is happening too fast for infrastructure to keep up. For a smaller metro, Austin's 52 hours of annual delay per commuter is seen as quite high. While traffic congestion is high, transit shares remain very low (Figure 4-8). Partly this is because Austin, like Houston is a very low density metro.

Figure 4-8: Transportation/Innovation Metrics for Austin and Houston

Commuting Modal Splits



Population & General Commuting Metrics

	Austin	Houston
Total Population	1,835,016	6,204,141
Weighted Population Density	3,131	4,110
% of Commuters with > 90 Minute Commutes	1.91	2.09
Transit/Carpool Ratio	0.25	0.22

Innovation Metrics

	Austin	Houston
Innovation Rank	10	16
2015 Venture Capital Deals	99	29
Patent Counts in 2013	2,683	2,655

Road & Congestion Metrics

	Austin	Houston
Travel Time Index	1.33	1.33
Freeway Planning Time Index – 95th Percentile	2.58	3.13
Annual Congestion Cost	$1.14 billion	$4.92 billion
Share of Driving Commutes > 60 Minutes	5.89%	8.68%
Freeway Lane Miles	964	3,137
Hours of Delay per Auto Commuter	52	61

Transit Metrics

	Austin	Houston
Total # Daily Rail Trips (Heavy + Light + Commuter)	--	31,016
Total # of Rail Stations (Heavy + Light + Commuter)	--	16
Total # Daily Bus Trips (Commuter + City)	95,166	189,275
% of Transit Commuters with > 60 Minute Commutes	24.51%	38.23%

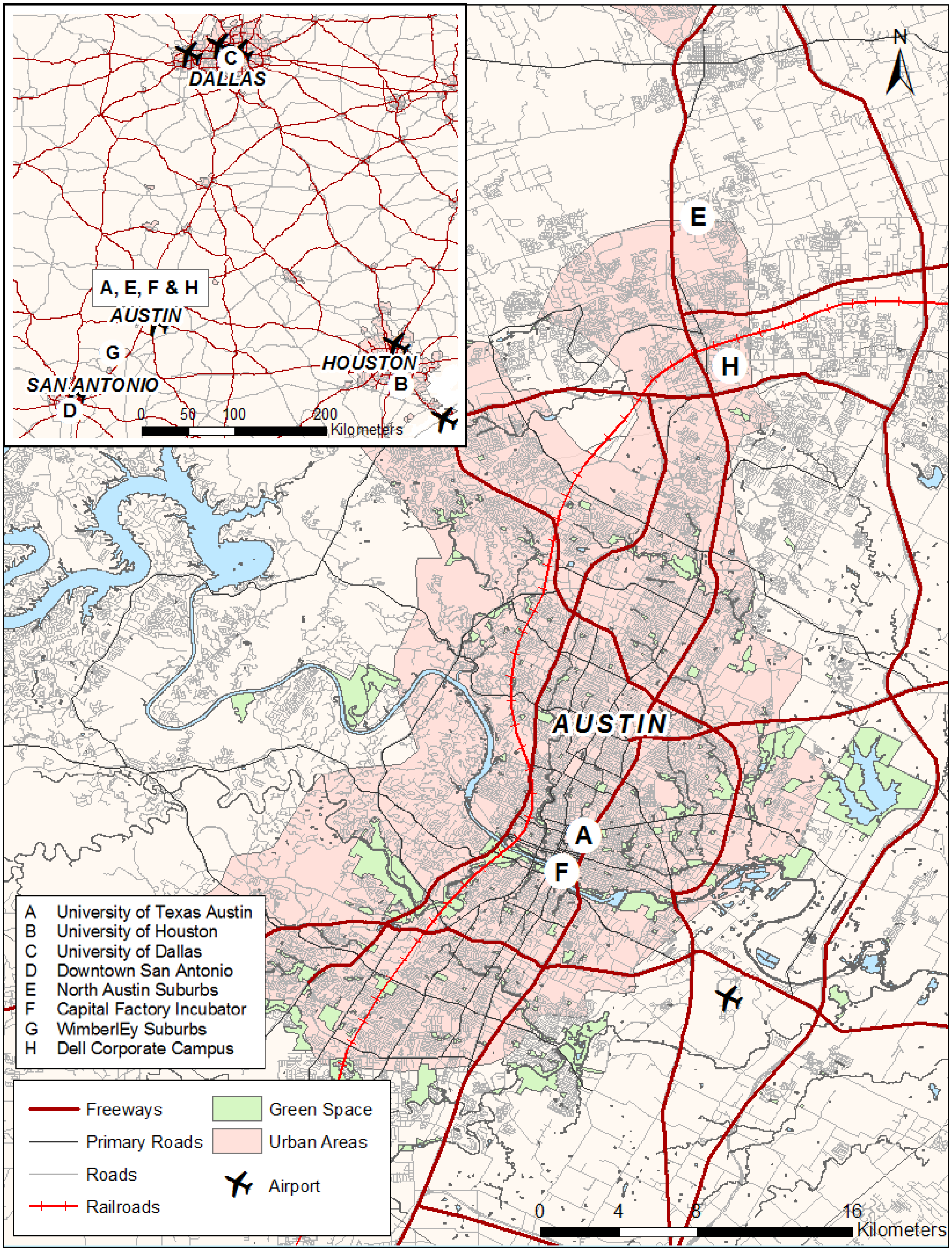
Austin is the largest metropolitan region in the U.S. with only one interstate highway but the prior dashboard does indicate that freeway infrastructure is quite well developed. Less than 50 years ago, Austin had a population of about 250,000 and there is concern that an associated "smaller town" mentality, or a desire to remain a small town, is affecting perceptions about what needs to be done for transport infrastructure (Goodwyn, 2013).

In Figure 4-9 and Table 4-5 a trip table for Austin and the region is provided and a supporting map is provided that shows Austin's locational context.

Table 4-5: AM Peak Travel Table for Austin Innovation Ecosystem

Start		End		Car	Public Transportation	Distance
A	**University of Texas Austin**	B	**University of Houston**	2h50min – 3h30min	**Total: 4h 38 min** [4min] Walk [5min] Bus [3h15min] Bus [5min] Walk [31min] LRT [12min] Walk [26min] Transfer/Wait	273km
A	**University of Texas Austin**	C	**University of Dallas**	2h50min – 3h30min	**Total: 4h 55min** [6min] Bus [32min] LRT [5min] Walk [3h25min] Bus [5min] Bus [42min] Transfer/Wait	325km
D	**Downtown (San Antonio)**	A	**University of Texas Austin**	1h15min – 1h40min	**Total: 2h 11 min** [3min] Walk [1h50min] Bus [3min] Bus [10min] Walk [5min] Transfer/Wait	129km
E	**North Austin Suburbs**	F	**Capital Factory Incubator/ Accelerator (Austin)**	24min - 45min	**Total: 45 min** [2min] Walk [37min] Bus [6min] Walk [0min] Transfer/Wait	18km
G	**Wimberley (Suburbs in Austin)**	H	**Dell Corporate Campus**	1h5min – 1h20min	**No Public Transit for this route**	86km

Figure 4-9: Map of Austin Innovation Ecosystem



4.5 Ann Arbor – Detroit

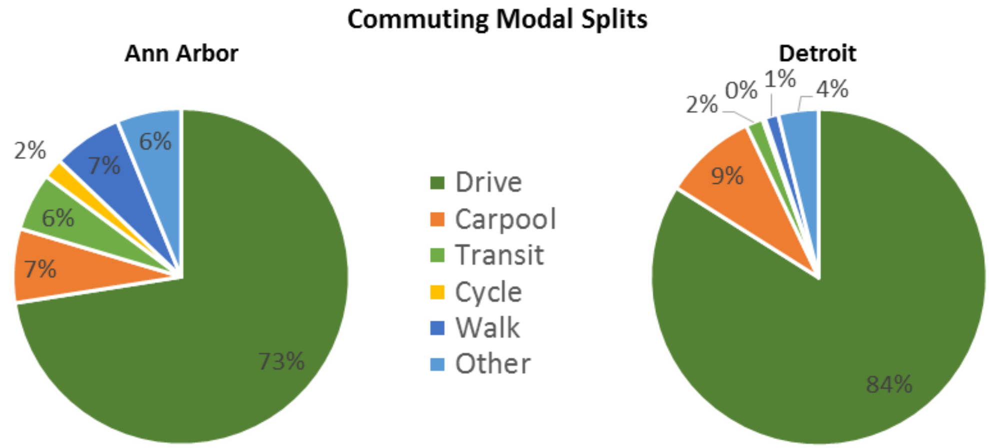
The Ann Arbor – Detroit region clearly has a rich transportation history centred on the rise of the automobile and to this day, the automotive sector is central to both local economies and the North American economy for that matter. Many of the statistics shown in Figure 4-10 reflect that the automobile has shaped the city in land use as well as economic terms. Ann Arbor is the home to the University of Michigan which is arguably the most important innovation node in the state and one of the results is that there were more venture capital deals there than in Detroit in 2015, though Detroit had far more patents. The regional economy has had some success in diversifying away from automotive sectors with large concentrations in health care, defense, aerospace and information technology.

One of the dominant transportation themes is the high level of automobile dependence in the region and especially so in Detroit which has had very little success in achieving any momentum in public transit. The reasons for poor transit in Detroit relate mainly to poor relations between cities and suburbs and concerns about high costs (Derringer, 2016). Comparisons with Table 2-3: Overview Table for U.S. Top 50 Innovation Ecosystems, show that while Detroit's population density is fairly low, it is not untypical for U.S. metros. It is a level of population density that makes it more challenging for public transit to succeed. Other problems include the fact that there is a mismatch between where people who take transit live and where they work (Derringer, 2016).

The Regional Transit Authority of Southeast Michigan was formed recently in 2012 and is the most recent of several attempts to reinvigorate transit and launch commuter services in the region. The state purchased 145 miles of rail line between Kalamazoo and the Detroit suburb of Dearborn. This rail line would join Ann Arbor to Detroit by commuter rail but as of yet has not come to pass. There has been talk of a high-quality conventional rail link across the state (Fleming & Oosting, 2016) from Detroit to the Lake Michigan coast via Grand Rapids and both proposed routes would pass through Ann Arbor. Service at 110 mph has been forecast to turn a profit but not at the slower speed scenario of 79mph.

The transportation profile of Ann Arbor is more balanced than that of Detroit with less dependence on the automobile. At present, connections between the two are premised on excellent highway infrastructure over multiple routes. The trip table results (Table 4-6) suggest that the quality of highway travel between the two regions is good with many parts of Detroit being easily reachable within an hour even at peak times. The results also illustrate that there are no real viable options except for the car. Traffic volumes on Interstate 94 between Ann Arbor and Detroit are at less than 100,000 vehicles per day which is much lower, for example, than Hwy 401 between Milton and Mississauga.

Figure 4-10: Transportation/Innovation Metrics for Ann Arbor and Detroit



Population & General Commuting Metrics

	Ann Arbor	Detroit
Total Population	351,454	4,292,647
Weighted Population Density	3,363	3,800
% of Commuters with > 90 Minute Commutes	1.04%	1.77%
Transit/Carpool Ratio	0.78	0.18

Innovation Metrics

Innovation Rank	28	23
2015 Venture Capital Deals	25	16
Patent Counts in 2013	734	3,000

Road & Congestion Metrics

Travel Time Index	1.16	1.24
Freeway Planning Time Index – 95th Percentile	2.15	2.8
Annual Congestion Cost	$194 million	$3.5 billion
Share of Driving Commutes > 60 Minutes	4.97%	6.02%
Freeway Lane Miles	249	2,049
Hours of Delay per Auto Commuter	28	52

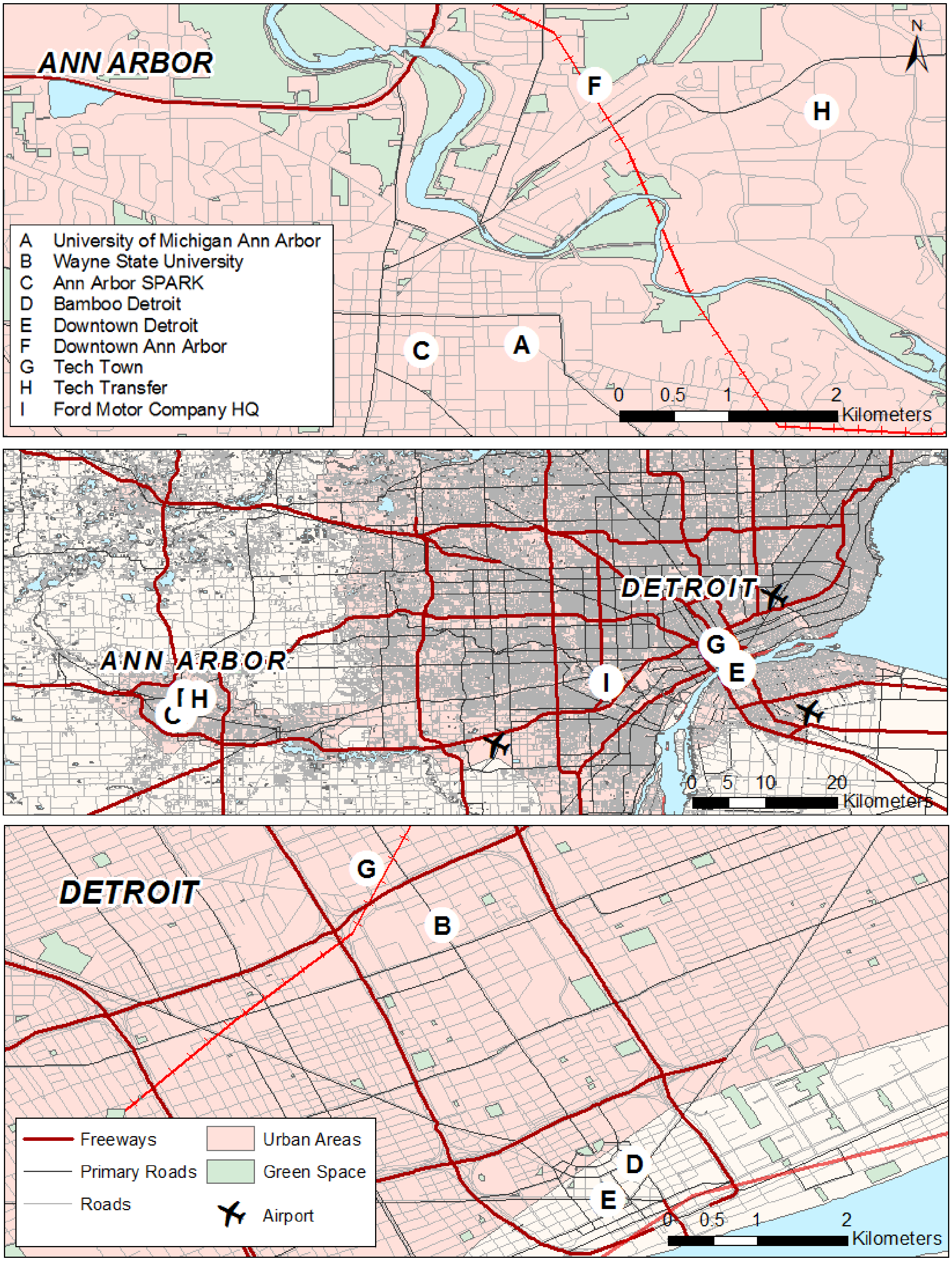
Transit Metrics

Total # Daily Rail Trips (Heavy + Light + Commuter)	--	--
Total # of Rail Stations (Heavy + Light + Commuter)	--	--
Total # Daily Bus Trips (Commuter + City)	37,775	110,585
% of Transit Commuters with > 60 Minute Commutes	11.19%	41.29%

Table 4-6: AM Peak Travel Table for Ann Arbor/Detroit Innovation Ecosystem

Start		End		Car	Public Transportation	Distance
A	**University of Michigan Ann Arbor**	**B**	**Wayne State University**	40min – 50min	**Total: 3h 38 min** [19min] Bus [1h17min] Bus [4min] Walk [30min] Bus [8min] Walk [19min] Bus [1h1min] Transfer/Wait	65.9km
C	**Ann Arbor SPARK**	**D**	**Bamboo Detroit (Incubator)**	40min – 55min	**Total: 3h 27min** [9min] Walk [1h9min] Bus [4min] Walk [30min] Bus [3min] Walk [24min] Bus [1h8min] Transfer/Wait	70.8km
E	**Downtown (Detroit)**	**F**	**Downtown (Ann Arbor)**	35min – 45min	**Total: 3h 18min** [5min] Walk [1h14min] Bus [4min] Walk [30min] Bus [3min] Walk [28min] Bus [4min] Walk	55.5km
G	**Tech Town (Detroit)**	**H**	**Tech Transfer (Ann Arbor)**	30min - 55min	**Total: 1h 39min** [7min] Walk [56min] Commuter Rail [2min] Walk [23min] Bus [11min] Transfer/Wait	61.8km
E	**Downtown Detroit**	**I**	**Ford Motor Company HQ**	16min – 22min	**Total: 34min** [5min] Walk [25min] Bus [4min] Walk [0min] Transfer/Walk	16km

Figure 4-11: Map of Detroit – Ann Arbor Innovation Ecosystem



4.6 Denver-Boulder

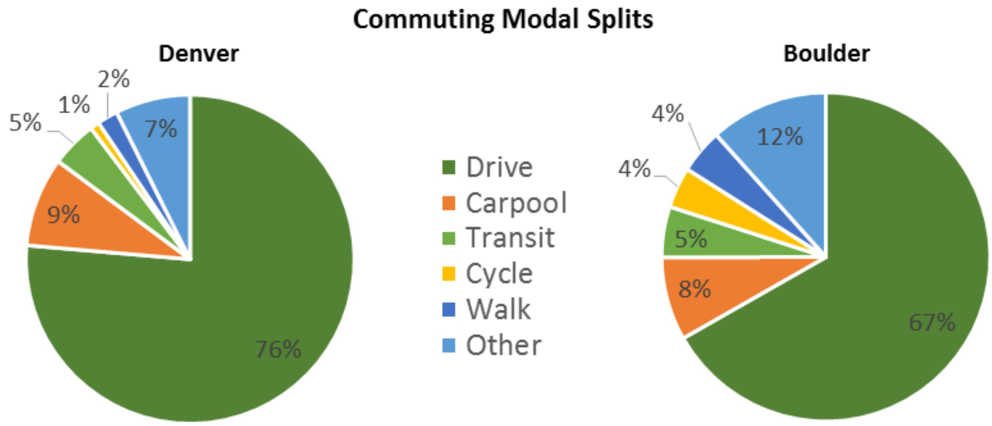
Denver and Boulder represent an interesting analogy to the Toronto-Waterloo corridor. However, the Denver metro is considerably smaller than Toronto and Boulder is smaller than the Region of Waterloo. Another difference is that Denver and Boulder are significantly closer together than Toronto and Waterloo. Results from Figure 4-12 suggest further that Denver is much less dense than Toronto. A prominent innovation hub in Boulder is the University of Colorado and this likely has a lot to do with Boulder having comparable innovation statistics to the much large Denver metro. Consistent with a university town, Boulder has much higher levels of walking and cycling than Denver and much higher levels than prevail in the U.S. as a whole. Denver in particular is quite driving oriented and ranks similar to Austin in this regard.

One of the interesting aspects of the Denver-Boulder case is that the local authorities have been pushing hard to diversify travel away from the automobile. The overall initiative is known as FasTracks. It is a metro-wide mass transit project which also features connections to Boulder (Whaley, 2015) which has similarities to the GTHA's Big Move. The Denver-Boulder region has been concerned with significant population growth combined with already high levels of traffic and congestion and has turned to mass transit in the past decade to deal with the problems on the horizon.

The cores of both cities are thriving in terms of innovation and startup activity (Sodd, 2015) and indeed there has been an unprecedented inward migration of young and educated people to the Denver core. Within the area, Boulder has traditionally been the centre of start-up activity in the Colorado. There is speculation that the corridor between Denver and Boulder is going to experience increased development activity though more in the context of large, more mature firms.

The first components of Fastracks call for 122 miles of new light rail and commuter rail. A proposed rail connection between Denver and Boulder is instead moving forward as a highway-oriented express Bus Rapid Transit service. This main highway route between Denver and Boulder is Route 36 also known as the Denver-Boulder Turnpike. A BRT bus service operates between Denver and Boulder and runs approximately 45km (Urban Land Institute , 2013). Toll lanes are to be developed with one of the objectives being to have the bus service move at 80km/h. There are projections that a BRT trip between Denver and Boulder will be faster than solo driving trip in general purpose lanes (Aguilar, 2011). Ultimately, the service is intended to be high-frequency at as little as every five minutes at peak times. There are some concerns that a nearby competing commuter rail service and the BRT service will cannibalize one another and that both are not needed. The proposed rail service terminates at Longmont, CO which is approximately 20km north east of Boulder and runs to the centre of Denver.

Figure 4-12: Transportation/Innovation Metrics for Boulder and Denver



Population & General Commuting Metrics

	Denver	Boulder
Total Population	2,651,392	305,166
Weighted Population Density	4,804	3,650
% of Commuters with > 90 Minute Commutes	1.92%	1.52%
Transit/Carpool Ratio	0.51	0.61

Innovation Metrics

Innovation Rank	19	25
2015 Venture Capital Deals	51	29
Patent Counts in 2013	1,064	768

Road & Congestion Metrics

Travel Time Index	1.30	1.20
Freeway Planning Time Index – 95th Percentile	2.97	2.48
Annual Congestion Cost	$2.06 billion	$89 million
Share of Driving Commutes > 60 Minutes	5.07%	4.05%
Freeway Lane Miles	1,280	59
Hours of Delay per Auto Commuter	49	35

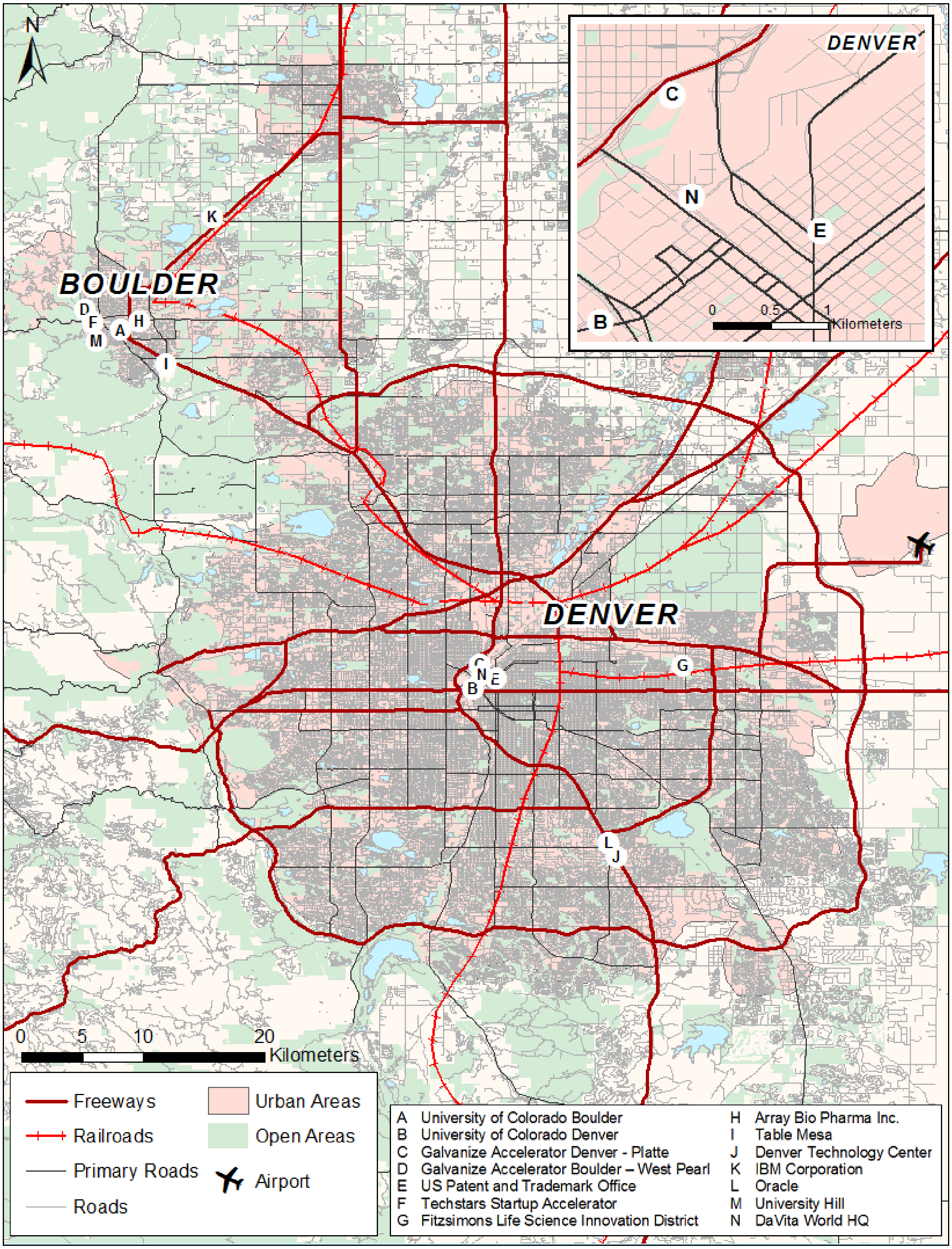
Transit Metrics

Total # Daily Rail Trips (Heavy + Light + Commuter)	65,314	--
Total # of Rail Stations (Heavy + Light + Commuter)	46	--
Total # Daily Bus Trips (Commuter + City)	209,174	--
% of Transit Commuters with > 60 Minute Commutes	34.85%	23.8%

Table 4-7: AM Peak Travel Table for Denver/Boulder Innovation Ecosystem

	Start		End	Car	Public Transportation	Distance
A	**University of Colorado Boulder**	**B**	**University of Colorado Denver**	30min – 45min	**Total: 58 min** [4min] Walk [41min] Bus [3min] Walk [3min] Bus [4min] Walk [3min] Transfer/Wait	43.4km
C	**Galvanize Accelerator Denver – Platte**	**D**	**Galvanize Accelerator Boulder – West Pearl**	35min – 50min	**Total: 1h 11min** [14min] Walk [50min] Bus [7min] Walk [0min] Transfer/Wait	44.2km
E	**US Patent and Trademark Office (Denver)**	**F**	**Techstars Startup Accelerator (Boulder)**	35min – 55min	**Total: 1h 12min** [4min] Walk [2min] Bus [49min] Bus [5min] Walk [12min] Transfer/Wait	44.7km
G	**Fitzsimons Life Sciences Innovation District (Aurora near Denver)**	**H**	**Array Bio Pharma Inc.**	40min – 1h 40min	**Total: 1h 29 min** [4min] Walk [1h5min] Bus [2min] Walk [6min] Bus [4min] Walk [8min] Transfer/Wait	50.9km
I	**Table Mesa (suburb in Boulder)**	**J**	**Denver Technology Center**	1h 10min – 1h 50min	**Total: 1h 47min** [14min] Walk [36min] Bus [5min] Walk [30min] LRT [16min] Walk [6min] Transfer/Wait	74.9km
K	**IBM Corporation (Boulder)**	**L**	**Oracle (Denver)**	55min – 1h 10min	**Total: 2h 19min** [6min] Walk [23min] Bus [47min] Bus [5min] Walk [28min] LRT [15min] Walk [15min] Transfer/Wait	72.4km
M	**University Hill (neighborhood in Boulder)**	**N**	**DaVita World HQ (Denver)**	35min – 50min	**Total: 55min** [3min] Walk [44min] Bus [8min] Walk [0min] Transfer/Wait	42.9km

Figure 4-13: Map of Denver-Boulder Innovation Ecosystem



About midway between Denver and Boulder, Broomfield is a suburban community that is working to co-ordinate BRT, HOT lanes and suburban mixed use development. Buses used to pick up passengers at a park-and-ride lot that was not integrated into the Route 36 and was some distance removed. Now buses pick up passengers on slip ramps[9] and a pedestrian overpass has been constructed. Associated with a mixed use development in the immediate vicinity of the interchange are a 6000 seat entertainment venue, extensive office space and compact residential development all of which are within easy walking distance of the bus service.

4.7 Boston

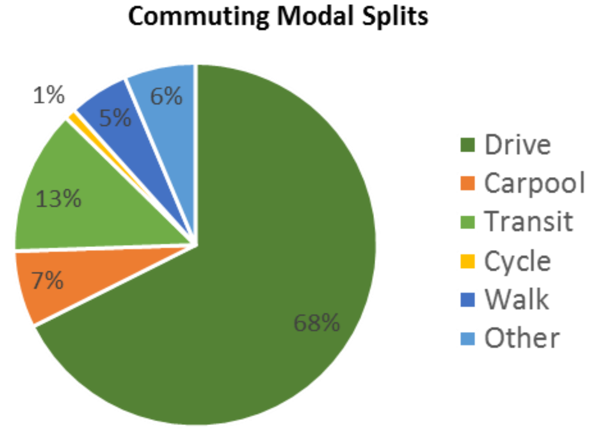
Boston is host to world-class innovation clusters and also some world-class transportation initiatives. There is a major focus on life sciences in the region and a long history of important technological advances (Temple, 2014). In the transportation context, the “Big Dig” involved dismantling the elevated Central Artery expressway of Interstate 93 (somewhat analogous to Toronto’s Gardiner Expressway) and renewing it as a tunnel under the city (Flint, 2015). This was a multi-decade task that was completed in 2006 and opened up the possibility for substantial urban redevelopment and beautification in the vicinity. The project had massive cost overruns and delays but has driven up real estate values considerably in the area. In retrospect, the project appears to be getting favourable reviews.

An important philosophy in Boston, as the Big Dig demonstrates, is a strong orientation to the central city and to public transit. The metropolitan area is one of the higher ranking in terms of population density and it is noteworthy that many of its most important innovation nodes are well-oriented to the extensive heavy and light rail systems. Even so, about ¾ of commuting trips are dependent on the automobile.

The Greater Boston Area has done a good job of integrating its heavy rail system with some of its main innovation hubs and indeed many of these hubs are proximate to the central City. Harvard and MIT are across the Charles River from the downtown core. The Kendall Square cluster in particular is highly concentrated and is in close proximity to both MIT and heavy rail. Table 4-8 shows that many important innovation nodes in Boston are comfortably linked, in terms of travel time, by transit. The famous Route 128 cluster, which is oriented to a suburban interstate, was seen as a counterpart/competitor to Silicon Valley in the 1970s but is relatively much less prominent nowadays and in comparison to the clusters that have been developing in the heart of Boston.

[9] These are pick-up and drop off areas that are engineered into existing highway on and off ramps so that buses are minimally disrupted in terms of achieving high overall average speeds.

Figure 4-14: Transportation/Innovation Metrics for Boston



Population & General Commuting Metrics

Total Population	4,650,876
Weighted Population Density	7,980
% of Commuters with > 90 Minute Commutes	2.88%
Transit/Carpool Ratio	1.88

Innovation Metrics

Innovation Rank	4
2015 Venture Capital Deals	428
Patent Counts in 2013	5,610

Road & Congestion Metrics

Travel Time Index	1.29
Freeway Planning Time Index – 95th Percentile	2.81
Annual Congestion Cost	$3.36 billion
Share of Driving Commutes > 60 Minutes	9.73%
Freeway Lane Miles	2,603
Annual Hours of Delay per Auto Commuter	64

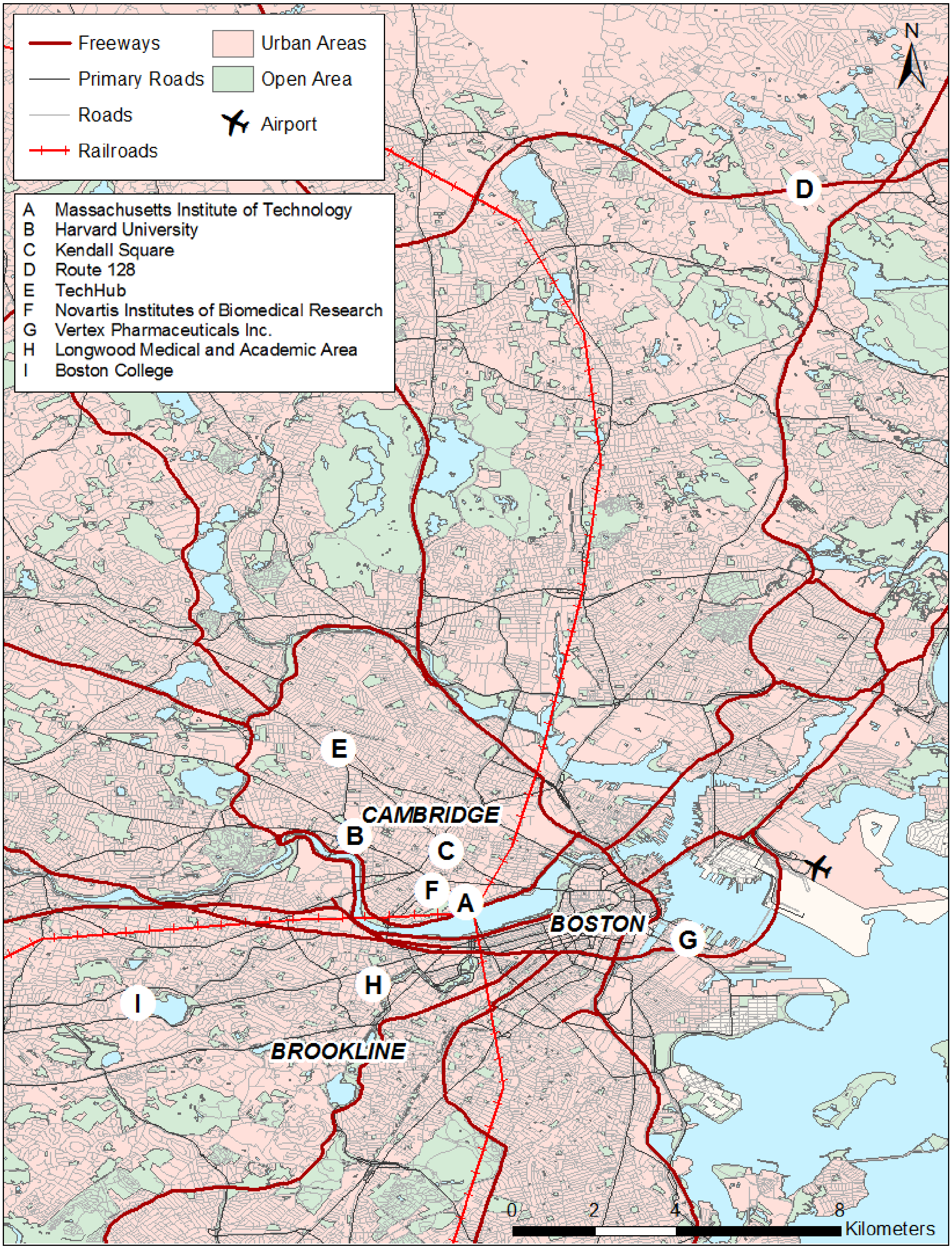
Transit Metrics

Total # Daily Rail Trips (Heavy + Light + Commuter)	750,616
Total # of Rail Stations (Heavy + Light + Commuter)	264
Total # Daily Bus Trips (Commuter + City)	336,061
% of Transit Commuters with > 60 Minute Commutes	30.91%

Table 4-8: AM Peak Travel Table for Boston Innovation Ecosystem

Start		End		Car	Public Transportation	Distance
A	**Massachusetts Institute of Technology**	**B**	**Harvard University**	3min – 6min	**Total: 13min** [12min] Bus [1min] Transfer/Wait	1.7km
C	**Kendall Square**	**D**	**Route 128**	28min – 40min	**Total: 2h 35min** [2min] Walk [21min] Bus [4min] Walk [33min] Commuter Rail [41min] Bus [15min] Walk [39min] Transfer/Wait	33.5km
E	**TechHub**	**A**	**Massachusetts Institute of Technology**	12min – 24min	**Total: 21min** [4min] Walk [11min] Subway [6min] Walk [0min] Transfer/Wait	5.2km
F	**Novartis Institutes of Biomedical Research**	**G**	**Vertex Pharmaceuticals Inc. (Seaport District)**	16min – 26min	**Total: 35min** [9min] Walk [13min] Subway [8min] Bus [1min] Walk [4min] Transfer/Wait	12.6km
H	**Longwood Medical and Academic Area**	**I**	**Boston College**	12min – 26min	**Total: 35min** [5min] Subway [7min] Walk [6min] Subway [12min] Walk [0min] Transfer/Wait	6.5km

Figure 4-15: Map of Boston Innovation Ecosystem



5

Characterizing Toronto-Waterloo-Hamilton Inter-City Travel Corridors

Prior chapters in this report have focused on characterizing the transportation context for mostly U.S. innovation clusters and associated transportation corridors that join innovation nodes. This chapter focuses on a similar characterization of the Toronto-Waterloo-Hamilton corridors from the transportation perspective.

The chapter is primarily empirical and presents data that are specific to the local corridors. There is a strong emphasis on assessing the performance of the road corridors in the region as we leverage 2014 speed data from INRIX Corporation. There is also discussion of important employment clusters in the region, many of which house innovative activities or have much to do with the large amounts of road traffic that are generated in the region.

5.1 Recent Transportation and Land Use Planning Documents

Initially, it is useful to provide an overview of the transportation and land use planning backdrop that prevails in the overall study region. Table 5-1 provides a brief overview of the major reports.

Each of these planning documents appear to be moving in the same direction. There is a strong emphasis on public transit, especially by rail. There is emphasis on multi-modal travel, compact cities and urban intensification and on restricting urban sprawl. In reading between the lines, there is really an important focus on reducing automobile dependence. There is not much emphasis on building new highway infrastructure – it is more about making efficient use of the infrastructure in place. Strategy #3 of the Big Move, for example, is to "Improve the Efficiency of the Road and Highway Network" and to the extent that new road infrastructure is emphasized, it seems to be for relief of bottlenecks.

Table 5-1: Major Transportation and Land Use Planning Documents in the Study Region

Planning Document	Description
The Big Move (2011) Metrolinx	A transportation plan for the Greater Toronto and Hamilton Area (GTHA) for the next 15 to 25 years. It accounts for all transportation modes, works towards easing congestion and commute times and promotes the integration of local transit systems and the GO Transit system. It talks about the current challenges in the region such as population growth, congestion and under-investment and plans to resolve these issues with 10 strategic points and 9 big moves.
Places to Grow – Growth Plan for the Greater Golden Horseshoe 2006	The vision for 2041 is for communities to have clean and healthy environments, social equity and a strong economy. This policy report proposes a plan to address current problems in transportation, infrastructure, land-use planning and protection of the natural environment. Urban intensification, an emphasis on public transit and containment of urban sprawl are important elements of this report.
Greenbelt Plan 2007	This report identifies agricultural and ecological landscapes in need of protection from urbanization. Goals include agricultural and environmental protection, increased recreation and tourism, and the protection of natural resources and the rural economies of settlement areas.
Regional Transportation Master Plan (2011) – Waterloo	The plan for 2031 in the Region of Waterloo is to prioritize moving goods and people efficiently and also help shape the community to become more vibrant, compact and sustainable. A multi-modal system of integrated transportation infrastructure and policies is proposed to maximize investments in existing infrastructure and help develop the transit corridor. There is no doubt that transit and active travel are important components of the plan.
Hamilton Transportation Master Plan 2007	The Hamilton Transportation Master Plan is currently in the midst of a review and update process. The 2007 plan is focused on reducing automobile dependence and on promoting improved options for walking, cycling and transit. Bus Rapid Transit is emphasized in this report but subsequently there was renewed emphasis on light rail transit and a major core-city project was approved for funding by the province.

As part of our earlier examination of case studies from elsewhere, we did not go to the extent of systematically gathering local planning documents for each case. Certainly, many of these same themes have been encountered elsewhere. But different metropolitan ecosystems are starting from very different places. Houston and Dallas, for example, have comparable populations to this region but these are much lower density places than the Toronto CMA. In these jurisdictions, it is a more daunting process to reduce automobile dependence.

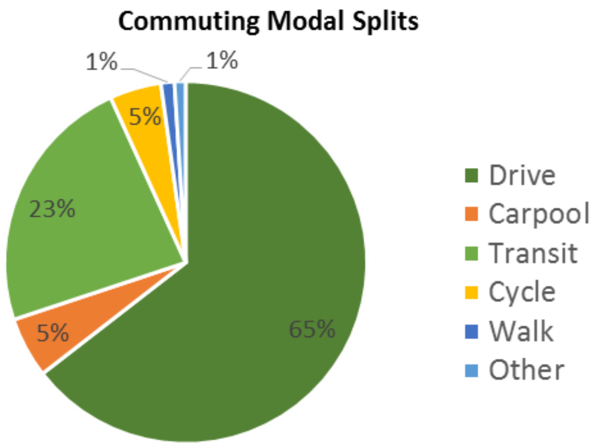
5.2 Transportation Innovation Metrics for Local Metropolitan Ecosystems

The three figures to follow are dashboards that have been created for each of the local ecosystems. Due to differences in data sources, they differ to some extent from similar figures of earlier U.S. case studies, but useful comparisons can still be made. The sources for the following dashboards include the 2011 National Household Survey from Statistics Canada, the Statistical Institute of Quebec, the Canadian Urban Transit Association, and a report titled *Startup City Canada* (Florida & King, 2015).

In Figure 5-1, the weighted population density for the Toronto CMA is high compared to other North American metropolitan areas studied but is about 2/3 that of the New York metro. Both the Kitchener CMA (Figure 5-2) and the Hamilton CMA (Figure 5-3) have relatively high population densities that are comparable to San Jose and San Francisco respectively. Generally speaking, higher population density is translating into reduced automobile dependency as observed in the commuting modal split pie charts. Of the three Canadian metros, the Kitchener CMA stands out as being the most automobile dependent and has the lowest population density. The number of rail stations (light + heavy + commuter) in Toronto is large, compared to Kitchener and Hamilton, and expanding. The associated improved connectivity will help to mitigate increases in traffic congestion.

In terms of venture capital, it is worth noting that investment per capita is largest in the Kitchener CMA compared to Toronto and Hamilton. The innovation heart of the Kitchener CMA is of course the Waterloo cluster centred on the universities. Comparisons can be made with Ann Arbor and Boulder although the Kitchener CMA is more heavily populated and denser than either. Kitchener-Waterloo fits the mold of a university town located in fairly close proximity to a large metropolitan area though the distances to Toronto are larger than Boulder-Denver and Ann Arbor-Detroit.

Figure 5-1: Key Transportation/Innovation Metrics for the Toronto CMA



Population & General Commuting Metrics

Total Population of Metropolitan Area, 2015	6,129,900
Weighted Population Density	20,803
% of Commuters with > 60 Minute Commutes	15.8%
Share of Driving Commutes > 60 Minutes	8.73%
Transit/Carpool Ratio	1.32

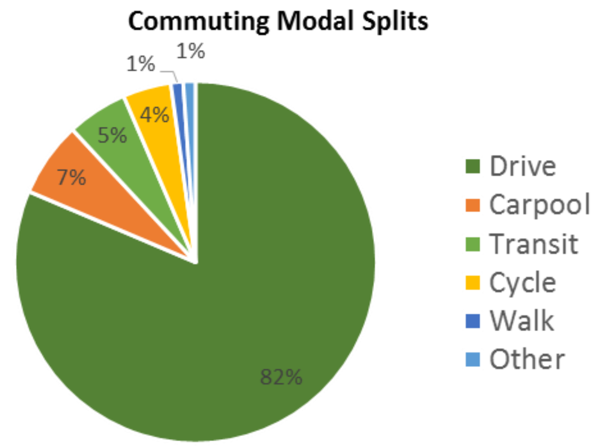
Innovation Metrics

2013 Venture Capital Investment	$358 million
2013 Venture Investment per 100,000 People	$6.4 million
Patent Counts in 2013	1,785

Transit Metrics

Daily Regular Service Passenger Trips for Greater Toronto and Hamilton Area	1,966,654
Total # of Rail Stations (Heavy + Light + Commuter)	132
% of Transit Commuters with > 60 Minute Commutes	29.78%

Figure 5-2: Key Transportation/Innovation Metrics for the Kitchener CMA



Population & General Commuting Metrics

Total Population of Metropolitan Area, 2015	511,300
Weighted Population Density	7,783
% of Commuters with > 60 Minute Commutes	6.2%
Share of Driving Commutes > 60 Minutes	5.37%
Transit/Carpool Ratio	0.34

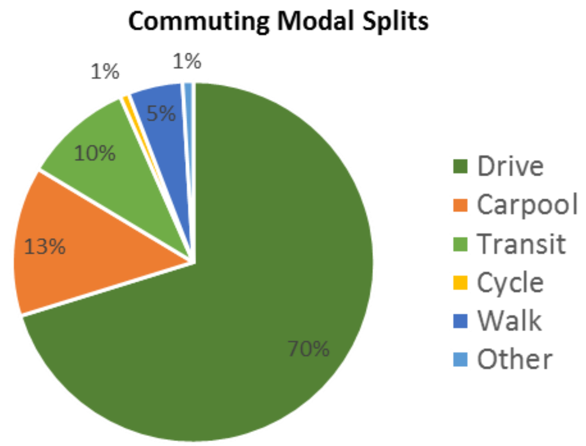
Innovation Metrics

2013 Venture Capital Investment	$57 million
2013 Venture Investment per 100,000 People	$12 million
Patent Counts in 2013	917

Transit Metrics

Daily Regular Service Passenger Trips for Waterloo Region	59,170
Total # of Rail Stations (Heavy + Light + Commuter)	1
% of Transit Commuters with > 60 Minute Commutes	23.75%

Figure 5-3: Key Transportation/Innovation Metrics for Hamilton CMA



Population & General Commuting Metrics

Total Population of Metropolitan Area, 2015	771,700
Weighted Population Density	10,915
% of Commuters with > 60 Minute Commutes	11%
Share of Driving Commutes > 60 Minutes	8.80%
Transit/Carpool Ratio	0.56

Innovation Metrics

2013 Venture Capital Investment	--
2013 Venture Investment per 100,000 People	$6.4 million
Patent Counts in 2012	188

Transit Metrics

Total # of Rail Stations (Heavy + Light + Commuter)	5
% of Transit Commuters with > 60 Minute Commutes	29.29%

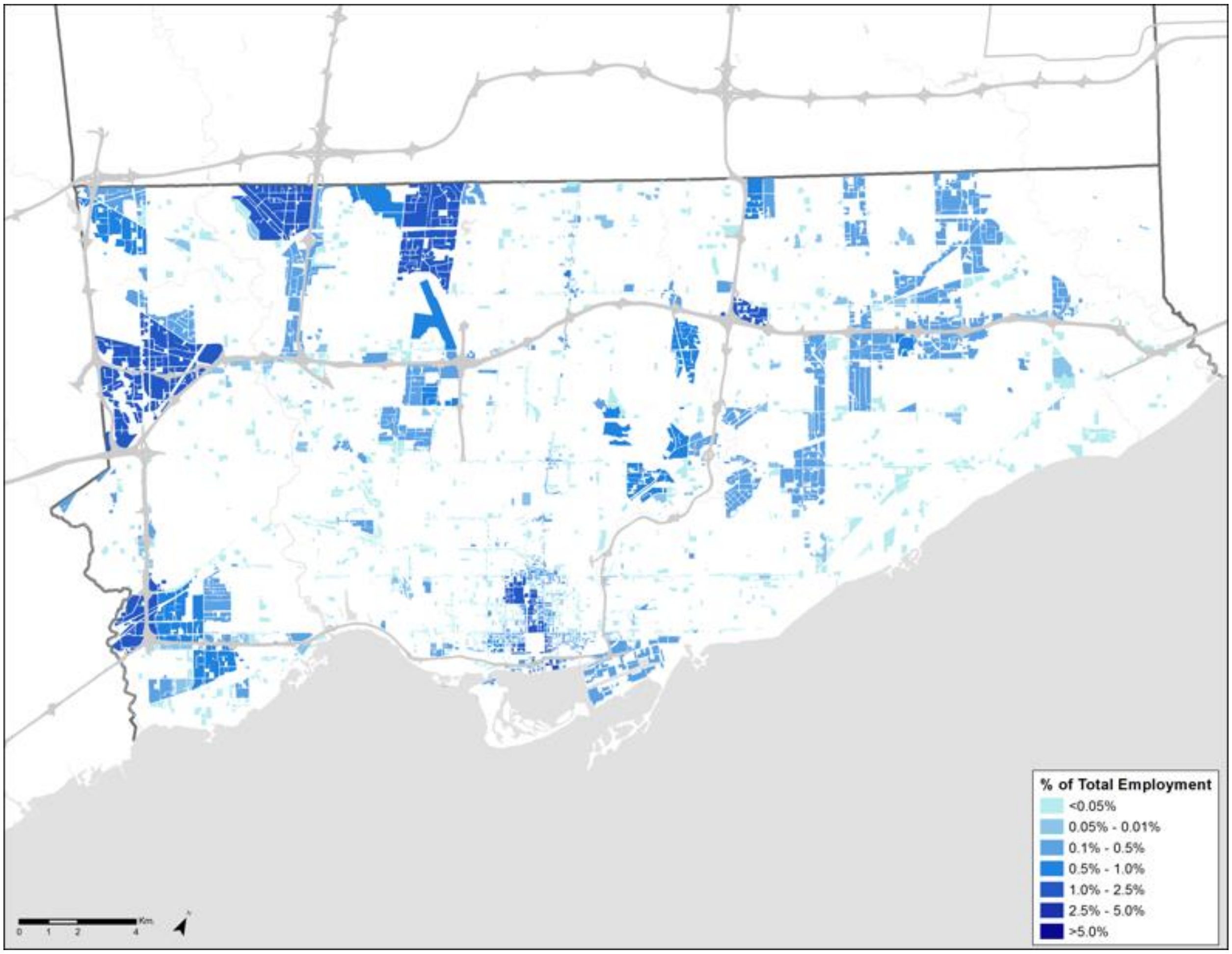
5.3 Important Geographic Elements Affecting Transportation Corridors in the Region

5.3.1 Major Employment Clusters and the Built-up Area

In understanding innovation clusters and the performance of the travel corridors on which they depend, it is useful to understand the size and locational characteristics of employment nodes.

A series of maps below assist in this regard. These are derived from a custom tabulation obtained by MITL from Statistics Canada. The data are based on the 2011 National Household Survey (i.e. "the Census") and represent workers at their place of work[10]. The data are at the dissemination area level and have been compiled from questions in the survey about where household members are working. Accurate data of this nature is notoriously hard to come by.

Figure 5-4: Distribution of City of Toronto Employment Across Employment Lands



In Figure 5-4 important employment nodes in the City of Toronto are quite evident. The darker blue colours indicate that the associated dissemination area accounts for a fairly high percentage of Toronto's total employment. The map focuses only on those areas that are zoned for activities that are associated with jobs. The land use patterns (e.g. the street grid) have been superimposed.

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[10] These data are segmented into certain occupational and sectoral codes but none that are sufficiently specific to focus on the main innovation sectors

Using the same data source, a GIS exercise was undertaken to identify the most significant job clusters[11] within the study region. The dissemination area totals from the national household survey were summed within custom polygons. These clusters do not respect geographic boundaries and are sprawling well beyond the boundaries of the City of Toronto. Results of this exercise are noted in Table 5-2.

Table 5-2: Significant Employment Clusters in Toronto Area

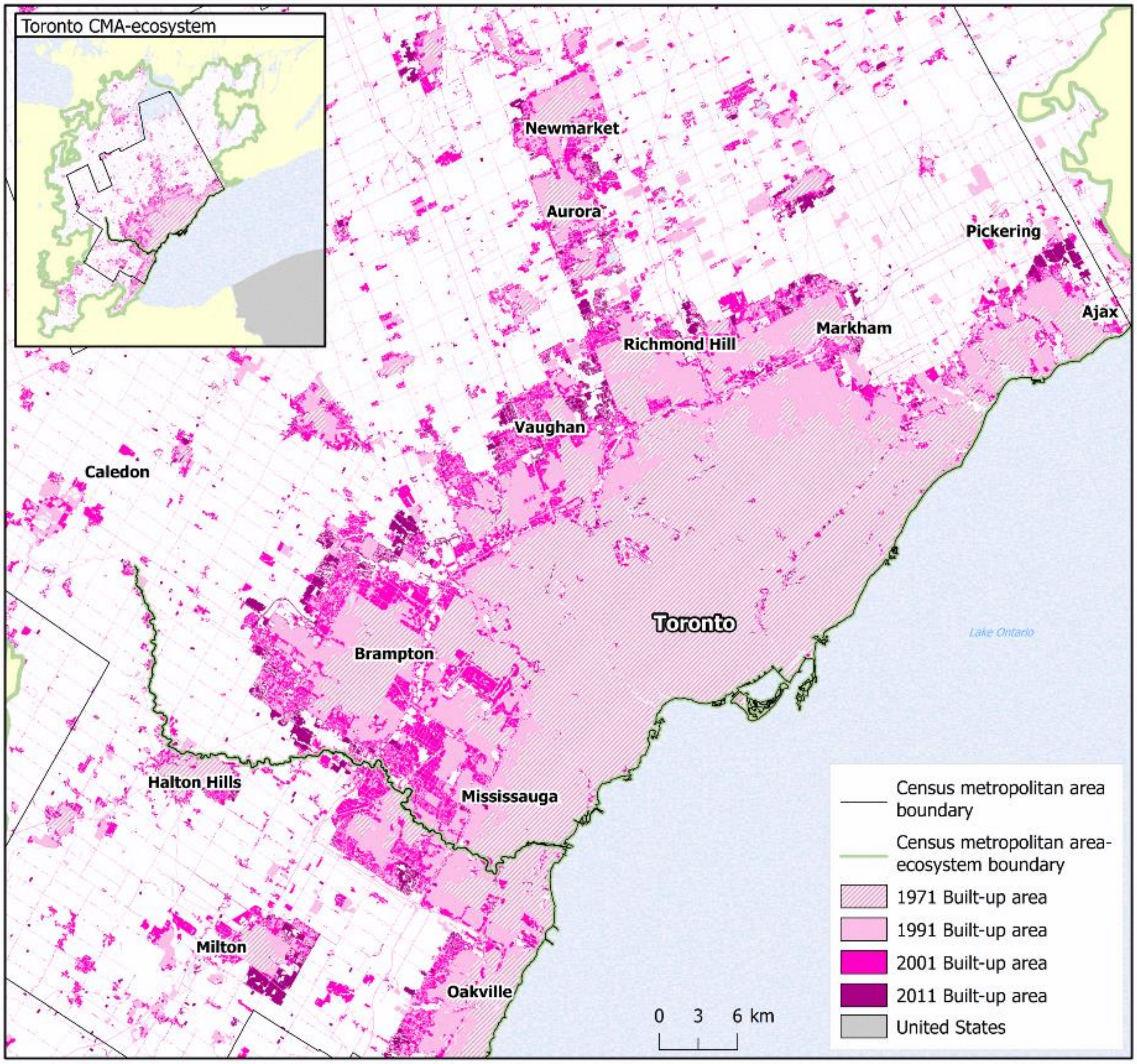
Employment Cluster Location	Estimated Job Count
Downtown Toronto	455,435
Toronto Pearson Airport Vicinity	372,405
South of Hwy 401; East of Don Valley Pkwy	182,540
Hwy 400	210,440
Hwy 404 / Hwy 407	128,250
Hwy 427 / Gardiner Expy /QEW	81,840

The largest job cluster is downtown Toronto and it is spatially very concentrated. Much more so than any other of the employment areas, the downtown node depends heavily on public transit, commuter rail and bus. There is a giant, sprawling employment cluster centred on Pearson airport that has almost as many jobs as the downtown but which is much more dependent on the automobile. This area is a major goods movement hub for Ontario and accordingly, the types of jobs found here will differ from what is found in the downtown core. Similar observations apply for a large employment cluster centred on Hwy 400. These two large employment clusters go a long way to explaining high levels of traffic and congestion, for example, on Hwy 401 between Hwy 427 and Hwy 400. For the Toronto-Waterloo corridor, sprawling patterns of highway-oriented employment in the GTA act as a real barrier to congestion-free travel.

The potential for traffic congestion on a critical route like Hwy 401 is further emphasized via Figure 5-5. This evolutionary map shows that in the period 1991-2001 in particular, there was a very significant increase in the built-up area of the metropolitan area to the west in Mississauga and Brampton. Hwy 401 passes through the heart of these areas but perhaps the main impetus for the expansion in built-up area was the opening of Hwy 407 during the 1990's. With the introduction of a new policy backdrop within the past decade, the expansion in built-up area has largely been stopped.

[11] These are general employment clusters as opposed to innovation clusters. Innovation clusters will be found in the downtown Toronto employment cluster in particular and to a lesser extent in the others. The magnitude and spatial character of these employment clusters, especially outlying ones, generate a large number of daily trips that in many cases are quite automobile dependent and are thus associated with high levels of traffic congestion. Such traffic hinders trip-making associated with innovation clusters.

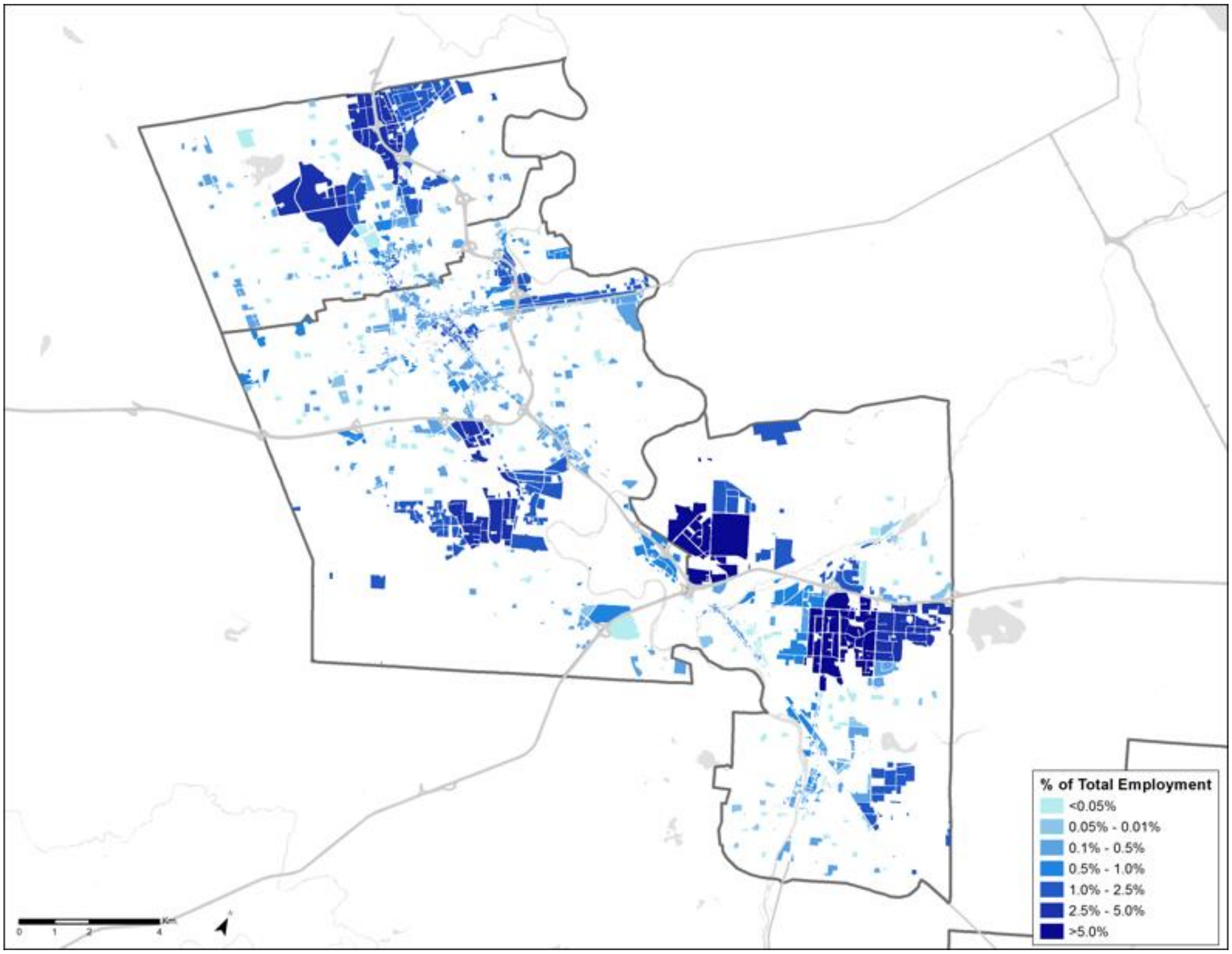
Figure 5-5: Evolution of Built-up Area for Toronto Census Metropolitan Area (1971-2011)



Source: Statistics Canada – Retrieved from: http://www.statcan.gc.ca/pub/16-201-x/2016000/m-c/map3.29-eng.htm

In Figure 5-6, a similar mapped exercise as was done for the City of Toronto is carried out for Region of Waterloo employment patterns using a map of the same scale. The absolute numbers of jobs are much smaller in this region but again the focus with the map is on the relative importance of clusters within the region. The lower concentrations of jobs and people leads to less immediate traffic congestion in the Region as will be seen. As an amalgamation of smaller cities, the region features several downtown areas but none which stand out on a relative basis as does downtown Toronto. Orientation to Hwy 401 appears quite important for the main Cambridge clusters and for those that are in the South of Kitchener. A major employment cluster has formed in the North of Waterloo that is oriented to the Conestoga Parkway. To the south and west there is the major innovation cluster that is associated with the two major universities in the City of Waterloo.

Figure 5-6: Distribution of Region of Waterloo Employment Across Employment Lands



5.3.2 Travel Patterns from the 2011 Transportation Tomorrow Survey

Another important regional perspective is provided by Table 5-3 above where general trip patterns within the survey region are characterized. This table does not contain all the regions and cities of the Great Golden Horseshoe Region but rather the ones that are of most relevance to the western travel corridors. Even so, it accounts for over 3 million trips in the AM peak. These represent the typical weekday and the time period is 6 AM to 9 AM. Trips are classified into two groups: work trips and trips for all other purposes. The table is organized as an origin-destination matrix. Moving across a row captures outflows from the city or region while moving down a column captures inflows of trips into a city or region. Note that the diagonal elements of this matrix house most trips because the largest flows of trips are internal to each city or region.

Table 5-3: Trip-Making within the Study Region (6AM to 9AM)

		City of Toronto	Region of Waterloo	City of Hamilton	City of Guelph	Region of Peel	Region of York	Region of Halton	Total
City of Toronto	Work	510,000	400	900	200	47,900	62,600	5,000	**627,000**
	Other	551,200	500	600	200	10,400	15,800	1,400	**580,100**
Region of Waterloo	Work	1,300	104,400	1,200	7,600	3,100	200	1,800	**119,600**
	Other	400	133,800	500	1,200	500	0	300	**136,700**
City of Hamilton	Work	4,600	2,000	72,700	500	6,100	600	21,000	**107,500**
	Other	800	500	107,100	200	500	0	5,000	**114,100**
City of Guelph	Work	800	3,400	400	21,000	1,400	200	1,500	**28,700**
	Other	200	2,300	300	25,800	100	100	300	**29,100**
Region of Peel	Work	92,600	1,200	1,400	600	188,600	18,200	15,900	**318,500**
	Other	30,100	500	1700	600	302,100	2,500	5,900	**343,400**
Region of York	Work	123,600	400	300	100	20,500	127,800	1,500	**274,200**
	Other	39,100	0	500	100	2,700	215,000	300	**257,700**
Region of Halton	Work	28,000	2,000	7,900	700	37,700	2,800	52,300	**131,400**
	Other	3,700	400	4,200	400	6,500	300	104,100	**119,600**
Total		**1,386,400**	**251,800**	**199,700**	**59,200**	**628,100**	**446,100**	**216,300**	**3,187,600**

Source: Transportation Tomorrow Survey, 2011

In terms of results, some of the most important are as follows:

- The split between work and other trips as captured by this table is almost exactly in half for the AM peak period.
- Work trips are clearly showing up as having longer average distances than trips for other purposes. The latter are more localized.
- In terms of work trips, nearly twice as many travel between the Region of Waterloo and the City of Hamilton than between the Region of Waterloo and the City of Toronto (3200 versus 1700).
- Other than intra-regional trips, the only inter-zonal interactions with large trip totals are between regions that are central to the Greater Toronto Area (e.g. Region of Peel with City of Toronto, Region of York with City of Toronto).

- The effect of distance decay on work trips is strong. For example, the City of Hamilton sends work trips to Toronto at more than 4 times the rate that the Region of Waterloo does. The Region of Waterloo is not four times further from the City of Toronto.
- It seems clear from the table that inter-city trips are not enough to cause heavy traffic congestion. Trips within the Toronto metropolitan area are the culprit and this certainly has a big impact on inter-city travel times as will be seen.

Table 5-4: Distribution of Automobile-based Home to Work Trip Lengths

DISTANCE (KM)	PERCENTILE
5	19.6
10	43.5
25	81.2
50	96.7
75	99.2
100	99.7
125	99.8

Source: Derived from 2011 Transport Tomorrow Survey

In Table 5-4 above, the TTS data are assessed using the distances associated with automobile-based home-to-work trips. Most of these are in AM peak but some are not. The results show quite vividly that within the region, trips of even fairly moderate distances are fairly rare. Driving commutes between 100 and 125 km in length account for only a tiny percentage of commutes.

5.3.3 Regional Trip Table and Supporting Map

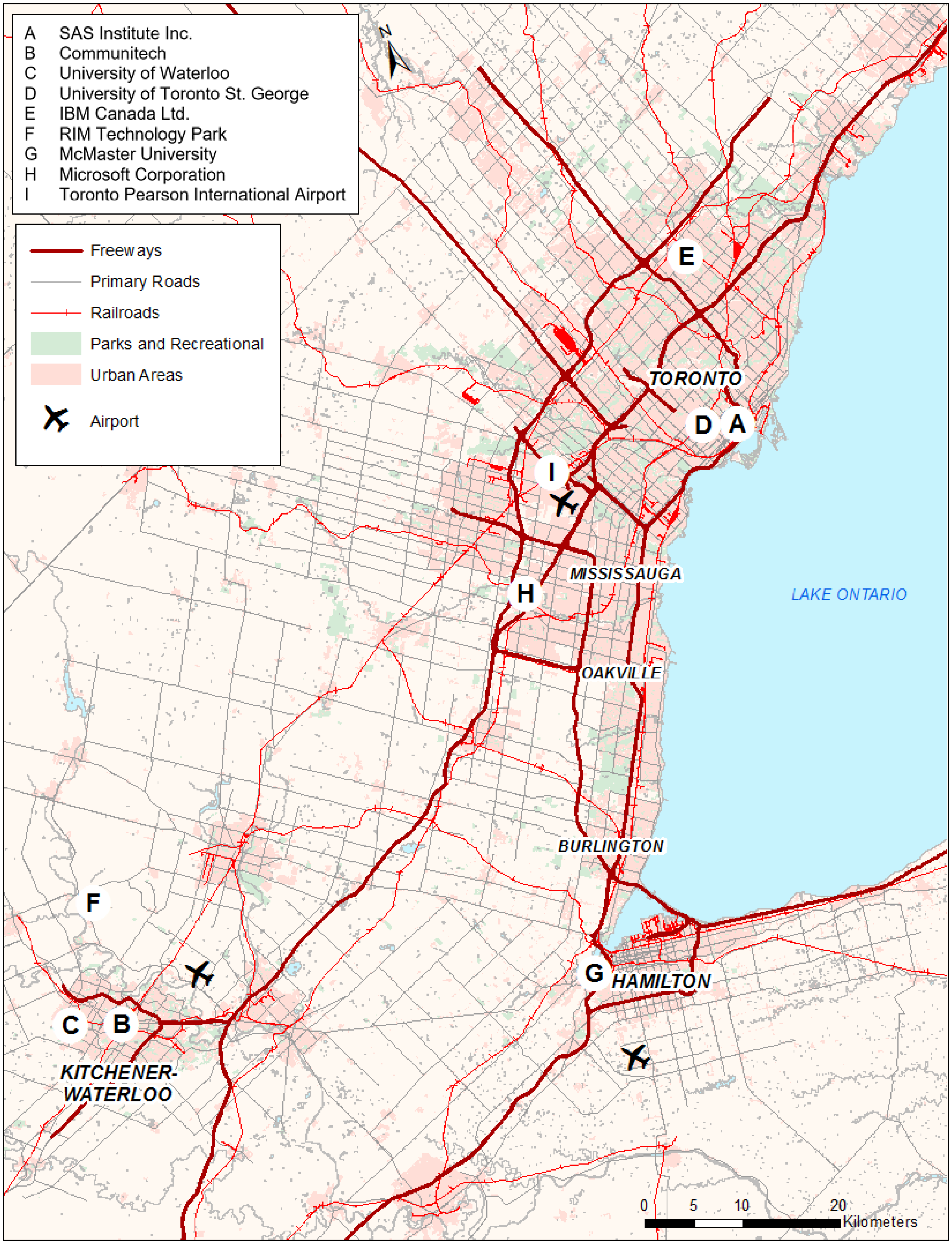
In Table 5-5, a similar exercise is carried out for selected AM peak commuting trips for this region as were carried out several times in Chapter 4. The travel times are generally unfavourable. While car travel is showing up as faster on average, it also has high travel time variation consistent with the types of congestion patterns seen in Section 5.2 to follow.

For a trip from McMaster University to the University of Toronto, the upper estimate for travel time by car is nearly twice the duration of the minimum estimate. The time estimate for a trip from McMaster to the University of Waterloo by car is much tighter. Trips that do not make use of the automobile in some way can be particularly unattractive. A trip from the University of Waterloo to the University of Toronto in the downtown is expected to take nearly three hours without an automobile. For this AM Peak trip, GO Transit is taken from downtown Kitchener. Accordingly, there are considerable ingress and egress times added on just to get to and from the train. A 51 km trip from Microsoft headquarters in Mississauga to IBM headquarters in Markham requires three buses and would take an estimated 1 hr 40 minutes.

Table 5-5: AM Peak Travel Table for Toronto-Waterloo Corridor

Start		End		Car	Public Transportation	Distance
A	**SAS Institute Inc. (Toronto)**	**B**	**Communitech (Kitchener)**	1 h 15min – 1h50min	**Total: 3h 15min** [5min] Bus [4min] Walk [2h22min] Bus (2) [13min] Walk [24min] Transfer/Wait	111km
C	**University of Waterloo**	**D**	**University of Toronto St. George**	1h 50min – 2h40min	**Total: 2h 54min** [29min] Bus (2) [2min] Walk [1h40min] Commuter Rail [2min] Walk [6min] Subway [3min] Walk [32min] Transfer/Wait	118km
E	**IBM Corporation (Toronto)**	**F**	**RIM Technology Park (Waterloo)**	1h10min – 2h30min	**Total: 3h 38min** [3h2min] Bus (5) [36min] Transfer/Wait	126km
A	**SAS Institute Inc. (Toronto)**	**F**	**RIM Technology Park (Waterloo)**	1h15min – 1h50min	**Total: 3h 47min** [5min] Bus [4min] Walk [2h49min] Bus [1min] Walk [48min] Transfer/Wait	118km
G	**McMaster University**	**D**	**University of Toronto (St. George)**	1h 10min – 2h10min	**Total: 2h 4min** [6min] Bus [4min] Walk [1h30min] Bus [6min] Subway [4min] Walk [14min] Transfer/Wait	69.7km
G	**McMaster University**	**C**	**University of Waterloo**	55min – 1h10min	**Total: 3h 14min** [2h24min] Bus (3) [50min] Transfer/Wait	70.6km
H	**Microsoft Corporation**	**F**	**RIM Technology Park (Waterloo)**	50min – 1h5min	**Total: 2h 35min** [9min] Walk [1h56min] Bus [30min] Transfer/Wait	79.4km
I	**Toronto Pearson International Airport**	**B**	**Communitech (Kitchener)**	55min – 1h15min	**Total: 2h10min** [5min] Walk [1h42min] Bus [13min] Walk [10min] Transfer/Wait	89.6km
H	**Microsoft Corporation**	**E**	**IBM Corporation**	30min – 45min	**Total: 1h40min** [9min] Walk [1h16min] Bus (3) [2min] Walk [13min] Transfer/Wait	51.2km

Figure 5-7: Map of the Toronto and Kitchener-Waterloo Innovation Corridor



5.4 Highway Corridors in the Region

Previous chapters in this report have shown clearly that roads and highways are very important enablers of commuting behaviour, goods movement and ultimately: economic activity. Accordingly, it is an important exercise to use the best in modern data resources to assess the “health” of important highway arteries related to the Toronto-Waterloo corridor. The purpose of this section is to use extensive speed data collected by INRIX Corporation in conjunction with information on traffic volumes and highway capacity to assess how major corridor highways are performing in serving the region between Toronto, Waterloo and Hamilton.

Initially, we present a series of overview maps (from Figure 5-8 to Figure 5-13) that give a good general sense of the congestion patterns. Because these maps represent a fairly large area, it is not possible to show both directions for each stretch of highway at the same time[12]. Based on the real-life observation that highways in Ontario are considered as either EB-WB or NB-SB these maps illustrate two directions at a time. They are designed to work in pairs on a single page so that all directions are covered. Upper maps cover eastbound and northbound travel while lower maps cover westbound and southbound travel. To clarify some of the examples that might seem more complicated: The Conestoga Parkway in Kitchener-Waterloo is NB-SB, Hwy 8 is EB-WB, the Gardiner Expressway is EB-WB and the Don Valley Parkway and Hwy 404 is NB-SB. Other cases seem directionally quite clear and not hard to interpret.

The presentation of congestion results by highway corridor is done via Tableau heatmaps. In each graphical presentation, specific locations along with distance ranges along a corridor are presented on a vertical axis while detailed 15 minute breakdowns of time are presented on a horizontal axis. Colours on the grid that is formed are associated with average observed speeds. Heatmaps are the most viable way to easily compare large amounts of quantitative information of this type on a single page. A whole set of these heatmaps has been developed and these appear on the pages below with some discussion following afterwards.

In terms of day of the week, Thursday has been chosen for maps and heatmaps as it is the busiest of the “typical” weekdays. There are different dynamics at play on Friday and the two days of the weekend. There is material in Appendix 7-1 that covers patterns by day of the week.

[12] Google Maps does have this functionality but at present we do not.

Figure 5-8: 8:30am Average Speeds – Eastbound and Northbound Travel

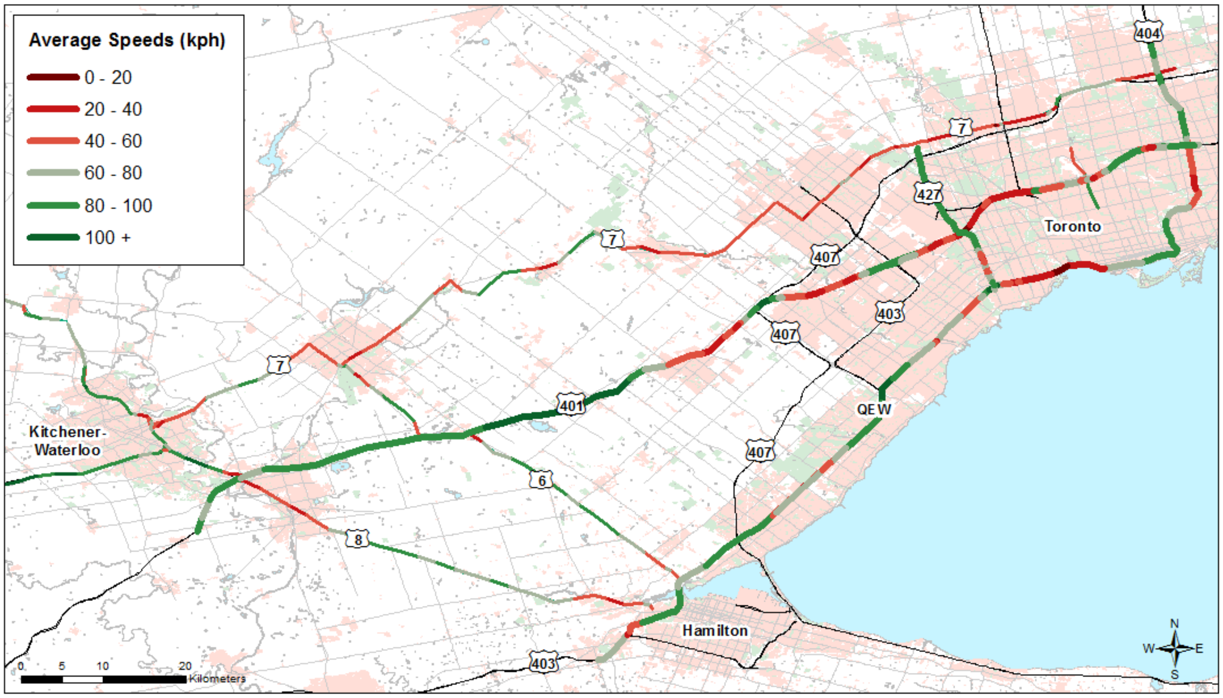


Figure 5-9: 8:30am Average Speeds – Westbound and Southbound Travel

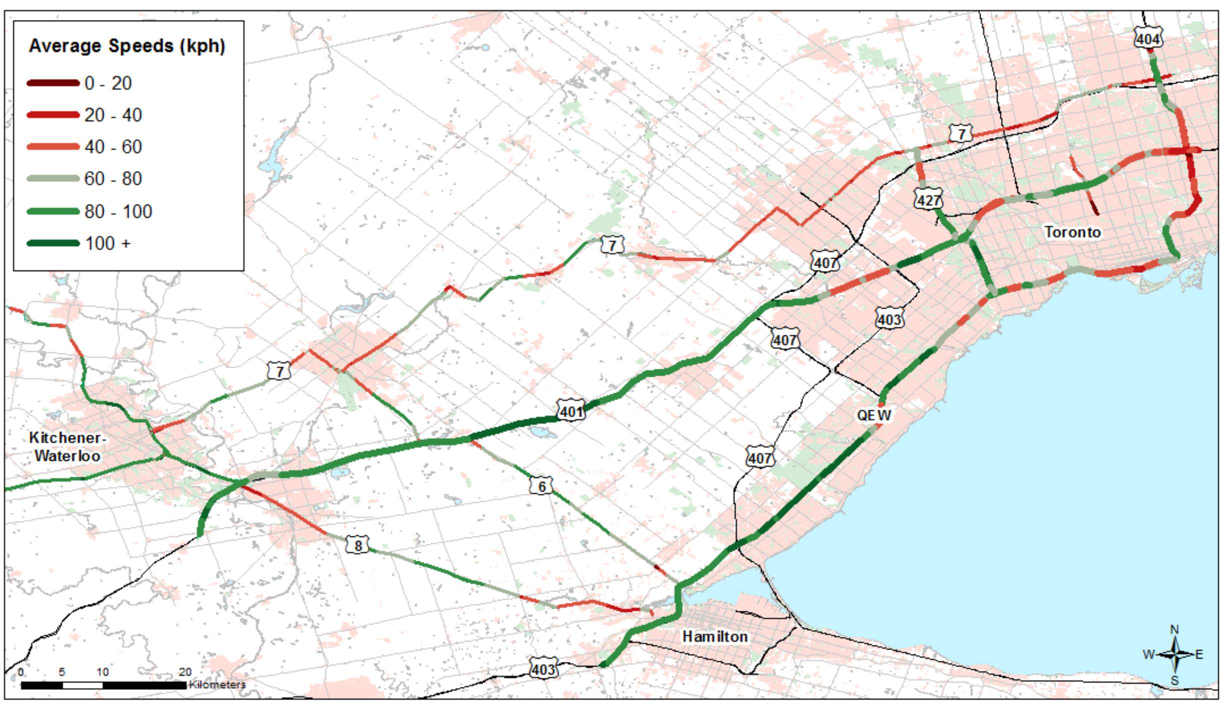


Figure 5-10: 5:30pm Average Speeds - Eastbound and Northbound Travel

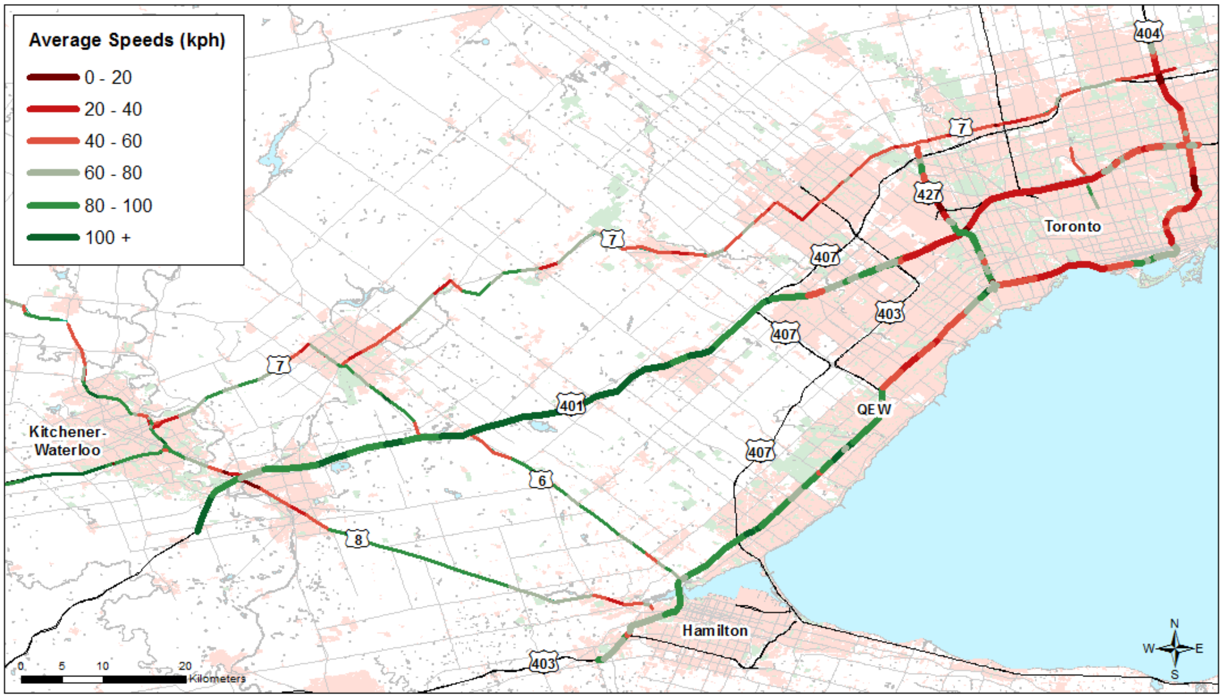


Figure 5-11: 5:30pm Average Speeds - Westbound and Southbound Travel

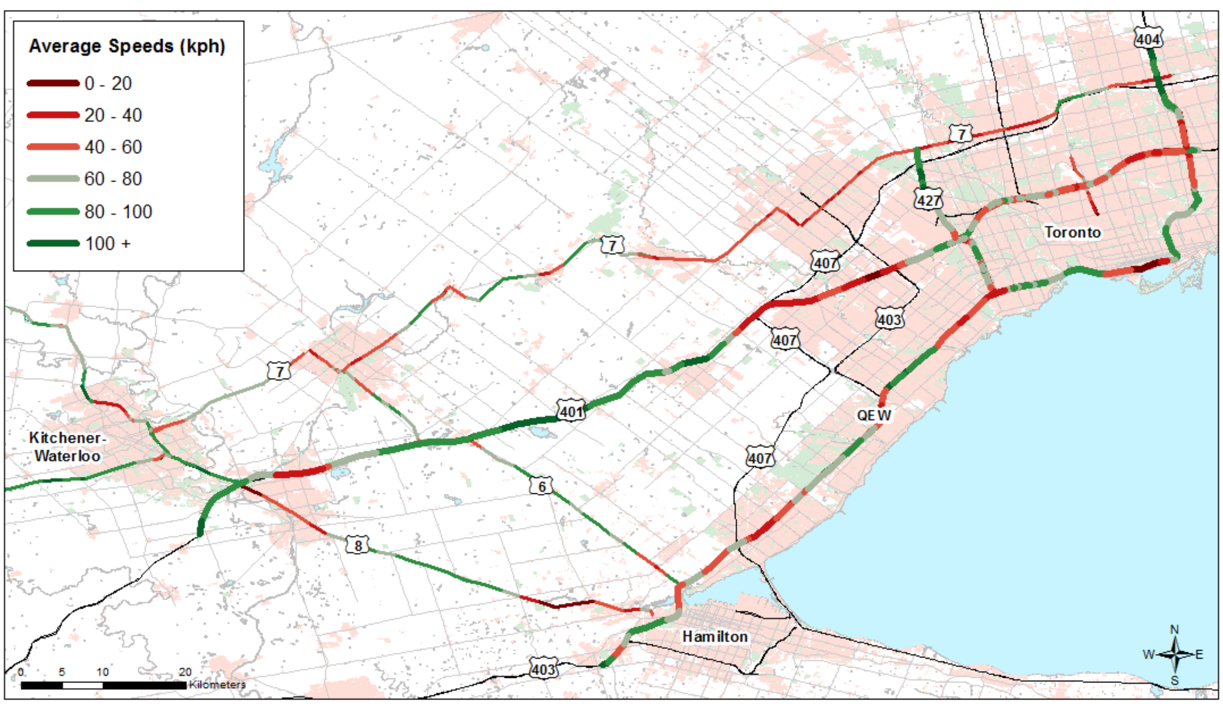


Figure 5-12: 1:00pm Average Speeds – Eastbound and Northbound Travel

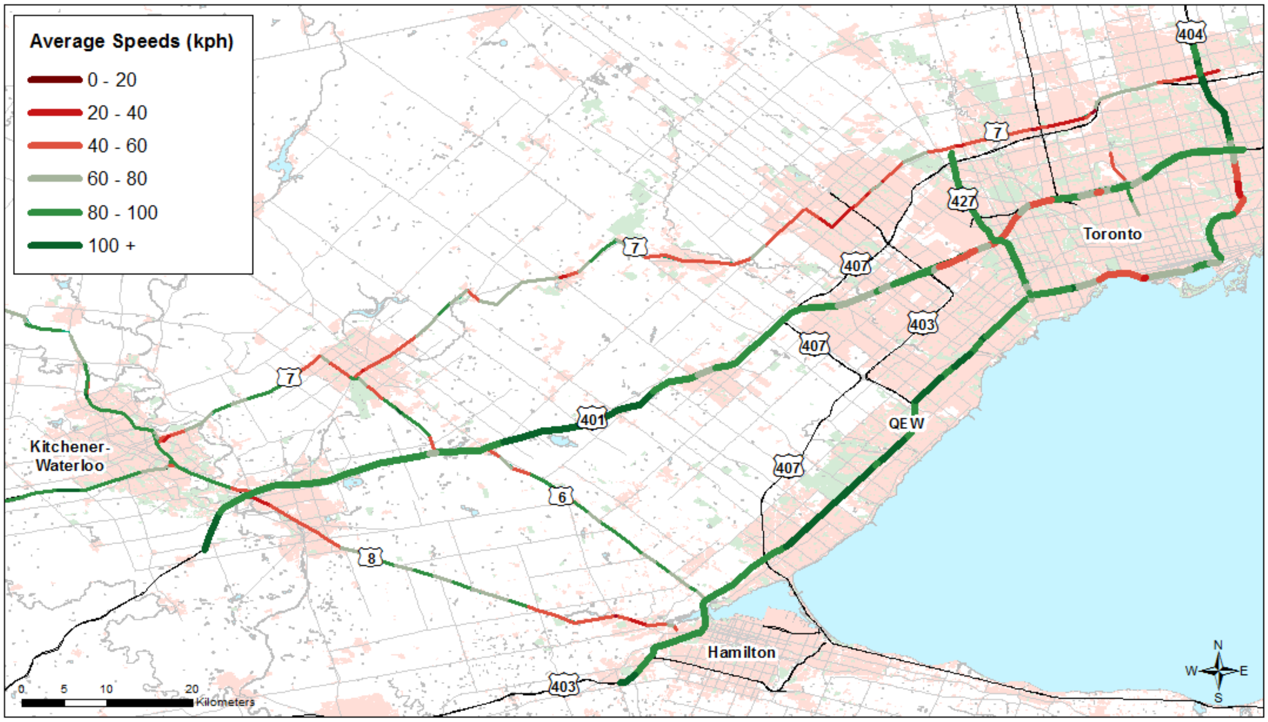


Figure 5-13: 1:00pm Average Speeds – Westbound and Southbound Travel

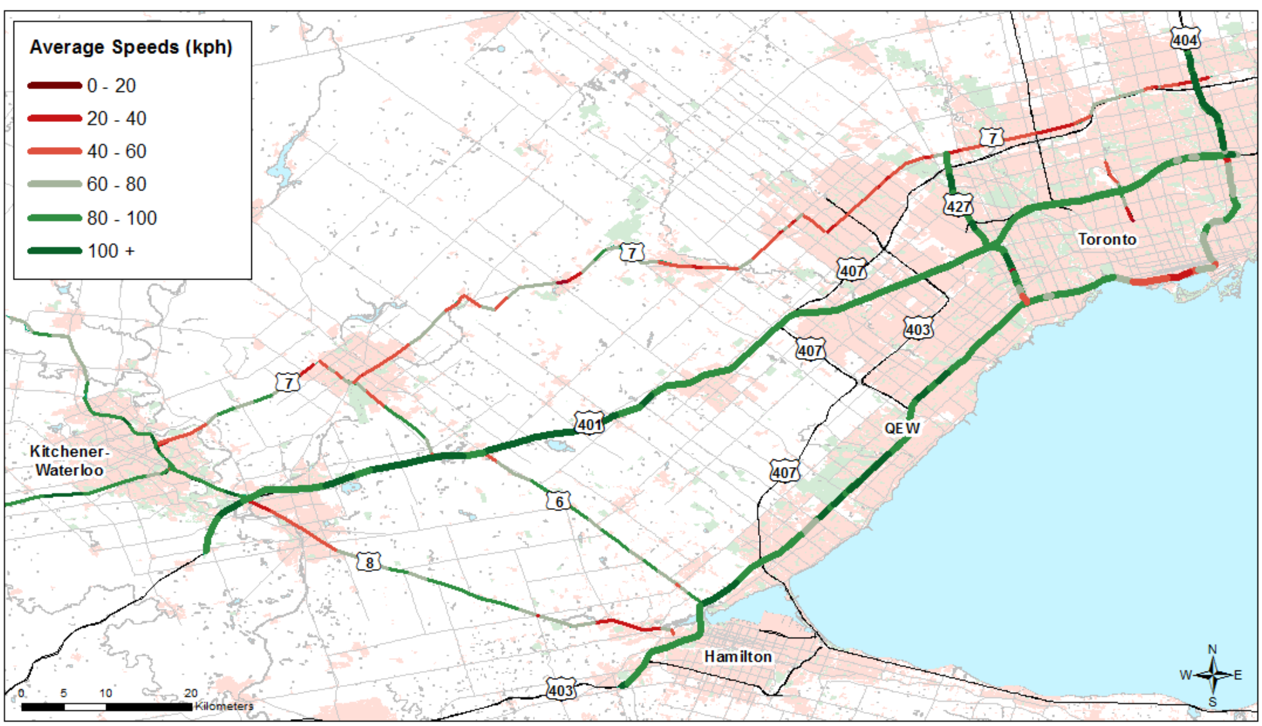


Figure 5-14. Highway 401 Average Speeds (Thursday)

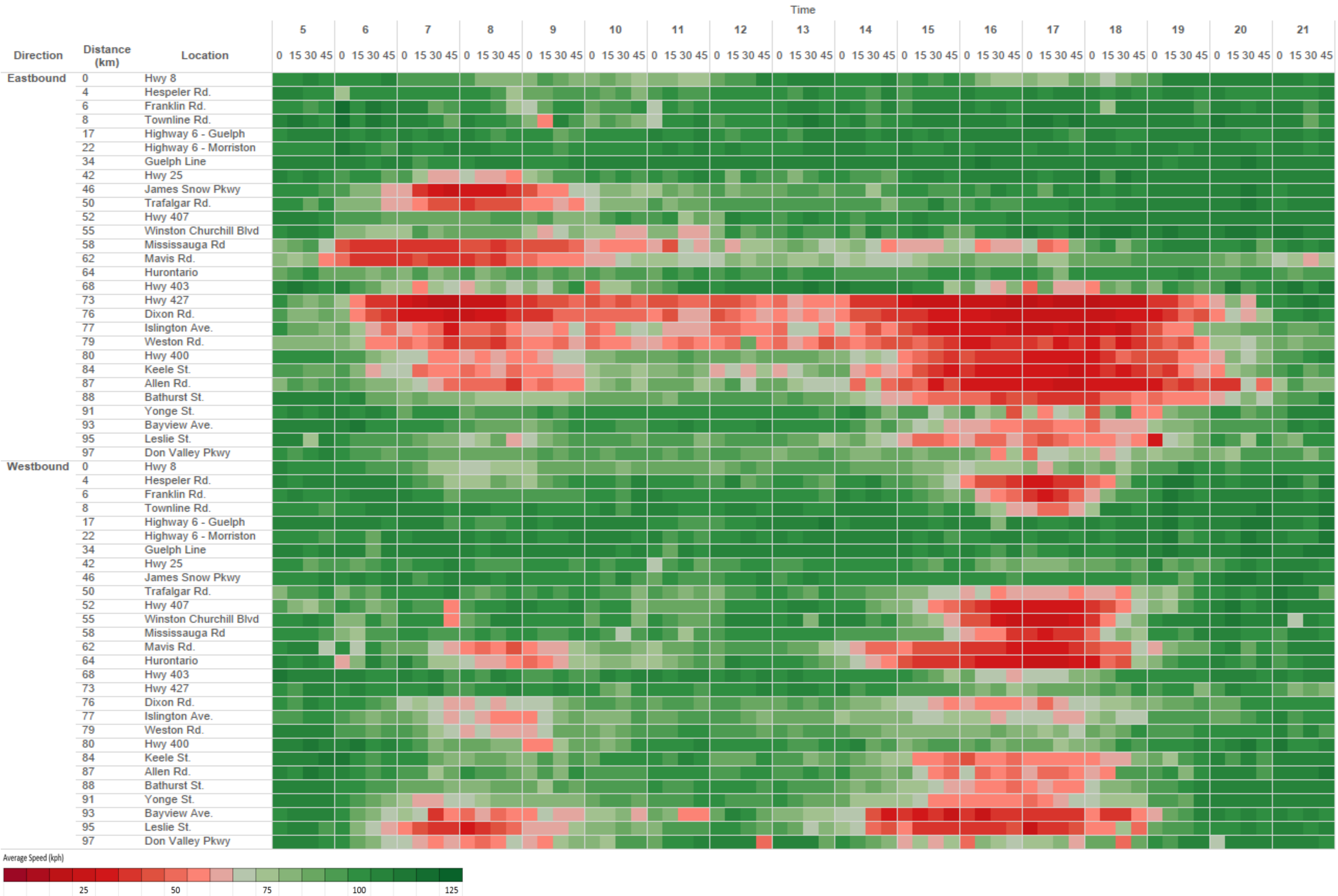


Figure 5-15. Highway 427 Average Speeds (Thursday)

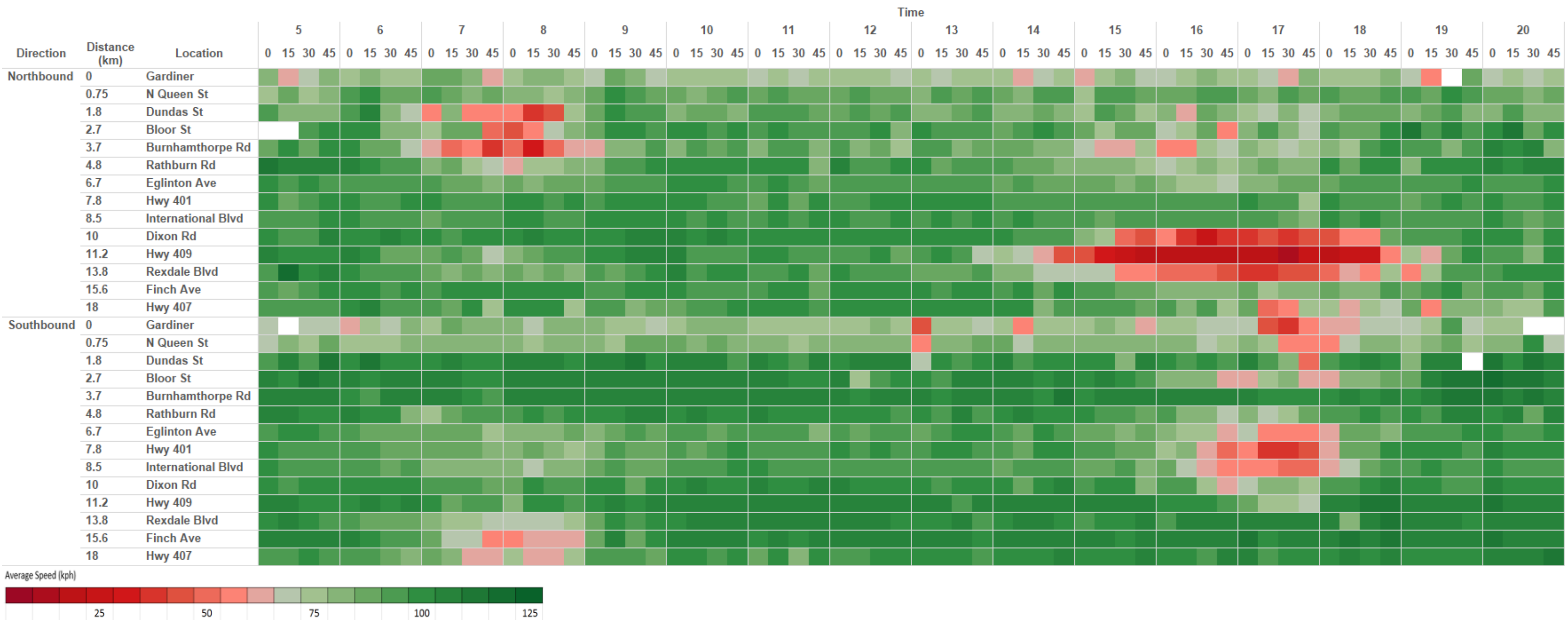


Figure 5-16. Allen Rd Average Speeds (Thursday)

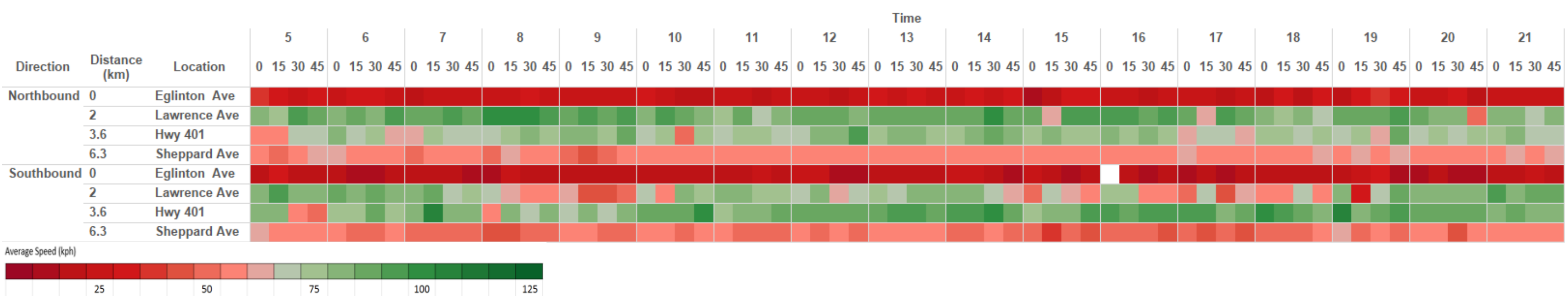


Figure 5-17. Don Valley Parkway and Highway 404 Average Speeds (Thursday)

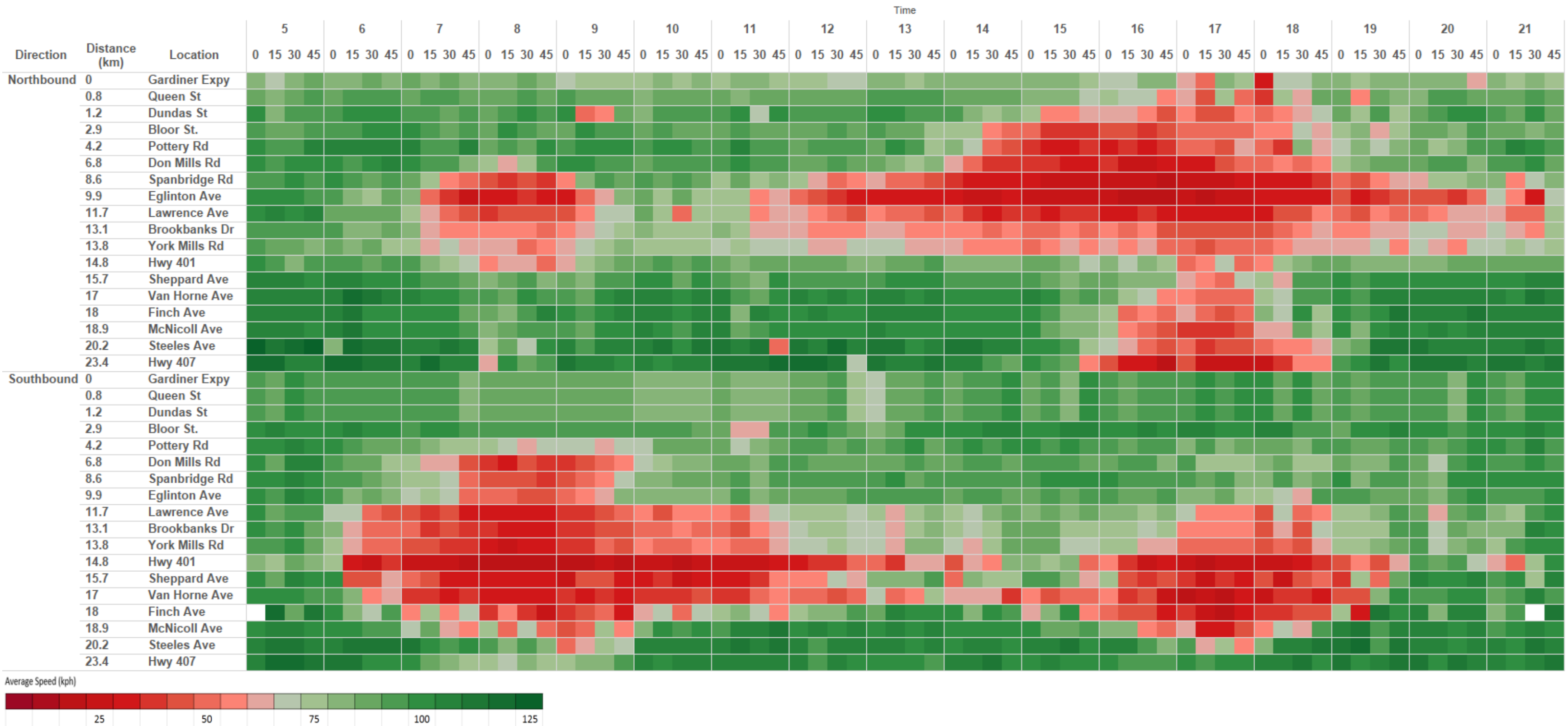


Figure 5-18. Gardiner Expressway Average Speeds (Thursday)

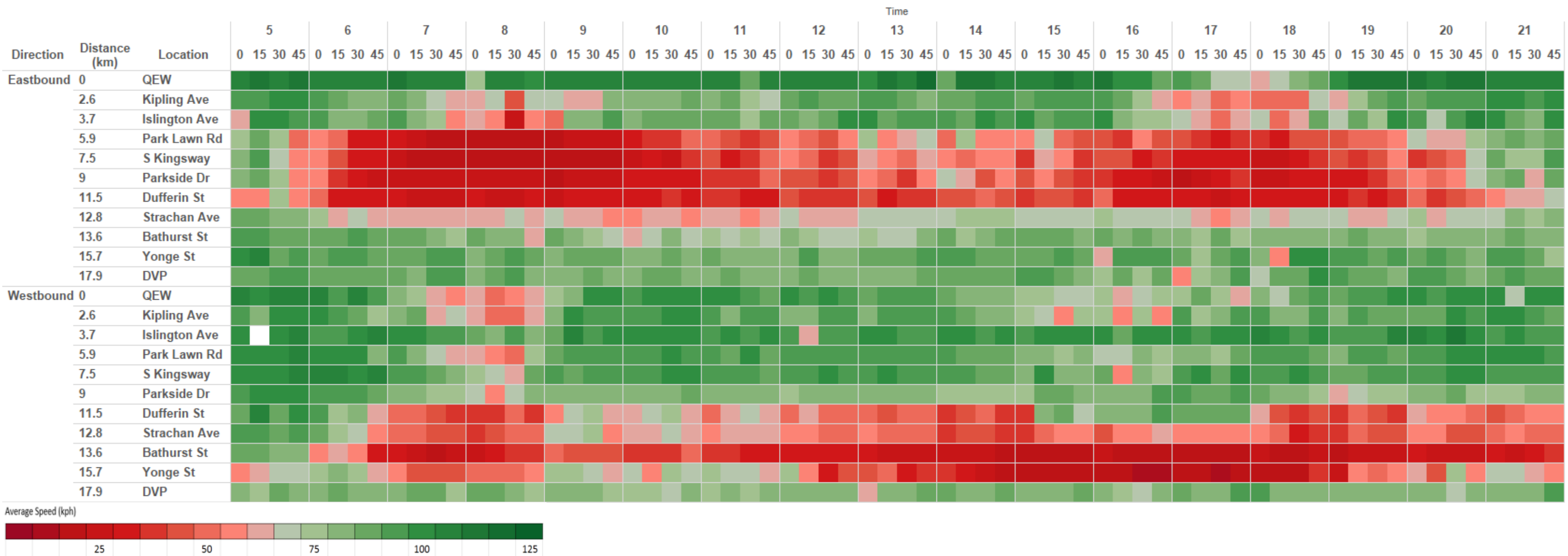


Figure 5-19. Queen Elizabeth Way / Highway 403 Average Speeds (Thursday)

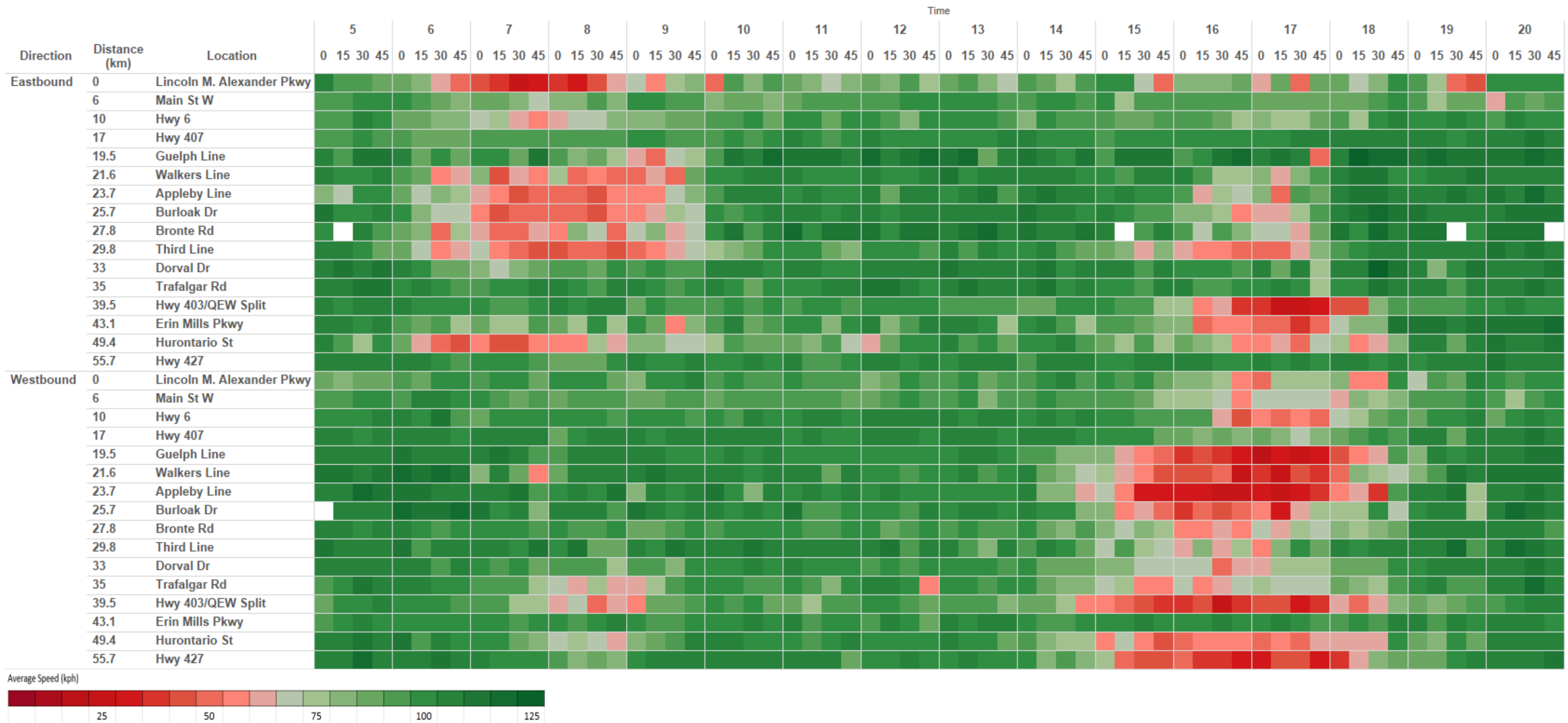


Figure 5-20. Highway 6 Average Speeds (Thursday)

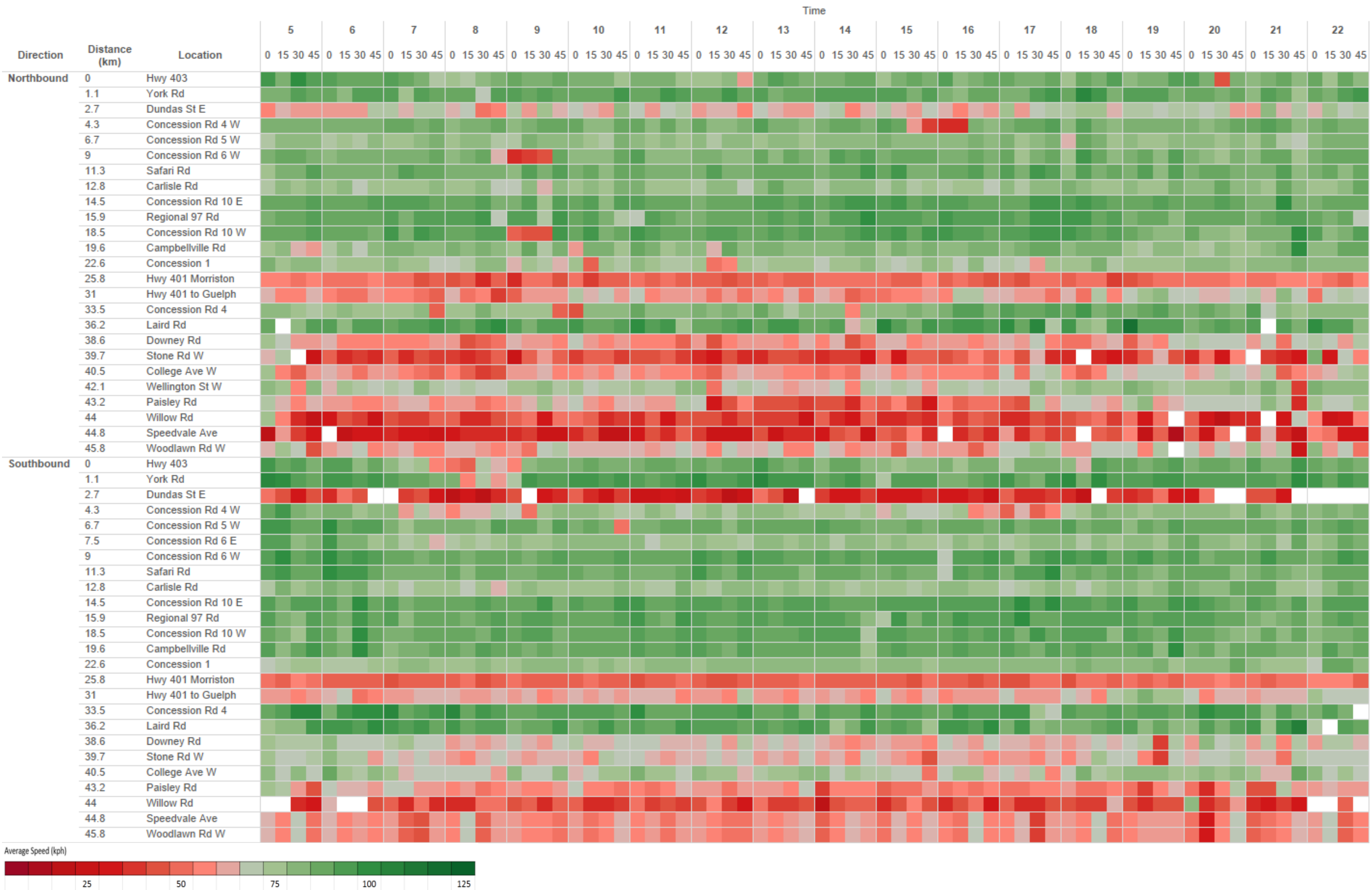


Figure 5-21. Highway 7 Average Speeds (Thursday)

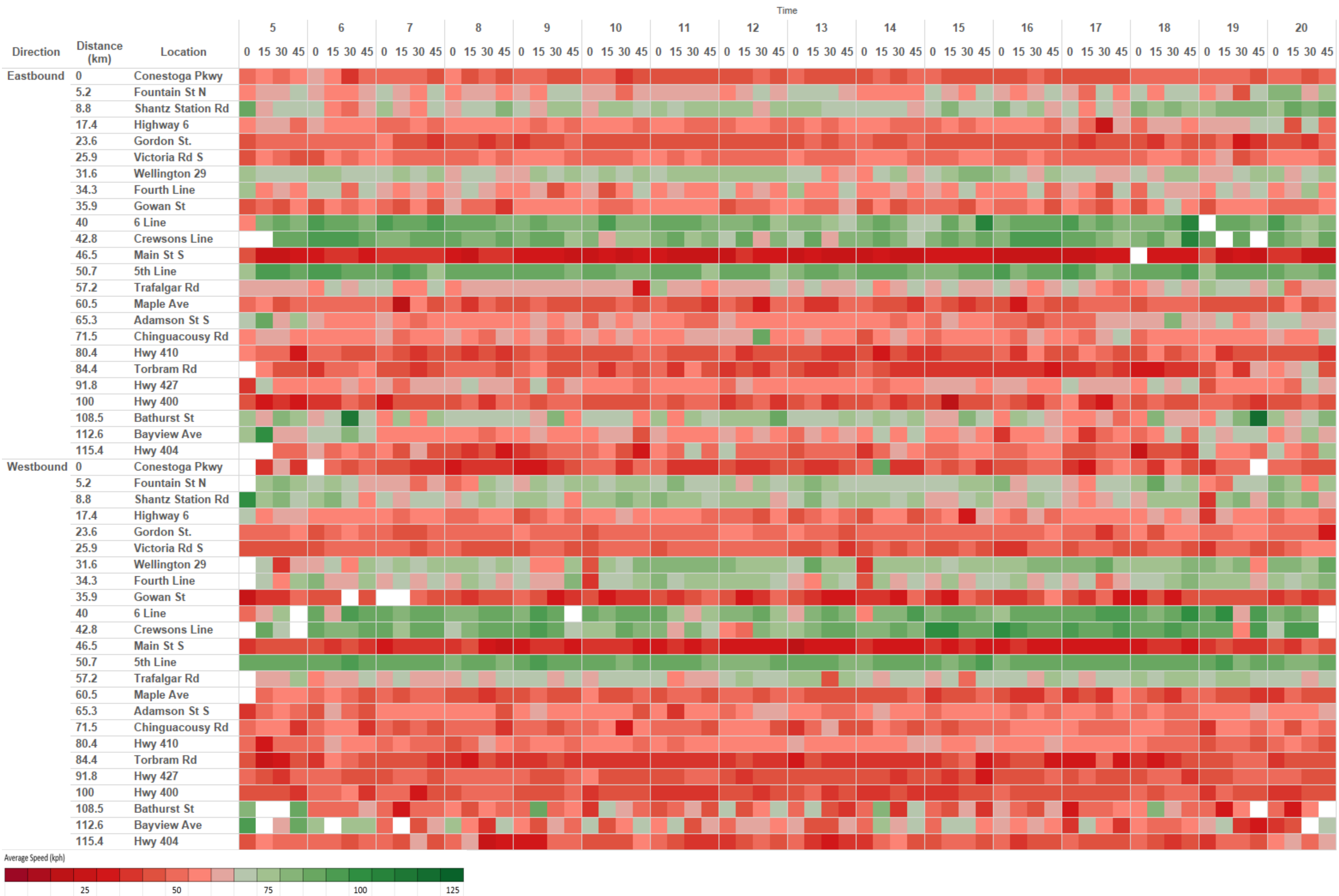


Figure 5-22. Highway 8 Average Speeds (Thursday)

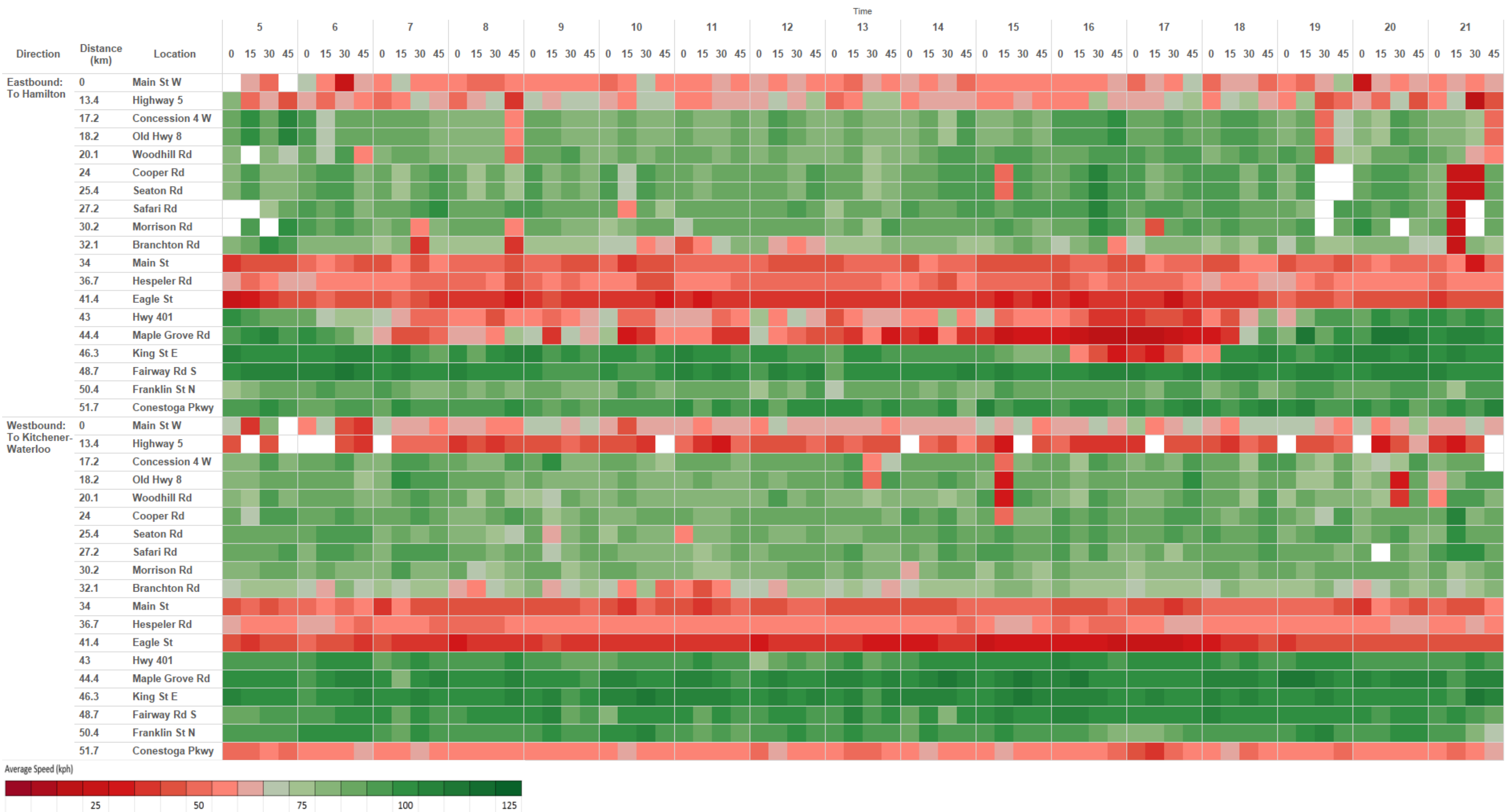
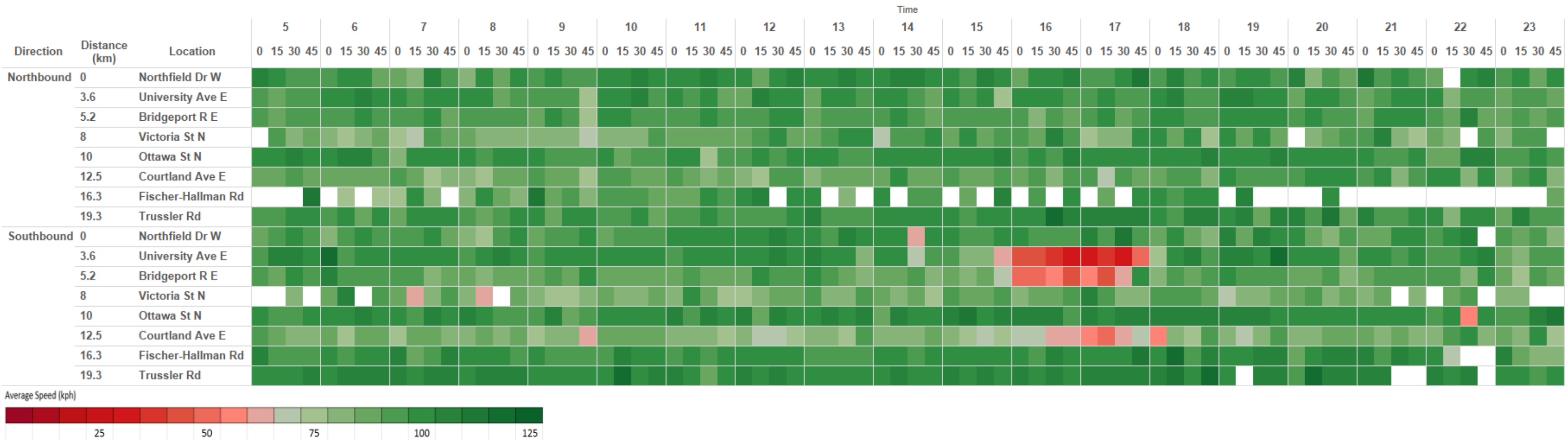


Figure 5-23. Conestoga Parkway Average Speed (Thursday)



5.4.1 Hwy 401

The Hwy 401 Corridor is the most important road corridor in the region and certainly it is critical to road movements between Waterloo and the Greater Toronto Area. The range of traffic volumes on Hwy 401 is quite wide along the corridor between Toronto and the Kitchener-Waterloo (KW) area. Based on 2010 data, there are many stretches in the heart of Toronto where over 350,000 and up to nearly 400,000 vehicles are accommodated per day. Compared to Figure 2-5: Heavily Travelled U.S. Urban Corridors – Average Annual Daily Traffic Volumes, it is clear that 401 volumes match or exceed any others in North America. Of course, it is generally taking eight lanes of capacity in either direction to accomplish this feat. These extremely high volumes extend well to the west with the highest volumes being seen near Pearson Airport at about 385,000 per day. Moving to the west, volumes fall: they are less than 200,000 on the stretch from the Hwy 403 interchange to Hurontario Road; less than 140,000 on the stretch from Hwy 407 interchange to Trafalgar Road and begin to tail off to little more than 100,000 until reaching the more heavily built up KW area. West of KW, volumes are well under 100,000.

In terms of traffic congestion patterns, some of the most important are as follows:

- Clearly, central-Toronto metropolitan traffic congestion on the 401 is a serious problem but given the massive capacities and infrastructure already in place, it would seem that little more can be done from the capacity/infrastructure perspective.

- Generally, eastbound congestion is worse than westbound congestion and PM congestion is worse than AM. The overall worst peak period congestion is eastbound in the PM east of Hwy 427 to beyond Hwy 400. The lightest peak period congestion is westbound in the AM.

- Major eastbound congestion is more oriented to the west in the AM and more oriented to the east in the PM. Westbound congestion is more oriented to the east in the AM and the west in the PM.

- There is significant congestion in stretches from Milton to the vicinity of Pearson airport EB in the AM peak and WB in the PM peak. These stretches of congestion are very problematic from the perspective of the Toronto-Waterloo corridor. Eastbound congestion in these stretches begins soon after 6 am.

- At the Kitchener end of the corridor, congestion is a less serious problem though there is significant PM peak congestion along westbound stretches of the 401 that link Cambridge to Kitchener.

Table 5-6: Traffic Volumes versus Capacity for the Western GTA Hwy 401 Corridor

From (east)	To (west)	Distance (km)	AADT 2010	Lanes per Direction
Hwy 427 352	Renforth Dr IC	0.8	384,900	8
Renforth Dr IC	Dixie Rd IC-Peel Rd 4	4.3	381,400	8
Dixie Rd IC-Peel Rd 4	Hwy 403/410 IC	1.5	353,100	8
Hwy 403/410 IC	Hwy 10/Hurontario St IC	2.8	187,700	6
Hwy 10/Hurontario St IC	Mavis Rd IC	2.1	187,100	4
Mavis Rd IC	Mississauga Rd IC	3.5	160,200	3
Mississauga Rd IC	Winston Churchill Blvd.	3.4	126,600	3
Winston Churchill Blvd.	Hwy 407	2.3	116,100	4
Hwy 407 IC	Trafalgar Rd IC- Milton	2.4	138,900	4
Trafalgar Rd IC- Milton	James Snow Pkwy	4.2	130,700	3
James Snow Pkwy	Hwy 25 - Milton	3.7	119,800	3
Hwy 25 IC – Milton	Guelph Line IC – Milton	8.2	103,600	3
Guelph Line - Milton	Milton WLTS	4.5	107,300	3
Milton WLTS	E Jct Hwy 6/Brock Rd IC	7.3	107,300	3
E Jct Hwy 6/Brock Rd IC	W Jct Hwy 6/Hanlon Expy IC	4.4	107,500	3
W Jct Hwy 6/Hanlon Expy IC	Reg Rd 33- Townline Rd	9.2	97,100	3
Reg Rd 33- Townline Rd	Franklin Blvd	2.3	112,000	3
Franklin Blvd	Hwy 24 - Hespeler Rd. - Cambridge	1.7	100,400	4
Hwy 24 - Hespeler Rd. - Cambridge	Hwy 8 - Kitchener	4.6	125,600	3
Hwy 8 - Kitchener	Waterloo Rd 28 Homer Watson	2.9	71,900	3

While 401 congestion across much of Toronto is not unexpected, the extent of congestion that is encountered out to the west is perhaps more surprising. In the eastbound direction, AM peak congestion near Milton and in the heavily built up areas of western Mississauga are quite serious. There is a lesser level of congestion even in the westbound direction. PM peak westbound congestion in these areas is even worse. Overall, a Waterloo to Toronto AM peak trip will be very difficult over these stretches. The trip “against the grain” from Toronto to Waterloo would be somewhat better.

In Table 5-6, there is some evidence that part of the problem here is simply too much volume for the capacity. The 24 hour volumes are less than 200,000 in these areas but much higher than the volumes that occur west of Milton and towards Kitchener. Meanwhile, recent provincial announcements on infrastructure improvements to Hwy 401 have focused on the immediate Kitchener-Cambridge vicinity.

5.4.2 Toronto-focused Expressways

In terms of the Toronto-focused expressways, there is serious congestion on the Don Valley Parkway and the Gardiner Expressway in particular with results from the latter being partly influenced by construction delays.

Hwy 427

The results for Hwy 427 are much better though there is some northbound congestion in the AM that would impact a trip from Toronto to Waterloo at that time. In the PM, the congestion is also northbound but north of the 401 which is less problematic for the Toronto-Waterloo corridor. The volumes on Hwy 427 are actually quite massive and are comparable to some of the highest volumes seen on Hwy 401. These peak volumes occur on the stretches south of the interchange with Hwy 401. The road infrastructure associated with Hwy 427 is much more extensive than either the Gardiner or the Don Valley Parkway and this goes a long way to explain the better congestion outcomes.

Don Valley Parkway/Hwy 404

For the Don Valley Parkway/Hwy 404 combination congestion on the former is worse. The heaviest congestion, not surprisingly, is AM southbound and PM northbound. PM northbound congestion is more pervasive throughout the day, especially in the area of Eglinton Avenue. There is a similar southbound pattern though it is closer to the 401. There is also PM northbound congestion that increases closer to Hwy 407 but this is of less importance for the Toronto-Waterloo corridor. Data from the City of Toronto from 2009 indicates that traffic volumes in the stretch between Eglinton and Lawrence Avenues are approximately 165,000 vehicle per day. Since this expressway does not have the same high levels of capacity as Hwy 401, these volumes translate into serious traffic congestion.

Gardiner Expressway

The Gardiner is not a high capacity route with some of its largest 24 hour volumes being in the range of 80,000 to 90,000 vehicles per day. The 2014 data suggest that the Gardiner was arguably the most persistently congested expressway link over the course of a typical weekday. Eastbound congestion appears somewhat worse than westbound congestion. The eastbound congestion occurs further to the west while the westbound congestion is nearer to the downtown. The overall result is that it is basically a difficult thing to access or leave the downtown core by car when travelling to or from the west. East of the downtown, congestion on the Gardiner is much less of a problem; however, there is a direct linkage to the congested Don Valley Parkway.

Allen Expressway

The Allen Expressway is a short north-south spur that speeds movements to and from the central core of the city. The biggest congestion problems associated with this link appear to be getting on and off it, particularly at Eglinton Avenue. This problem is pervasive throughout the day and the same thing happens to a lesser extent at Sheppard Avenue. At both ends, the expressway ends rather awkwardly at typical arterial intersections so the observed congestion near these endpoints is not surprising.

5.4.3 Region of Waterloo/Hamilton-Oriented Highways and Expressways

Overall, congestion in or near the Region of Waterloo and Hamilton is much less than what is experienced nearer to Toronto but there are some sore spots worth mentioning.

Conestoga Parkway

The Conestoga Parkway which travels through the heart of Kitchener-Waterloo was completed in the 1960's but to this day remains relatively uncongested. There does not appear to be any significant northbound congestion and the most significant southbound congestion is at PM peak near to University Avenue which accesses the two major universities. As such, it would not be problematic for the Toronto-Waterloo corridor.

Hwy 8

Hwy 8, which connects the Conestoga Parkway to the 401, and also to Hamilton via Cambridge is more problematic. Until long after the Conestoga Parkway was completed, connections to the 401 were poor but they were upgraded significantly with the construction of the "Freeport Diversion" or "Highway 8 Expressway" which is a modern thoroughfare linking to the 401. Even this modern addition is experiencing some congestion as it moves eastbound towards the 401 and Toronto

In the stretch between Hamilton and Cambridge, Hwy 8 is a two-lane highway that passes through urbanized areas for large stretches in Cambridge and Hamilton. Average speeds through the built up areas are sufficiently slow that Highway 6 is generally seen as the preferred route to link Hamilton and the Region of Waterloo. Apart from built-up areas, which is a big issue, Highway 8 moves well between Cambridge and Hamilton.

Hwy 6

In terms of the corridors relevant to this study, Highway 6 runs as two corridors that join to Hwy 401. A longer one that connects to Hwy 403 at Hamilton, and a shorter one that links the west of Guelph to Hwy 401.

With regard to the former, the main congestion pain points have been at Morriston at Hwy 401 and at the intersection with Highway 5/Dundas Street (also known as Clappison Corners). For years, highway volumes have been overwhelming the small town of Morriston and reducing connectivity between Hamilton and the 401. This will be addressed in a few years with the new Morriston bypass which will be about 5km in length. Connectivity to Hwy 403 has been improved as well with a recently completed short section that turns Highway 6 into an expressway between Hwy 403 and Hwy 5. At Clappison Corners, however, traffic is handled as it would be at a large metropolitan intersection of arterials. As such, this piece of Hwy 6 shows up as a bottleneck in the southbound direction towards Hamilton and to a much lesser extent northbound.

Hwy 6 from Hwy 401 to the west of Guelph functions more like an arterial than an expressway. Low average speeds are more pervasive in the northbound direction as opposed to southbound.

Hwy 7

For all intents and purposes, Hwy 7 does not emerge from this analysis as a highly viable corridor between central Toronto and Waterloo. Too much of this corridor passes directly through built-up areas, progress is slowed by numerous traffic lights and average speeds are quite low. Even with congestion on Hwy 401, most would perceive Hwy 7 to be a second or third route choice. By showing what the alternative is like, the Hwy 7 heat map based on INRIX data does a good job of illustrating how the modern limited-access expressway is an important time-saver along important travel corridors.

QEW/Hwy 403

Hwy 403/QEW is included in this analysis because it is the main highway link between Hamilton and Toronto. In general, congestion is less severe for this major expressway than others in and around Toronto with the exception of Hwy 427. Traffic congestion is worse in the PM than in the AM. Westbound travel in the AM is actually quite good along this route. In the eastbound AM, it is interesting to note that one of the more severe bottlenecks occurs where Hwy 403 intersects with the Lincoln Alexander Parkway on the Hamilton Mountain – far away from Toronto. Arguably the most congested stretch on the QEW is westbound through Burlington during PM peak. Local afternoon traffic mixes with regional through-traffic and the nearby QEW/403 split appears to cause a bottleneck effect.

5.5 A Review by Mode

5.5.1 Passenger Vehicle

Prior results in this chapter suggest that a trip by passenger vehicle from downtown Toronto to central Waterloo is likely the best from a series of options that are not ideal. An early AM commute from downtown Toronto would not typically expect to encounter high congestion levels on the Gardiner Expressway, Hwy 427 or Hwy 401 but the return trip would likely offer more problems. A return-trip commute from Waterloo to Toronto would not work out as well as the Toronto-Waterloo counterpart.

On a daily basis, the driving distance associated with this commute is one that only a very small percentage of commuters would ever contemplate. The 2011 Transportation Tomorrow Survey, which covers the entire study region, confirms this fact. Certainly, the possibility of periodic significant traffic congestion increases the risk associated with this commute.

One of the disadvantages of driving an automobile is that one is not free to do other things while travelling. In the case of busy knowledge workers, this can be a real disadvantage of driving. Commuting by train or bus solves this problem and of course San Francisco-Silicon Valley is noted for its company-specific private shuttles that spare the commuter from driving. The concept of shuttling workers from downtown Toronto to Waterloo could have potential but the commute distance is on average 40 to 50% longer than the comparable commute in the California example and there could be problems of insufficient demand if shuttles were to be operated on a company-specific basis as they are for the likes of Google or Apple. Even with the shorter commutes in the Silicon Valley example, commuters know that on any given day their shuttle could be slowed by severe traffic congestion. To some extent this threat is reduced in that a shuttle can use an HOV lane for part of the Silicon Valley trip. At present, this cannot be done on the Toronto-Waterloo trip.

One noteworthy observation about the passenger vehicle trip between Toronto and Waterloo is that the emphasis is almost all on good infrastructure or the use of high capacity roads to accommodate demand. And in some sections, such as Hwy 401 in the vicinity of Hwy 407, even this approach has potentially not gone far enough. On the supply side, we do not see evidence of the managed expressway approach that is succeeding in the UK and Europe and which has the philosophy to use technology and approaches such as hard shoulder running to make the most of all available space on the right-of-way and to minimize the congestion effects of highway accidents. On the demand side, no initiatives have been implemented to price road travel through tolls, time-of-day pricing or HOT lanes which combine pricing with HOV lanes. A new HOT lane pilot project on the QEW does suggest a tentative shift in this general direction.

5.5.2 Commuter Rail

The discussion about the main collective modes of transit: rail and bus is assisted by Table 5-7 which provides scheduling information for travel between downtown Kitchener and downtown Toronto. Of interest for this section on commuter rail is the clear result that present day commuter rail service between Union Station in Toronto and the Kitchener GO/VIA station in the downtown core of Kitchener is not an attractive option for the full journey. There is an AM service from Kitchener into Toronto and a PM service for the reverse journey with each trip coming in at just over two hours. Clearly, this service is not aligned, due to a lack of demand, with the concept of a morning commuter leaving Toronto to work in Waterloo. The service that is available makes numerous stops which has the effect of significantly increasing the overall travel time.

Table 5-7: Existing Rail and Bus Options between Toronto-Kitchener

Company	Route	Location	Time (AM)	Route	Location	Time (PM)
GO Transit	**Kitchener – Toronto**	**Kitchener GO**	**7:10**	**Toronto – Kitchener**	**Union Station**	**16:50**
	Train: 2H 3 M	Guelph Central GO	7:34	Train: 2H 7M	Bloor GO	17:00
		Acton GO	7:51		Weston GO	17:09
		Georgetown GO	8:09		Etobicoke North GO	17:16
		Mount Pleasant GO	8:18		Malton GO	17:23
		Brampton GO	8:25		Bramalea GO	17:31
		Bramalea GO	8:35		Brampton GO	17:40
		Malton GO	8:41		Mount Pleasant GO	17:46
		Etobicoke North GO	8:47		Georgetown GO	17:56
		Weston GO	8:53		Acton GO	18:10
		Bloor GO	9:01		Guelph Central GO	18:25
		Union Station	9:13		Kitchener GO	18:57
VIA Rail	**Kitchener – Toronto**	**Kitchener**	**9:18**	**Toronto – Kitchener**	**Toronto**	**17:40**
	Train: 1H 35M	Guelph	9:44	Train: 1H 36M	Malton	18:00
		Georgetown	10:10		Brampton	18:12
		Brampton	10:20		Georgetown	18:24
		Malton	10:32		Guelph	18:49
		Toronto	10:53		Kitchener	19:16
Greyhound	**Toronto – Kitchener**	**Toronto**	**7:15**	**Kitchener – Toronto**	**Kitchener Charles St.**	**17:30**
	Bus: 1H 20M	Toronto U & Wellington	7:20	Bus: 1H 35M	Kitchener Sportsworld	17:40
		Kitchener Sportsworld	8:30		Cambridge GLC	17:50
		Kitchener Charles St.	8:35		Toronto Royal York Hotel	19:00
					Toronto	19:05

One noteworthy aspect about the Region of Waterloo is that major transport facilities (i.e. main train and bus stations) are located in the heart of Kitchener as opposed to the heart of Waterloo. As such, an inter-city traveler arriving by rail, for example, will likely utilize the upcoming light rail system to complete a trip to the heart of Waterloo or to either of the two main universities. Indeed, part of what will make light rail transit work in the Region of Waterloo will be the ability to connect directly to inter-city forms of transport.

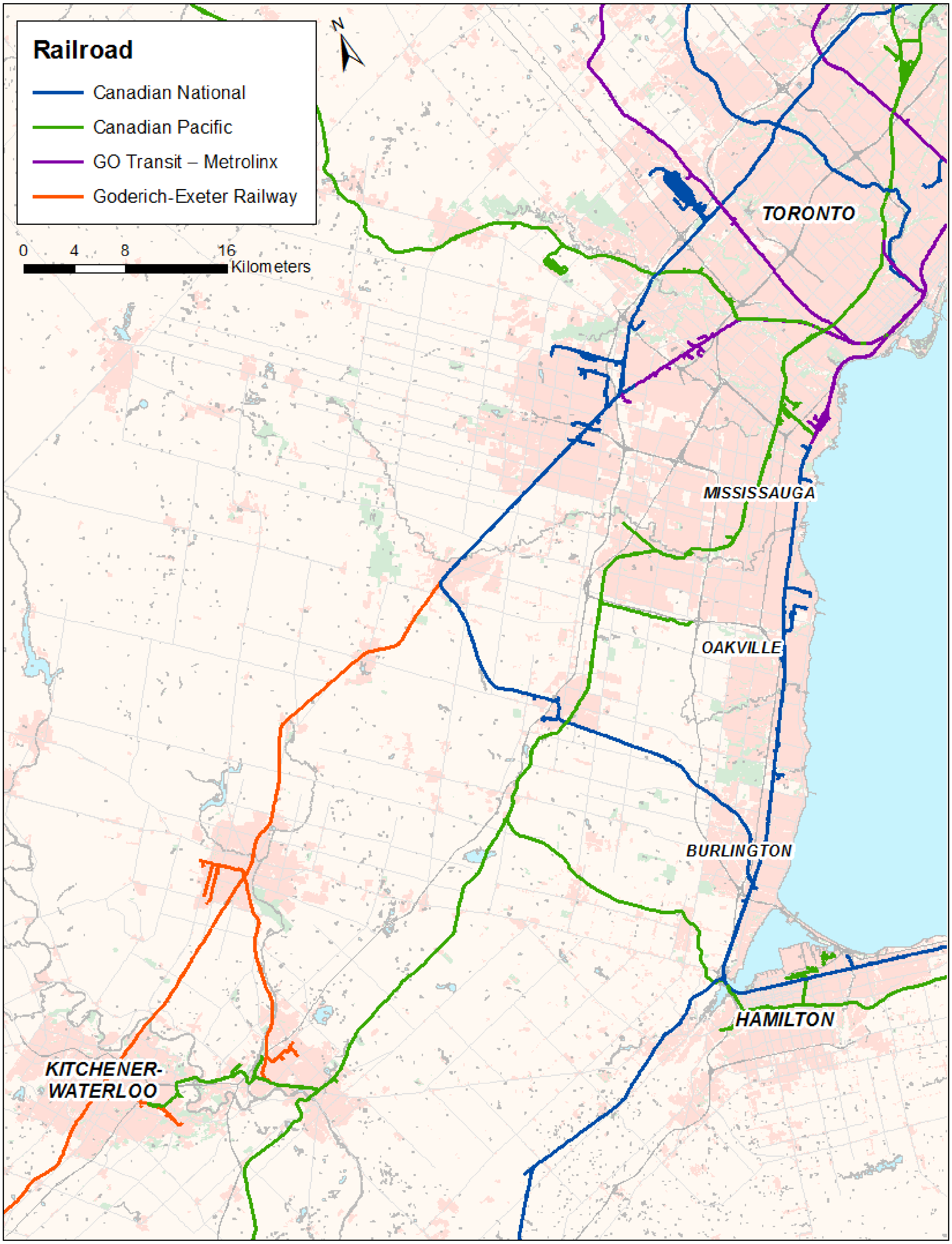
GO service by rail between Kitchener and Toronto is perhaps a bit under the radar relative to other GO improvements that will unfold in upcoming years. Already GO's commuter rail service is one of the leaders for its type in North America and indeed, there are only a handful of services in North America that approach the scale of GO Transit. In terms of daily ridership, the closest comparison appears to be with the Chicago Metra commuter service. Ridership in the Greater Toronto region is increasing over time and significant investments are taking place to improve the service over time. There are expectations in fact that GO ridership will double by 2031 (Brennan, 2014).

With regards to the future improvements, the service is essentially being transformed from primarily rush hour commuter rail to a regional rapid transit service (Thompson, 2015). In this regard, what will happen to GO Transit has already occurred to a large extent with the Paris RER system that was previously described in Section 3.4.2. That train service has a frequency that approaches that of an Underground Metro combined with the speed of a much larger train. Certainly, it is designed to cover longer distances than the typical heavy rail subway and the spacing between stops is greater than what would be encountered with a Subway.

The RER service in Paris is electrified and electrification is an important element in the transformation that will take place in the Greater Toronto region. Electrified trains are able to accelerate more quickly, which is important with the frequent stopping encountered in commuter services, and electrified rail has many energy efficiency and environmental benefits.

While the significance of the improvement for the overall region will be quite massive, the impact on rail travel between Toronto and Kitchener will be somewhat muted in comparison. Current plans for electrification of the Kitchener line extend only as far as Bramalea, Ontario (Thompson, 2015) which represents about 1/3 of the rail distance between Union Station and the heart of Kitchener. Initial efforts are focused on electrifying rail corridors that are actually owned by Metrolinx (Figure 5-24) along with other important corridors. Much of the right-of-way for the critical Lakeshore West route, for example, is owned largely by Canadian National and is to be electrified to Burlington, though not all the way to Hamilton. Less frequent services to Kitchener and Hamilton will be diesel-hauled and thus do not conceptually fit with the idea of frequent, high-capacity regional rapid transit. This is in contrast to the train frequencies of every 15 minutes which will prevail on key corridors.

Figure 5-24: Rail Corridors in the Toronto and Kitchener-Waterloo Region



One critical point about commuter services, and also commuter services that are morphing into regional rapid transit, is that in the context of a longer rail trip, they tend to have many stops. The lack of an express, or more of an inter-city, service means that a trip between downtown Hamilton and Toronto or Kitchener and Toronto can be quite time consuming. Express trains are offered on the Lakeshore West line, for example, that skip stops between Oakville and Union Station but there is no concept of an urban hierarchy in the GO system where the likes of Hamilton or Kitchener are given priority over intervening centres on the routes. With all the progress that will take place with GO Transit over the next decade, this is a gap that is likely to remain, especially in the Kitchener-Toronto context. The ultimate solution, from a rail perspective, may be a renewed emphasis on inter-city service.

5.5.3 Inter-City Rail

Canada's inter-city rail service is VIA rail and some indication of its performance is provided in Table 5-8. These scheduled travel times are certainly well below the standards of countries that have invested heavily in passenger rail. Clearly the travel times are below the standards of high-speed rail but more importantly, they are below the standards of well-executed conventional rail. Of particular interest for this study is the travel time for the Kitchener to Toronto route which is at approximately 95 minutes. This is too long a travel time for the distance and does not offer a compelling value proposition relative to road travel. The prior Table 5-7 offers some further details on the timing of stops that are made along the way during this time-consuming trip.

Table 5-8: VIA Inter-City Rail for Various Ontario Corridors

Route	VIA Rail		Car		Distance
Toronto to Montreal	9:20 – 14:18	[4h 58min]	[09:20]	4h50min – 5h50min	545km
Montreal to Toronto	10:10 – 15:30	[5h 20min]	[10:10]	5h – 5h50min	545km
Toronto to Windsor	6:35 – 10:49	[4h 14min]	[06:35]	3h20min – 4h	366km
Windsor to Toronto	9:05 – 13:11	[4h 06min]	[09:05]	3h30min – 4h10min	366km
Toronto to Kitchener	10:55 – 12:32	[1h 37min]	[10:55]	1h5min – 1h25min	108km
Kitchener to Toronto	9:18 – 10:53	[1h 35min]	[09:18]	1h25min – 2h	108km
Toronto to Ottawa	9:20 – 13:57	[4h 27min]	[09:20]	4h – 4h40min	453km
Ottawa to Toronto	10:30 – 14:48	[4h 18min]	[10:30]	4h – 4h40min	453km
London to Kitchener	7:32 – 9:18	[1h 46min]	[07:32]	1h10min – 1h30min	110km
Kitchener to London	12:32 – 14:17	[1h 45min]	[12:32]	1h5min – 1h25min	110km

Another important issue is delay (Shron, 2015; Freeman, 2015) which is an additional risk that potential passengers must take into account when they choose their mode of travel. On-time performance was at 84% in 2011 and has declined to 74% largely due to increased rail freight traffic. The Toronto to Vancouver train is regularly late by 7 to 10 hours. Performance on the Toronto-Montreal route has actually declined over the last decade. If the same standards for

Toronto-Montreal were achieved as has been done for the Tokyo-Osaka route in Japan, the trip would take 2 hrs 36 mins and the average delay for the train trip, regardless of weather conditions, would be measured in seconds (Hongo, 2014).

When it comes to inter-city rail in Canada and Southern Ontario, first thing is first though, and the fact of the matter is inter-city corridors do not feature dedicated passenger rail corridors. The quality of service is at the mercy of freight rail and as freight volumes increase over time, the problem only gets worse. 90% of VIA tracks are owned by CN. This is something that has historically had a negative effect for GO Transit performance in the region but the effect is devastating for inter-city service which is naturally more premium in nature. Accordingly, there are some who are calling for investments in dedicated track rather than a massive push toward high-speed rail (Owram, 2015; Tencer, 2015). A dedicated corridor alone is estimated to reduce the travel time between Toronto and Montreal down to a respectable 3.5 hours. This has been characterized as delivering two-thirds of the benefit of high-speed rail with one-third of the cost. There are estimates that dedicated tracks could triple, over fifteen years, the number of passengers that would use a Toronto-Montreal service (Fekete, 2016) and it has been suggested that pricing highways would also help to develop inter-city rail along with collaborations between all three levels of government.

The idea of dedicated passenger rail corridors between Toronto-Kitchener, Toronto-London and Toronto-Windsor is a very interesting possibility as well. The review from Section 3.4.1 suggested that high-speed rail is not suited to these corridors. Population centres to the west of Toronto are not sufficiently large to merit the massive investment in the type of high-capacity, frequent service that defines high-speed rail. High-speed connections to Detroit would be hampered by its low population densities and generally decentralized nature; and Windsor is not heavily populated. Even so the Ontario government is pressing ahead to study the concept (CBC Windsor, 2016). Results from this research suggest that a high-quality conventional service, of the type that runs between London and Cambridge in the U.K, would cut rail travel times between Kitchener and Toronto to under an hour. Combined with the substantial transit investments that are taking place on both ends of this inter-city trip, there would appear to be good potential for success.

5.5.4 Bus

The concept of Inter-city bus services was reviewed in Section 3.3.2 and it was discovered that this mode has been thriving in the past decade after prior periods of decline. The core of the appeal is economical, express service between metropolitan areas. As O'Toole (2011) has pointed out, bus is doing a good job of competing with rail as a value alternative. In Canada, inter-city bus service is noted to be much more regulated compared to the U.K. or United States (Geloso, 2012) and this may have hampered growth in the industry.

Many of the corridors along which bus succeeds are longer than the Toronto-Waterloo corridor. For example, the Red Arrow Motorcoach serves the 300km Calgary-Edmonton corridor and similar corridor lengths are served across the U.S. by other firms. Overall, one of the biggest differences between bus services of this type and the concept of the private shuttle as operated by firms like Google is that the latter are free for employees. In this regard, the private bus shuttle concept would seem to have a major advantage for achieving significant scale in the movement of knowledge workers.

The performance of the Greyhound service that links Toronto and Kitchener has been noted in Table 5-7. By schedule at least, this service is very competitive with VIA rail and GO Transit though there will be variability caused by traffic congestion. This service is express-oriented with few stops for the downtown-to-downtown trip. Megabus does not offer a scheduled service between Toronto and Kitchener though there is one between Kitchener and Hamilton. The latter route is associated with two intermediate stops and the total duration of the trip is lengthy at approximately 90 minutes.

On the other hand, GO Bus service is more commuter-oriented, as would be expected, and it mirrors the rail offering to some extent. There are two buses in the morning that travel between the two downtowns and two in the PM peak. Duration of the trip is approximately two hours and there are frequent stops along the route which focuses on Hwy 7, as opposed to Hwy 401. GO Bus service along the corridor also features more frequent connections of Kitchener to intermediate destinations along the corridor such as Georgetown and Bramalea. There is an express service between Bramalea and Kitchener with a trip duration of about 1 hr 10 minutes.

Another bus-oriented possibility to speed travel along the Hwy 401 corridor is a highway oriented Bus Rapid transit service. This topic was examined in Section 3.3.3 and it was discovered that examples of such services have recently appeared or are planned to appear in the United States. As of yet, there are no examples that span more than 30km but one is in the planning stages for the Tampa-St. Petersburg vicinity that could run for up to 80km.

The Mississauga Transitway, which is scheduled to be fully completed in 2017 is an interesting local example. This BRT service features 12 stations over 18 kilometres along the Hwy 403 corridor and stretches from Winston Churchill Boulevard to Renforth Gateway. Travel time along the entire corridor is expected to be from 15 to 18 minutes. In the future, there will be a good connection from the Renforth mobility hub to Pearson Airport. The BRT was first conceptualized decades ago and development of the Hwy 403 corridor took into account the possibility of the Transitway. Partly the right-of-way uses dedicated shoulder lanes on Hwy 403 and partly there are sections that are dedicated only to buses and which run parallel to Hwy 403.

Bus Rapid Transit could be a possibility to address problems with the Hwy 401 corridor. A problem area for Hwy 401 is also through Mississauga as the earlier INRIX results have shown. Since such a service has apparently not been pre-planned for the Hwy 401 corridor, it would likely feature fewer stops than the Mississauga Transitway and would rely on HOV lanes that as of yet have not materialized. The likelihood for success of such a project would depend on good transit connections to rapid transit within Toronto. Clearly, further study is required.

6

Conclusions

This study has focused on quantitative metrics and experiences elsewhere to derive an understanding of the transportation corridors that link southern Ontario metropolitan innovation ecosystems. There is a particular emphasis, in this report, on the Toronto-Waterloo corridor. Metropolitan areas themselves are very important to the analysis because innovation clusters are an inherently metropolitan concept. Larger metros may lead to more innovation but also larger transportation problems and a requirement for more complex transportation solutions. Also, heavily built up areas generate considerable intra-city travel that may negatively impact travel on inter-city corridors.

Each primary conclusion from this research is bolded below followed by supporting text that explains and justifies the conclusion based on the evidence in the body of the report.

Leading metropolitan innovation ecosystems feature serious transportation problems mixed with innovative transportation solutions

In terms of best practices from elsewhere, it is true that some of the most innovative transportation initiatives do emerge from what are generally considered the most innovative metropolitan areas. But some have emerged from other jurisdictions as well. The most innovative of metropolitan ecosystems are often some of the most congested and have some of the most challenging transportation issues. Success as an innovation ecosystem may be achieved despite these transportation problems. Transportation innovations of recent years and decades include electronic tolling, HOV and HOT lanes, modern inter-city bus services, high-speed rail, suburban bus rapid transit systems, advanced commuter rail systems and regional rapid transit, managed lanes and expressways and others.

There are varied transportation models for metropolitan innovation ecosystems

Metropolitan areas with high populations and densities do seem to prosper as innovation ecosystems. Many of the largest and most successful feature considerable transportation diversity: there can be multiple transit systems in place (e.g. heavy, light, and commuter rail and others). When the likes of ridesharing, taxis or short term car rentals are taken into account, there can be multiple transport providers also. Even so, all of this transport diversity typically does not mean that traffic congestion is not a serious problem. Most major U.S. metros experience high costs due to traffic congestion. Based on the U.S. experience, the most innovative metropolitan areas are not necessarily the densest. It appears that some minimum level of density may be important. It seems clear that the least dense of metropolitan areas are less likely to host a prominent innovation ecosystem. In the lower population success cases, such as Ann Arbor, Boulder or New Haven, the presence of top-flight universities is very important. In these cases, corridors to nearby large metros are very relevant as is the case for Waterloo.

The corridor between the cores of Toronto and Waterloo, at 115 km, is a relatively long one for daily travel

A metropolitan area defines a catchment area for a range of daily travel interaction possibilities, including commuting. The fact that firms have access to large labour pools within the catchment area and people have a wide range of job options in the metropolitan context is a driver of metropolitan productivity. Analysis of 2011 Transportation Tomorrow survey (TTS) data has revealed that driving commutes of over 100 km are exceedingly rare relative to all driving commutes. The data suggest that less than one-third of one percent of driving commutes within the TTS catchment area exceed 100 km. Driving distances from downtown San Francisco to Silicon Valley corporate campuses are in the range of 50-75km and this shorter distance than the Toronto-Waterloo case is very significant in terms of facilitating interactions that occur every day.

The urbanization and centralization of start-up geography does nothing to shrink the 115 km Toronto-Waterloo corridor.

Metropolitan population density, when measured properly, is one of the most important transportation metrics

Is Toronto a sprawling metropolitan area? There are many who would suggest it is. For too long population density for metropolitan areas has been calculated in a simplistic manner: divide metropolitan population by total land area. Typically the vast land area on the denominator will include essentially empty space where no one lives. Problems like this and others render comparisons between metropolitan areas rather useless. On the other hand, the population-weighted population density works based on a calculation over the many small census areas in a metro and weights them by how many people live in each small area. Zero inhabitant zones gets zero weight. The result is a very useful quantity that measures the average density experienced by households in the city. As it turns out, the average density experienced in the Toronto CMA is 20,803 persons per square mile. This is about 2/3 the density of New York, which is by far the densest U.S. metro, and approximately 10 times more dense than Atlanta which has a similar metropolitan population to Toronto. Results suggest that Toronto is quite a dense place – which is not to say that it does not contain sprawl. At the other end of local corridors, the Hamilton CMA is at 10,915 per square mile and the Kitchener CMA is at 7,783 per square mile. These are all reasonably high densities for places of their size and suggest that there is hope to reduce and minimize automobile dependence along corridors that join the metros.

All signs point to rail as an important means to draw innovation clusters within our region closer together

Through means such as electrification, the gradual development of rail by GO Transit into a regional rapid transit system is very positive for drawing regional clusters closer together but the missing piece is a top-notch inter-city service to serve longer corridors in Southern Ontario. There is a perception that inter-city rail does not, or cannot, work well in this region but all that is needed are competitive travel times and reliable service, neither of which prevail at present. Other required ingredients are present or trending in the right direction. Start-up geography is becoming increasingly oriented to downtown cores as recent experience in San Francisco illustrates. There is emphasis on "complete streets" (Ferguson et al., 2015) which to some extent regulate the automobile in urban contexts, and emphasis on the use of a variety of transport modes within cities (e.g. walking, cycling, public transit, ride sharing with the likes of Uber and Split) that have little to do with the sole occupant automobile. Rail-based forms of transit such as light rail are gaining increasing momentum and it is only natural that they should connect directly to good quality inter-city services. Meanwhile, bus rapid transit (BRT) systems such as the Mississauga Transitway promise to effectively mimic rail. Major transportation and land use policies within the region are all emphasizing multi-modal travel and urban intensification. All of these aspects should be a tailwind for inter-city rail.

There is an imbalance between inter-city highway infrastructure and inter-city passenger rail infrastructure in this region that ideally would be corrected over time

Highway infrastructure in this region is world-class and in general has gotten much better in the past 25 years. There have been a number of improvements in the Toronto, Hamilton and Kitchener-Waterloo areas among others, that have greatly improved highway connectivity. The contrast with passenger rail infrastructure is strong. Much of the passenger rail infrastructure in this region is first and foremost freight rail infrastructure. In order to correct this imbalance, which essentially makes the Toronto-Waterloo and other corridors automobile-dependent, passenger rail needs its own dedicated tracks. This is a basic starting point for a good conventional inter-city rail service, which in itself would make a big difference, and is certainly a pre-requisite for high-speed rail. Data from the Transportation Tomorrow survey suggest that there is not a great deal of commuting interaction from the Region of Waterloo to the heart of Toronto and even less in the reverse direction. Inter-city rail is quite likely the best way to induce such interaction and increase economic integration of many types along this corridor. A review of the U.K. case of Cambridge-London and others supports this conclusion.

Solutions less oriented to infrastructure are needed for local highways

Ontario's Highway 407, which opened in 1997, was the world's first all-electronic, barrier-free toll road. Results from this research suggest that our regional highways might benefit from more "world firsts" in emphasizing solutions that are more technology than infra-structure based. The utility of our world-class highway infrastructure has not, to this point, been refined through modern approaches that better manage traffic. Other than Hwy 407, there are no tolling or pricing mechanisms on regional highways to regulate demand or reallocate some of it to non-peak times, though HOT lanes for Ontario appear to be on the horizon. A large share of trips at peak times are discretionary in nature and pricing mechanisms could encourage shifts in time for such trips. New tolling technologies make it possible to implement these approaches without old-fashioned toll booths. Meanwhile, the rise of fuel-efficient and electric cars promises to render equally old-fashioned gasoline taxes obsolete or unfair. Managed Expressways and intelligent transportation systems allow for lane-specific communication and information display for drivers which can better manage congestion due to accidents, prevent follow-on accidents, or open up lanes to smooth traffic flows. Much more can be done in this regard to streamline highway corridors.

Targeted road infrastructure improvements are appropriate

There are cases where it will be appropriate to add lanes to highways. Congestion analysis of 2014 INRIX highway speed data suggests that Hwy 401 through Mississauga is quite congested. It is troubling that a stretch of major highway that is a significant distance away from the core of the metropolitan area is so congested. It certainly hampers movements along the Toronto-Waterloo corridor. Given that 24 hour traffic volumes along this stretch are not excessively high, a simple case could be made that Hwy 401 infrastructure simply tapers off too quickly as one moves west from Pearson airport. West of Milton, traffic congestion along the corridor does not appear serious with some exceptions near the built-up area of Kitchener-Cambridge. In the case of HOV or HOT lanes, adding new lanes, rather than subtracting general purpose lanes, may be the only palatable means to implement these concepts.

For the objective of joining innovation clusters at least, "two-tier" thinking is preferable to egalitarian thinking

If the objective is to offer options and possibilities for the fastest legally allowed trip along the Toronto-Waterloo corridor, then some differential treatment of traffic flows is needed. Highway travel in Ontario is largely general purpose in its implementation and orientation. More extensive use of HOV lanes would allow buses or private shuttles to travel less impeded along the corridor. Some pricing mechanisms, such as through HOT lanes, allow the sole occupant private vehicle to get through for those willing to pay. While there is probably some truth to the characterization of HOT lanes as "Lexus Lanes", experiences from other jurisdictions suggest that these lanes are used widely and most people are happy to at least have the option. Nevertheless, the hard reality is that the transportation needs related to the support for innovation clusters are likely at odds with the concept of equality for all.

Dislodging truck freight from important regional highway innovation corridors to speed traffic flows would not be easy and is probably not wise

This report does not dwell on the geography and dynamics of trucking in Southern Ontario, nor its tremendous importance to the economy. The interested reader is referred to Ferguson et al. (2014) for a detailed review of this topic based on analysis of empirical data. One observation is that congested sections of Hwy 401 on the Toronto-Waterloo corridor host 25,000 or more trips by larger trucks per day so there is no question that trucks have an impact on congestion patterns and are more damaging to roads than the typical light vehicle. But the value of cargo on any given truck is $500,000 on average and can reach into the millions of dollars for high-order goods such as pharmaceuticals or auto components (Ferguson et al., 2014). Meanwhile, a significant percentage of road space is occupied by discretionary personal trips with one person in a vehicle. These incremental discretionary trips are much less valuable to the economy but quite integral to congestion. With the exception of a pair of U.S. projects that are in the planning stages, exclusive truck facilities of any significant distance have not made an impact in North

American to this point. Meanwhile, trucks stay away from tolled facilities in droves because profit margins are tight and there is no means to pass the costs onto customers.

A balanced approach to innovation corridors seems prudent for this region

If there is an over-arching conclusion from this work, it is probably that balance is the best policy. Earlier conclusions have indicated that we do not have balance at this point, though trends are moving in that direction with the emphasis on intensification and collective modes of travel. The days of massive investments in highway infrastructure appear to be behind us but maintaining what we have, in itself, will be costly. Optimizing the use of highways will help to achieve greater balance. Moreover, there are numerous technological “wild cards” on the horizon that suggest caution on big investments in new highway infrastructure. Carpooling and ridesharing, for example, already account for a substantial share of trip-making but with the rise of advanced technological platforms, such as Uber and Split, there could be considerable growth ahead for the concept that could extend into longer commutes as well. Research suggests that there is plenty of untapped potential for more rides to be shared based on where people live and work. And much is to be done to ascertain the potential impact of autonomous vehicles. In the shorter run, local solutions could be as simple as the private shuttle approach used to ferry workers from San Francisco to Silicon Valley campuses.

Appendix

7.1 Other Heat Maps

Figure 7-1: Gardiner Expressway Westbound Average Speeds per Weekday

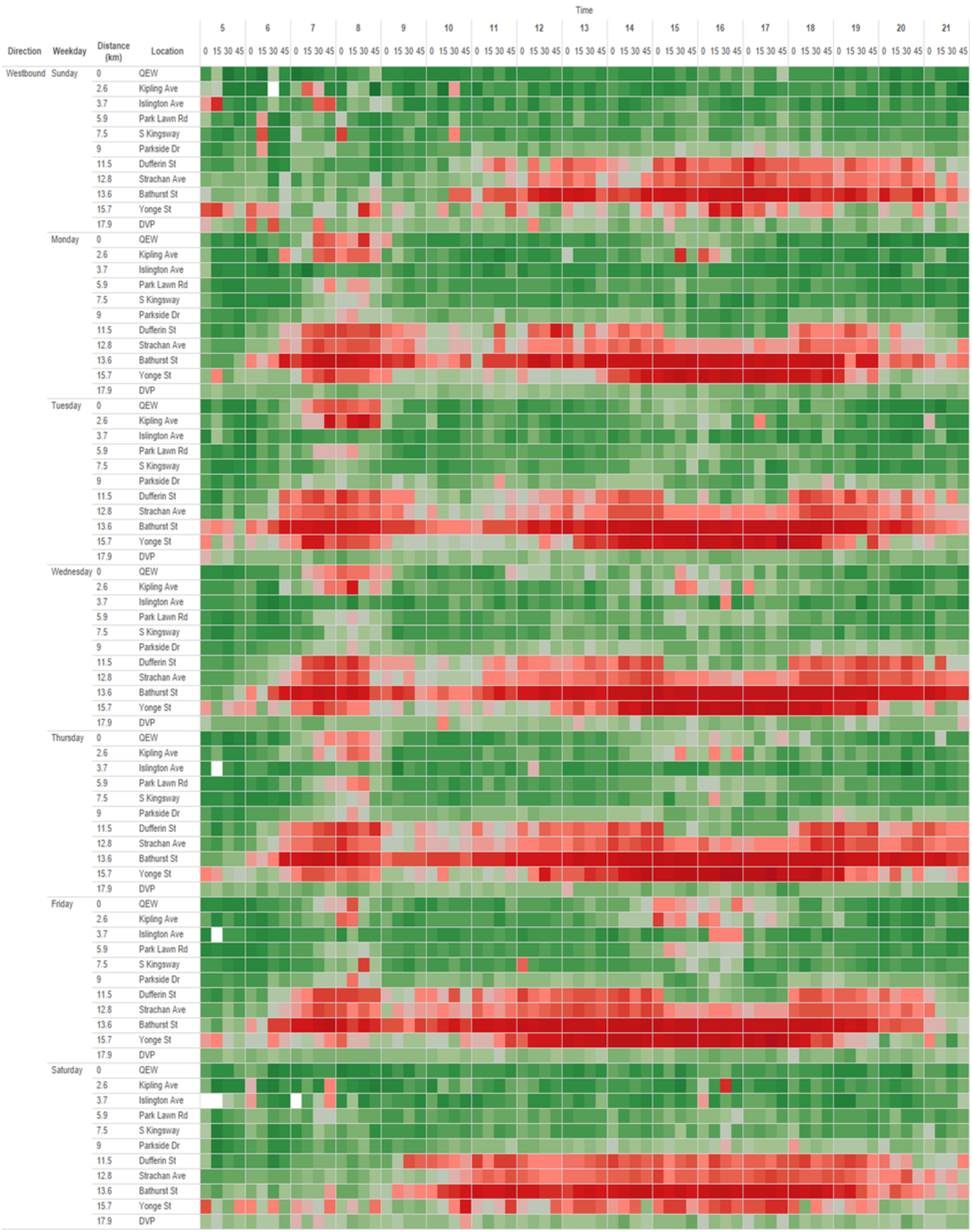
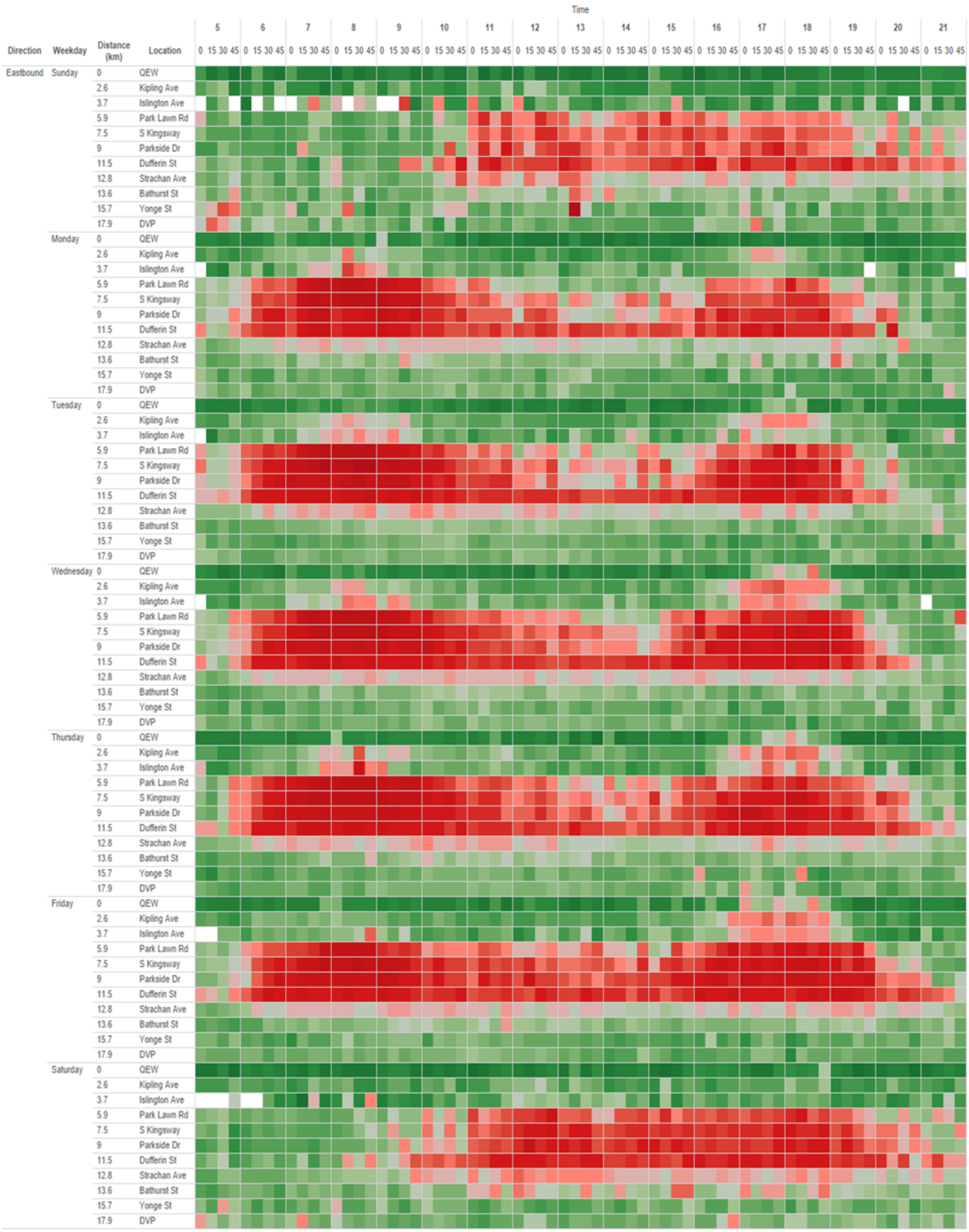


Figure 7-2: Gardiner Expressway Eastbound Average Speeds per Weekday



7.2 Transit/Rail Selected Summaries by Metro

Figure 7-3: Light Rail Transit Route Infrastructure and Ridership by U.S Metro

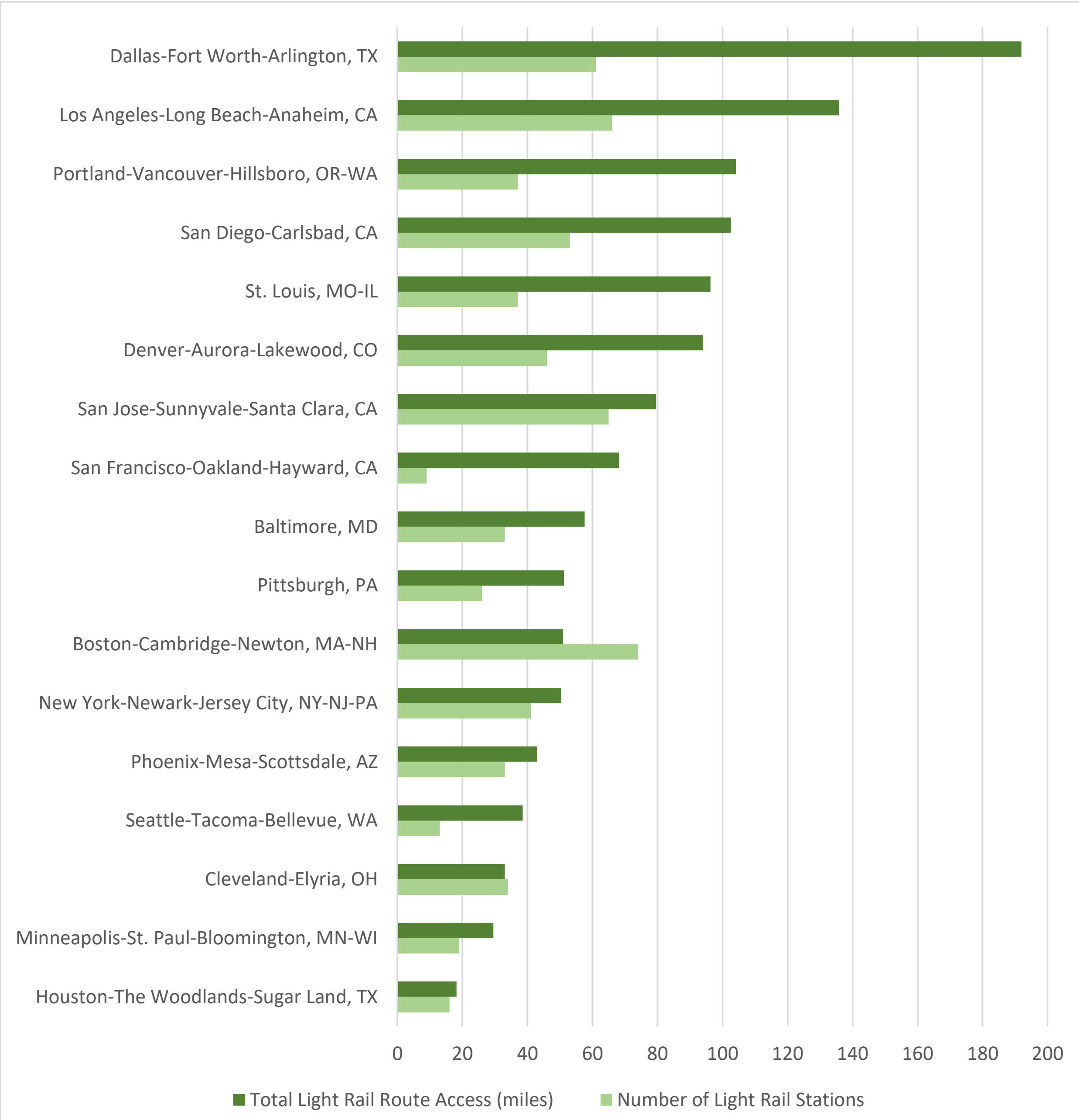


Figure 7-4: Heavy Rail / Subway Route Infrastructure and Ridership by U.S. Metro

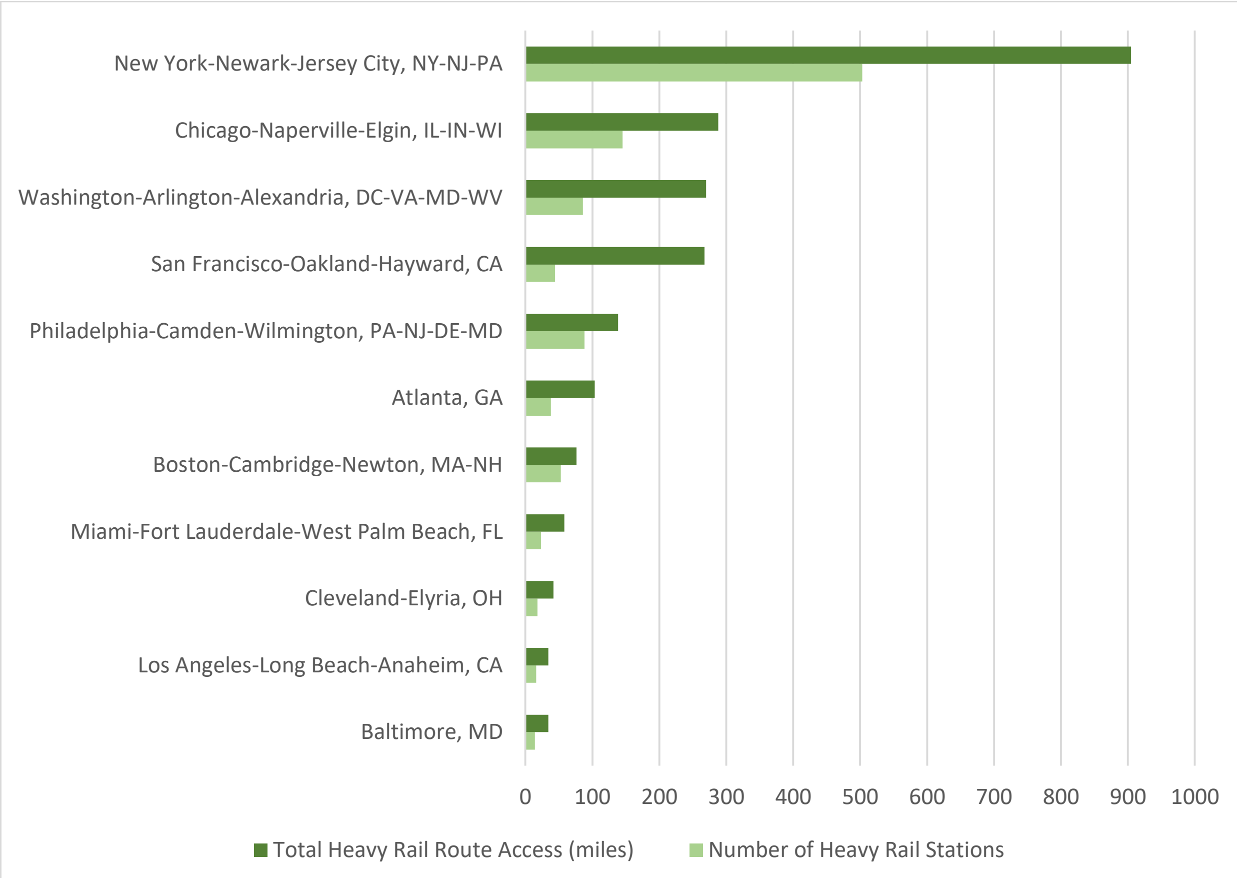


Figure 7-5: Commuter Rail Routes and Ridership by U.S. Metro

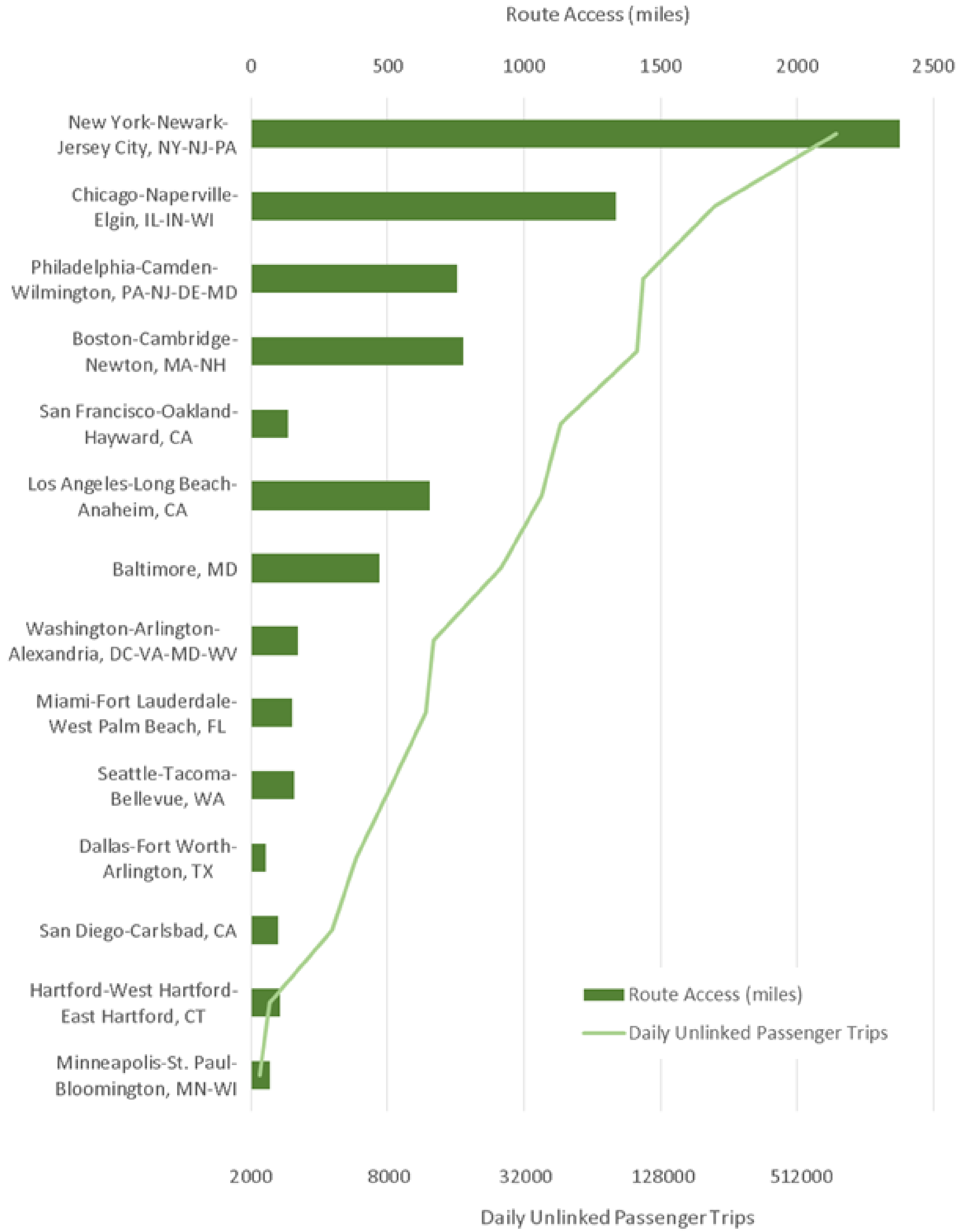


Figure 7-6: Commuter Bus Routes and Ridership by U.S. Metro

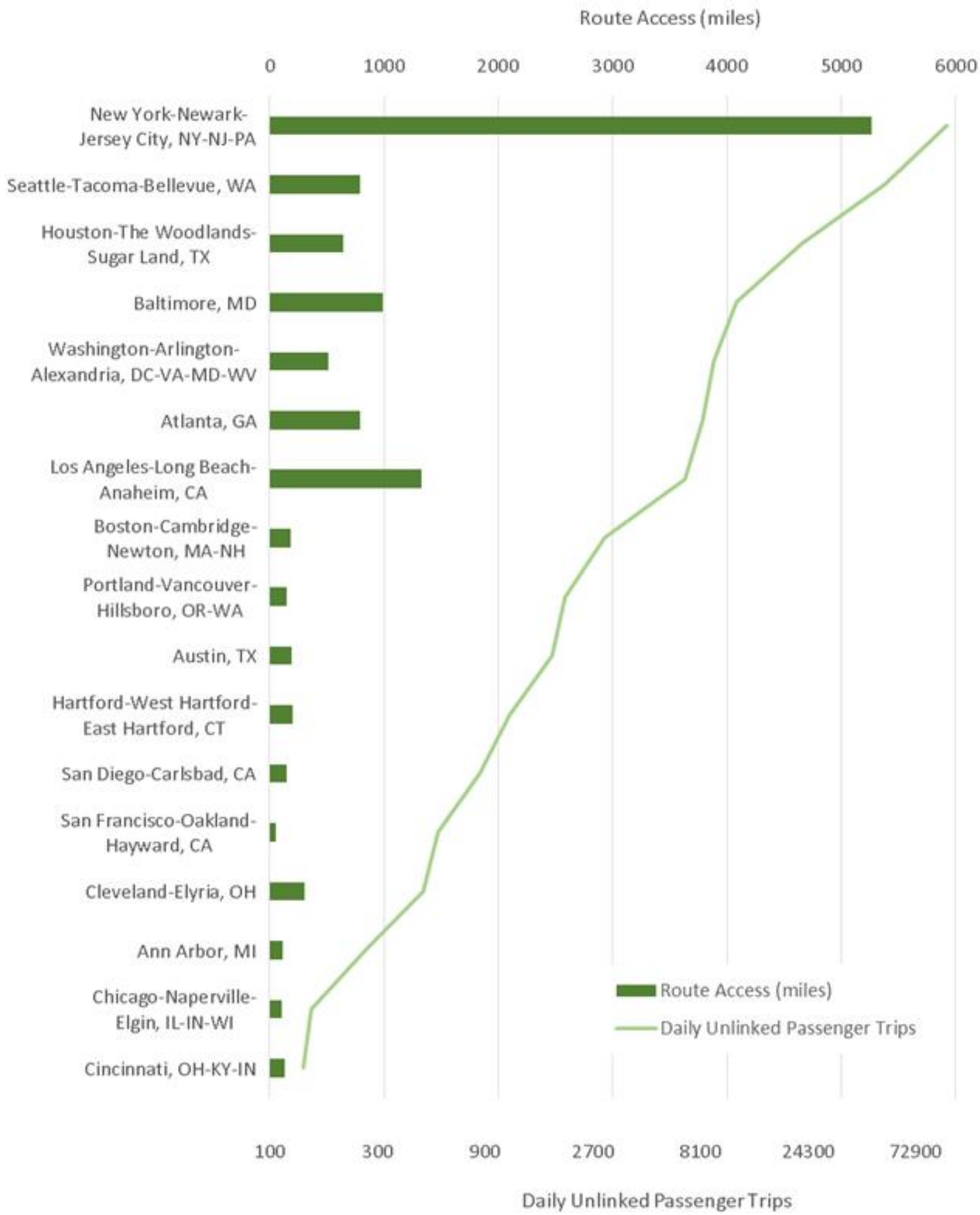


Figure 7-7: Changes in Amtrak Ridership by Metro

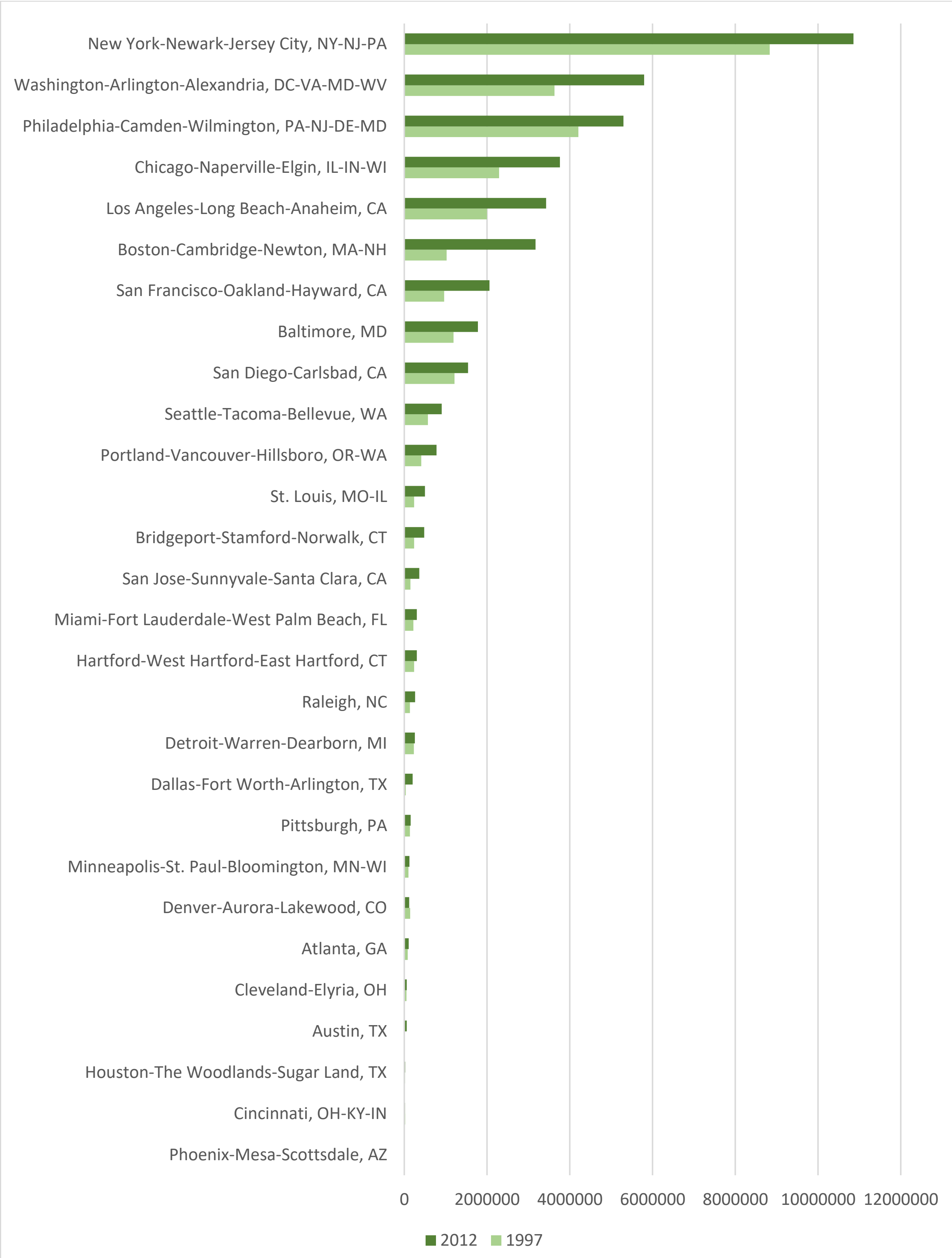
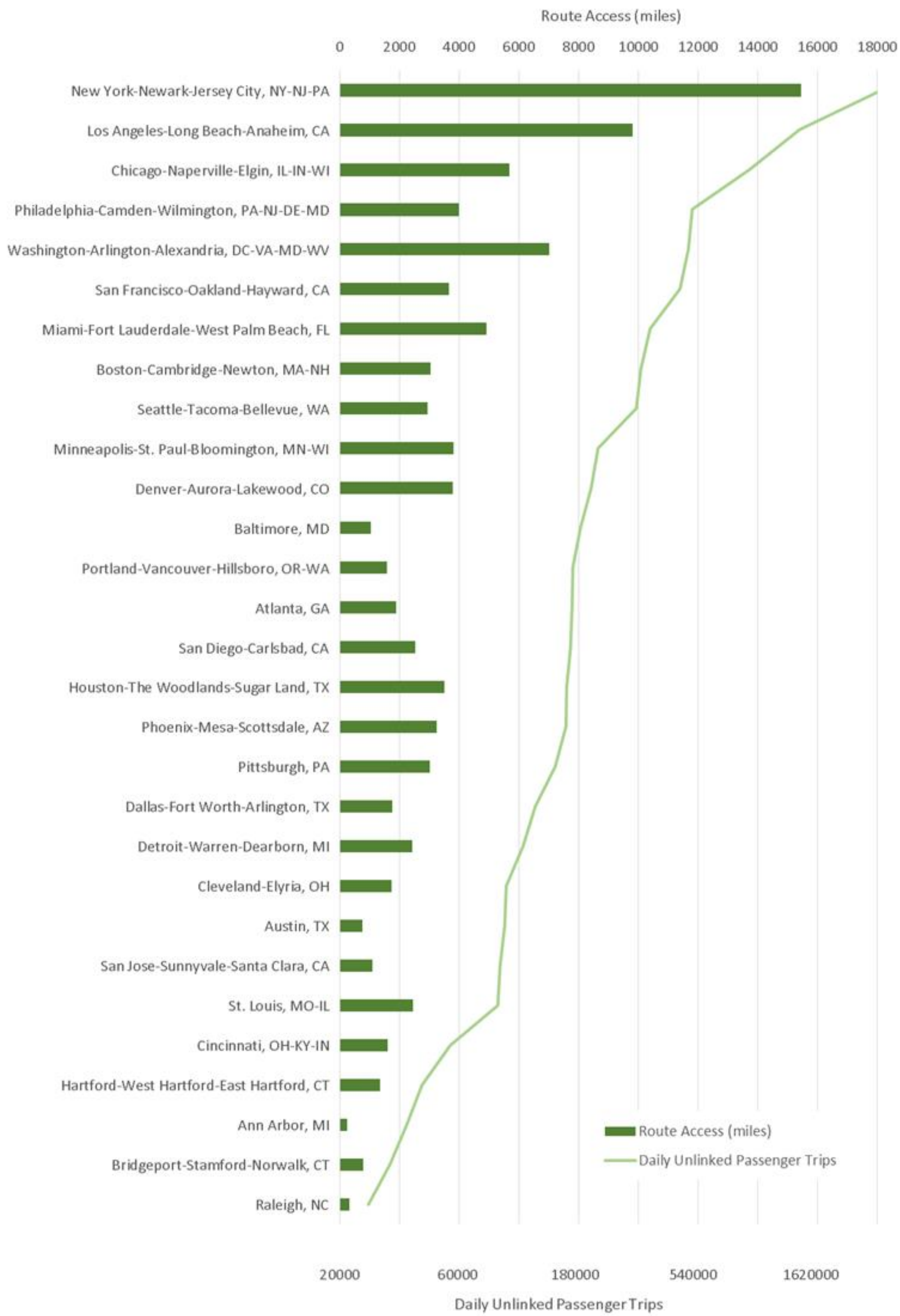


Figure 7-8: City Bus Routes and Ridership by U.S. Metros



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