Measuring Public-Transport Network Connectivity Using Google Transit with Comparison across Cities

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Abstract

The aim of the study was to construct a framework to determine interconnectivity among public transport routes using the information provided by Google Transit and to apply this framework to appraise and compare the network connectivity of Auckland, London, and Paris. Google Transit provides both spatial and network data that are sourced directly from transport agencies, thus making it an efficient tool for retrieving the data required to measure connectivity. This study contributes to previously-developed methodologies for determining connectivity by (a) including the qualitative measures, which are smoothness of transfer and information availability, along with the quantitative measures, and (b) using Google Transit as an alternative data source. The results showed that the overall public transport connectivity of the network in Paris is better than that in London and Auckland. Auckland's network had the most poor connectivity values. Findings suggest that Auckland's network would benefit from more integrated services.

Introduction and Research Objectives

The need for user-friendly public transport (PT) systems has become crucial, with private vehicles contributing significantly towards climate change (Black and Sato 2007; Uherek, Halenka et al. 2010). Kingham et al. (2001) revealed that travelers are aware of the negative impact that excessive private vehicle use has on the environment and are willing to use PT, if it is a viable alternative. In today's society, the share of so-called "captive" PT users is seen to be declining as more households own cars (Kuhnimhof, Chlond et al. 2006; Chapman 2007). As such, "non-captive" travelers' mode choice depends on the activities that will be undertaken and the location of those activities. This brings a major change in the types of users. Patronage needs to be gained from those who have a choice between PT and car (Kuhnimhof, Chlond et al. 2006). It is evident that to attract a large number of car users to switch to PT, the service quality offered has to be more market-competitive (Anable 2005). Globally, transport agencies have responded by implementing integrated multi-modal systems with effective interconnectivity as a strategy for attracting and retaining patronage (Ibrahim 2003; Matas 2004). As such, methods to assess interconnectivity are required to maintain and improve the function of the system.

Previous studies (Ceder, Le Net et al. 2009; Ceder and Teh 2010) have used surveys and transport agencies' commercial data to evaluate interconnectivity among PT routes. The present study provides an adapted methodology to evaluate connectivity using data provided by online journey planners such as Google Transit. The aim was to assess and compare connectivity of PT networks using Google Transit as an alternative data source. This work had three objectives: (i) construct a framework to determine interconnectivity among PT routes using the information provided by Google's online route planner, (ii) apply this framework to assess the overall connectivity of Auckland, London, and Paris, and (iii) conduct comparisons between the cities and provide recommendation for service improvement to PT planners and operators.

Literature Review

Service Accessibility and Connectivity

Service accessibility is a geographical factor determined by the percentage of network coverage (Beimborn, Greenwald et al. 2003). Clever (1997) stated that an integrated transport system allows PT users to board not a single line, but a whole system. With integrated services, operators also are able to minimize the resources required (Navarrete and Ortuzar 2013). Strategic location of transfer points can expand the destination choices for PT users and thus improving service accessibility (Luk and Olszewski 2003). Chowdhury and Ceder (2013) discussed the importance of integration in a PT network to improve connectivity of the network and user perception of transfers. The study proposed a definition-based framework to assist policymakers and planners in designing "seamless" transfers in an integrated network.

Service Reliability

Reliability is one of the most important operational attributes of PT services (Redman, Friman et al. 2013). Dorbritz et al. (2009) discussed the importance of punctuality in timed-transfer type systems; small delays in arriving to timed-transfer points can cause missed connection for users. Delays and missed connections were shown to be a main source of anxiety related to riding on routes involving transfers (Cheng 2010). A number of studies on timetable scheduling have been done to determine methods of improving reliability (Carey 1994). Muller and Furth (2009) examined how better planning can minimize the inconvenience to users who are making transfers. Results emphasized the importance of optimal offset in schedule planning to minimize transfer waiting times as well as to reduce missed connections.

Security and Information

The importance of personal safety at terminals has been echoed in several travel behavior studies (Atkins 1990; Volinski and Page 2006; Iseki and Taylor 2008). A study in the UK has shown that an additional 10.5 percent of rail trips would be generated if PT users' fears were addressed (Currie and Delbosc 2013). As such, personal security of users needs to be considered in the design, planning, operation, and management of the system (Atkins 1990). Kumar et al. (2011) discussed that security at terminals can be provided through the station environment such as good lighting, architectural design of the station for clear lines of sight, and other provisions such as closed circuit TV cameras (CCTV), security personnel, and emergency telephone booths. Security measures also need to be undertaken at pathways connecting terminals (Currie and Willis 1998).

Providing easily-accessible information to PT users is essential to ensure good service (Kenyon and Lyons 2003). Integration between various operators is required for an information system to facilitate urban and interurban multimodal trip planning (Zografos, Spitadakis et al. 2008). Grotenhuis et al. (2007) discussed that travel information is needed during all three stages of the journey—pre-trip, wayside, and on-board—to save time and effort for users.

Methodology

Connectivity Measures of a Network

For the present study, the connectivity measures selected for analysis were based on those determined by Ceder (2007). The measures are grouped into quantitative and qualitative attributes, as given in Table 1. The weighting attributes (α) of the measures, which reflect the relative importance, were adopted from Ceder et al. (2009). Treating these two categories separately allows greater precision in the weighting calibration. The notations and the equations adopted from Ceder (2007) are given below.

TABLE 1.
Connectivity Measures

Quantitative Attributes		
Notation	*Measure*	*Weighting Attributes (α)*
e_1	Average ride time	$\alpha_1 = 3.9$
e_2	Variance of ride time	$\alpha_2 = 4.6$
e_3	Average waiting time	$\alpha_3 = 4.0$
e_4	Variance of waiting time	$\alpha_4 = 4.9$
e_5	Average walking time	$\alpha_5 = 3.6$
Qualitative Attributes		
e_6	Smoothness of transfer	N/A
e_7	Availability of information	N/A

N/A = not applicable

O = = set of origins O_i

$D = \{D_u\}$ = set of destinations D_u

$P_{Dk} = \{P\}$ = set of inter-route and intermodal paths to D_k

$M_p = \{m\}$ = set of public transport routes and modes included in path p

t = index of quantitative attributes

l = index of qualitative attributes

e^j_{mp} = the value of attribute e^j, j= *t*, ℓ, related to mode m on path p

α_e = weight/coefficient for each attribute e^j, j= *t*

c_p^j = quantitative (j= t) connectivity measure of path p

C_{Dk}^j = sum of connectivity measures of inter-route and inter-modal paths to destination D

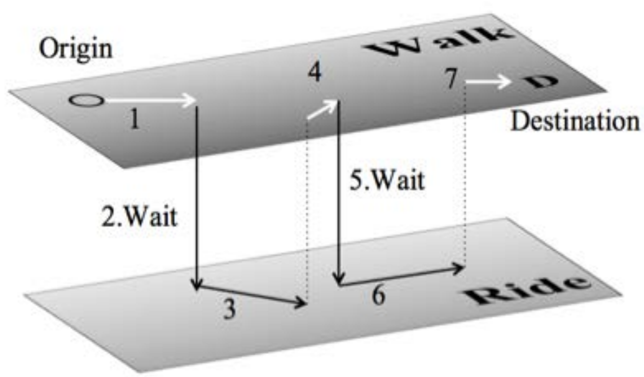
Based on the notations above, the following equations were established. It should be noted that a greater value suggests a poor connectivity with longer total ride, waiting, and walking times.

$$c_p^j = \sum_{m \in M_p} \sum_{e^j \in E_j} \alpha_e e_{mp}^j \,, j = t \quad (1)$$

$$C_{Dk}^j = \sum_{p \in P_{Dk}} c_p^j, j = t \quad (2)$$

The quantitative measures—ride times and transfer walking and waiting times—are dependent on the chosen path. A path is a combination of intermodal routes that connect an origin to a destination. A typical path is composed of a succession of riding, walking, and waiting times. An example of path with one connection is given in Figure 1. The diagram illustrates that path lines 3 and 6 represent riding time. Path lines 2 and 5 represent waiting time, and lines 1, 4, and 7 are the walking times. When an origin-destination (OD) pair and a path are selected, the distance to the first stop and the distance between the transit stops determine the walking times, considering an average speed of 4 kph. When the next stop is reached, the time until the arrival of the scheduled vehicle constitutes the waiting time. The initial waiting time was assumed to be a constant value. The required data for time-related trip attributes were distances between each node of the path and timetables.

FIGURE 1.
Decomposition of path with one connection



Qualitative measures were formulated based on findings from previous research. The smoothness of transfer measure (e_9) included ease of transfer walking times, presence of comfort provisions when making transfers, level of fare integration, and security at terminals. Guo and Wilson (2004) discussed that the penalty imposed for transfer walking time can be reduced by the presence of escalators, longer ramps, and same-level interchange. Fare system integration across operators facilitates the ease of making transfers by reducing the time and effort required for obtaining tickets for the second stage of the journey (Buehler 2011; Sharaby and Shiftan 2012).

As discussed previously, security at terminals has an effect on the attractiveness of routes involving transfers. A study by Currie and Willis (1998) showed that basic amenities such as the availability of seating and weather-protected shelters for transfer waiting times and weather-protected walkways for transfer walking times are important factors in user satisfaction and perceived connectivity. Measure e_9 is the combined value of the rating for each feature given in Table 2.

TABLE 2.
Smoothness of Transfer Measure's (e_9) Features

Category	Feature	Rating
Transfer walking	Escalators/stairs	1/0
	Same-level transfer	1/0
	No crossing	1/0
Comfort	Shelter – weather protection	1/0
	Seating, covered walkways	1/0
Fare payment method	Smart card	1/0
	Integrated ticket	1/0
Security	Personnel & CCTV	1/0
	Station design & neighborhood	1/0

Ceder (2007) defined the availability of information measure (e_{10}) as the effect of information provisions made available to the users on their perceived ease of making transfers. Measure e_{10} is the sum value of the rating for each feature given in Table 3.

TABLE 3.
Availability of Information Measure's (e_{10}) Features

Feature	Level of Integration	Rating
Integration	Full integration	1
	Partial integration	0.5
	No integration	0
Pre-Trip Information		
Journey Planner	Yes/No	1/0
At-Terminal and Platform Information		
Timetable and route map	Yes/No	1/0
Customer service	Yes/No	1/0
Real-time displays	Yes/No	1/0
Delay reporting	Yes/No	1/0
Signage	Yes/No	1/0
On-Board Information		
Route map	Yes/No	1/0
Announcements (e.g., next stop)	Yes/No	1/0
Extra Assistance		
Personalized en-route information to mobiles	Yes/No	1/0

For $i \in [9,10]$, let e_i to be the qualitative attribute. In a given OD pair, for the path j, the quality indicator (QI) was derived using Equation 3. It should be noted that a greater QI indicates a better service for connectivity of the network.

$$QI_{OD}^{j} = \sum_{i \epsilon [9;10]} e_i^{OD,j}, j = l \tag{3}$$

Normalization

To keep weights from being skewed by scale differences, it is necessary to normalize the attributes before calculating the connectivity indicators. For $i \in [1,6]$ in a given path, the normalized connectivity attribute is determined by Equation 4,

$$\|e_i\| = \frac{e_i}{\sum_{1 \leq j \leq n_p} e_i^j} \tag{4}$$

where $e_i > 0$ and n_p is the number of paths.

Data Collection

Data Sources

A transportation network analysis requires either a survey phase or the compliance of local transportation agencies, the latter being, in some cases, reluctant to release their commercial data for competitive or political reasons. In 2006, Google introduced a supplementary service to Google Maps, Google Transit. The addition of this service allows travelers to plan their trips with PT. Google's initiative to create an international network data format to be integrated into Google Transit is persuading agencies to release their data. This specification is known as the General Transit Feed Specification (GTFS). Transit authorities worldwide provide a full set of network data (routes, number of stops, trips, timetables) according to this specification. The GTFS file provided by transportation agencies consists of several text files (Google Transit 2012). Table 4 provides a detail of the contents in the text files.This specification enables PT providers to upload relevant information to the web and allows users to plan trips from any web browser. The data obtained from these text files were used for calculating the quantitative measures.

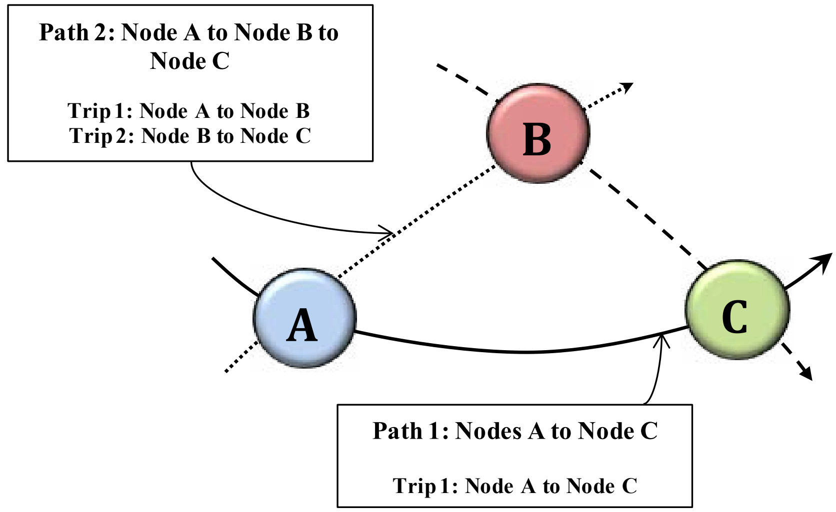
TABLE 4.
GTFS File Content from Google Transit (2012)

Data File	Description
Agency	Contains information about one or more transit agencies that provide the data in this feed.
Stops	Contains information about the individual locations where vehicles pick up or drop off passengers.
Routes	Contains information about a transit organization's routes. A route is a group of trips that is displayed to riders as a single service.
Trips	Lists all trips and their routes. A trip is a sequence of two or more stops that occurs at specific time.
Stop times	Lists the times that a vehicle arrives at and departs from individual stops for each trip.
Calendar	Defines dates for service IDs using a weekly schedule. Specifies when service starts and ends, as well as days of the week where service is available.
Calendar dates	Lists exceptions for the service IDs defined in the calendar.txt file. If calendar_dates.txt includes ALL dates of service, this file may be specified instead of calendar.txt.
Fare attributes	Defines fare information for a transit organization's route.
Fare rules	Defines the rules for applying fare information for a transit organization's routes.
Shapes	Defines the rules for drawing lines on a map to represent a transit organization's routes.
Frequencies	Defines the headway (time between trips) for routes with variable frequency of service.
Transfers	Defines the rules for making connections at transfer points between routes.

Data Collection

Google Transit combines spatial data such as terminal locations with non-spatial data such as routes and timetables. For this study, only the morning peak period (7–9 AM) commute was assessed for two reasons: to narrow the time window and to focus on the most demanding time period of a working day (Monday–Friday). Once the origin, destination, and departure time within the peak period was set, the journey planner considered all possible paths matching these requirements and displayed a maximum number of four shortest paths; that is, the shortest path and the 2nd, 3rd, and 4th shortest paths. The total travel time of the alternative displayed paths (2nd, 3rd, and 4th) were constrained to be no longer than 150 percent of the shortest path. To conduct a comprehensive collection of the relevant paths during the 2-hour time period window, departure times were changed at 2-minute intervals. The difference between path and trip is illustrated in Figure 2, which shows two paths connecting an OD pair. As shown, Path 1 has one trip and Path 2 has two trips.

FIGURE 2.
Illustrated difference between path and trip definition



Assumptions

For the quantitative measures, the average and variance values for each path were calculated by retrieving the ride time, waiting time, and walking time of all corresponding trips within the peak period. Each ride time and waiting time was obtained by the journey planner from the timetables provided by the transportation agencies. For this reason, the following assumptions were made:

(i) As the journey planner is timetable-based and does not include vehicle speeds, ride time was defined as the difference between access-stop departure and egress-stop arrival. It was assumed that the timetables were designed according to service performance in daily traffic conditions.

(ii) For a given path, walking time has been fixed by the chosen origin. The journey planner considers all stops within a 400-meter range from the origin. Since only the departure time changes at a two-minute interval within the peak period, the total walking time (sum of initial and transfer walking time) will remain constant for a given path. Therefore, the calculation of variance was not required, and the average walking time for a path is a constant value.

(iii) A default waiting time of one minute was assumed for the first vehicle access. It was assumed that the vehicles arrived as scheduled. The variance of the waiting time was estimated as half of the scheduled average headway (Ceder, Le Net et al. 2009).

Regarding the qualitative measures, the features specified in Table 2 and 3 were dependent on either the PT agency or the network. The following assumptions were made:

(i) The level of fare integration and information integration was assumed to be consistent for all paths considered in the network of each city.

(ii) Information provisions at stops (except for real-time displays) and on-board were assumed to be consistent for all paths operated by a particular brand of PT service.

(iii) Features facilitating the transfer walking times and real-time displays were assumed to be specific to the station/stop, and their existence was determined using Google Street View for each path. It was assumed that all stations provide escalators or stairs.

(iv) Due to the difficulty in determining PT user perception of security for each path, it was assumed that users perceived all the paths in all three cities to be safe.

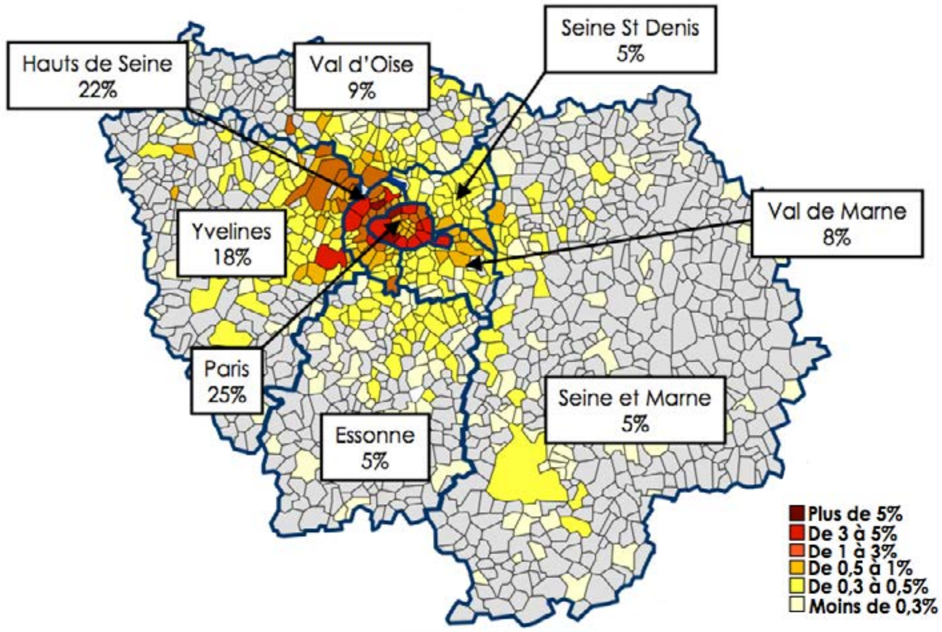
Case Study

The methodology developed in this study enables comparison of connectivity among different networks with relative ease. Auckland, London, and Paris were chosen for the case study. Auckland's PT network consists of three modes: bus, ferry, and rail. More than 60 million trips have been estimated to be made annually with Auckland's PT network. Britomart is the central interchange that provides links between all rail lines (Eastern, Southern, Western and Onehunga), the central ferry terminal (Devonport), and buses servicing central Auckland suburbs. London's PT network is composed of heavy rail (London Underground), light rapid transit, tram, ferry, and bus. Bank Tube station is a key interchange of London Underground and serves the city center. Paris's PT network is supported by heavy rail (Metro), express heavy rail for linking the city center to the outer suburbs (RER), and bus. Buses operate to complete the service coverage of the region.

To evaluate the connectivity of the PT networks during the morning peak period, the main business district of each city was selected as the destination. In Auckland, the city center and the main employment area are located in the vicinity of the main transport center Britomart. In London, the largest business district is situated in the center of London around Bank Tube station. In France, the main business district of La Défense is not located in the city center of Paris but in the suburb of Courbevoie. This particularity causes relocation of the morning peak period traffic away from the city center of Paris.

The 17 most-dense residential areas in London were selected as the origins (Office for National Statistics 2011). For Paris, the origins selected are the residential suburbs from which commute for work to La Défense occurs the most (≥ 5%), as shown in Figure 3. The three residential suburbs of Seine St Denis, Val de Marne, and Hauts de Seine were selected from the suburbs of Petite Couronne (TEMIS 2006; Bureau and Glachant 2011). Similar to the study by Hadas and Ranjitkar (2012), the origins selected for Auckland's network are the main residential suburbs in North Shore and central Auckland.

FIGURE 3.
La Défense (Paris) worker residential suburbs (adapted from TEMIS, 2006)



This approach of selecting only the dense areas for the origins and the main, typical area for the destination has been used in other studies that also analysed the connectivity of PT networks. For example, Hadas and Ranjitkar (2012) considered Auckland and North Shore, the two densest areas in the Auckland region, for attaining OD pairs and their respective paths. Ceder and Teh (2010) compared the PT network connectivity between Auckland, Wellington, and Christchurch, the three major cities in New Zealand. The network nodes selected for the origins and destinations were the key points, which were determined by frequency of use. Connectivity measures are used to assess how well the routes in a PT network are connected, i.e., how easy it is to make transfers; such routes are predominantly part of high frequency lines that serve dense areas.

Results and Discussion

Quantitative Measures Comparison

Figure 4 provides the comparison between the three cities for average and variance of ride time per path. Variance of ride time indicates the consistency of the in-vehicle times. The diagram shows that the average ride time per path in the Auckland and London networks is equal, whereas the average ride time in the Paris network is lower by 12 minutes. It should be noted that the origins selected for Paris are much fewer compared to the origins selected for Auckland and London. The variance of ride time per path in Auckland is the highest among the three cities. This finding suggested that PT users in Auckland are more likely to experience inconsistency in ride time than users in London and Paris. The variance of ride time in Paris is considerably lower than that of the other two cities, which leads to the understanding that users of the Paris PT network experience high reliability in their ride times. A possible explanation for this result is that the paths considered in Paris involved the highest percentage of rail, for which ride times are less affected by traffic conditions. Auckland's PT network, in comparison, is greatly dependent on bus services, of which a small percentage is bus rapid transit (Ceder, Le Net et al. 2009). The ride times of surface transit can be adversely affected by traffic conditions if right-of-way provisions are not present (Kunihiro, Chandana et al. 2007).

FIGURE 4.
Ride time per path

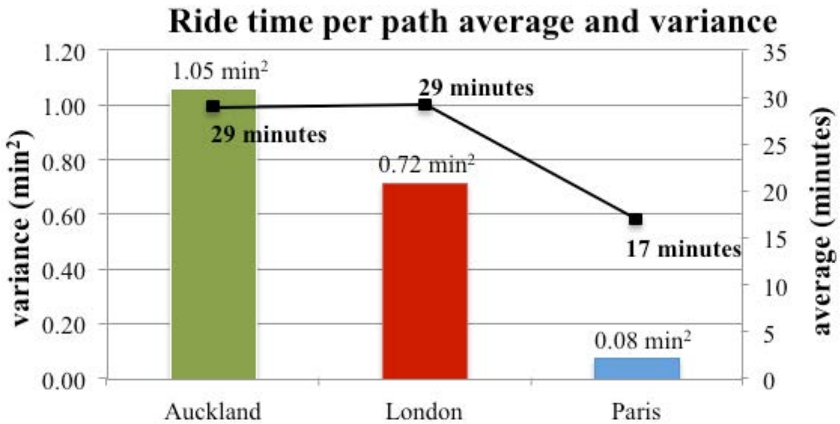


Figure 5 shows that the paths considered in the Auckland and London networks consist of, on average, six minutes waiting time at stations and stops. For users of the Paris network, the average waiting time is approximately half in comparison. One possible reason for this result is that the high level of integration among PT operators in Paris allows synchronized transfers to be provided to users and thus minimized their waiting time (Syndicat des Transports d'Ile-de-France 2003). The diagram also indicates that the variance of waiting time is higher in the Auckland and London networks than in the Paris network. A higher variance of waiting time suggests that users are less likely to experience consistency in their waiting time. Results indicate that PT users in Paris are very likely to experience a consistent waiting time for their regular trips. This finding is, again, due to Paris's well-integrated PT system, which focuses on providing users with high-quality services (Syndicat des Transports d'Ile-de-France 2003, Bureau and Glachant 2011).

FIGURE 5.
Waiting time per path

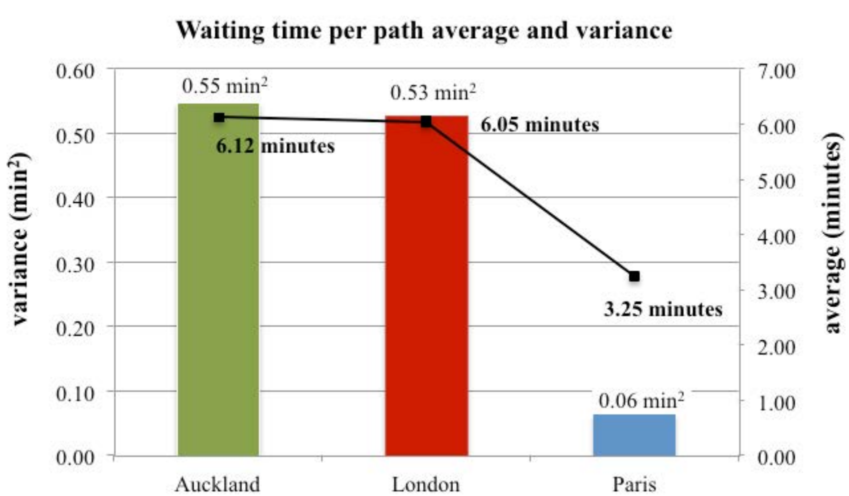


Table 5 shows that PT users are less likely to walk for a longer period in Auckland and most likely to walk longer in Paris. A greater distance between the origin and the first access-stop usually causes longer walking times. This is one possible explanation for users in London experiencing longer walking times than those in Auckland; some of the suburban origins are not near the first access-stations/stops. However, this is not the case for users in Paris (Mogridge 1986). Service coverage is considered to be good around the selected origins in Paris, but the subway stations are known to be extremely complicated in terms of way-finding. Many of them offer a connection with several other lines, and some connections require a long transfer walking time to be made by the users.

TABLE 5.
Average Walking Time per Path and Single-Path Indicator.

	Average Walking Time per Path	Average Single-Path Indicator
Auckland	6.58 minutes	3.68
London	9.92 minutes	3.67
Paris	12.86 minutes	3.63

The single-path time indicator takes all the quantitative measures into account. Table 5 shows the average single-path time indicator for each city; the values are very similar. Paris's network was seen to have the lowest average single-path time indicator. As the weighting attribute (α_5 = 3.6) for walking time is the lowest of all five attributes, Paris's network having a longer average walking time per path did not have a significant adverse effect on the overall connectivity. Although London's network is seen to have a better overall path connectivity compared to Auckland's, the difference between the two cities is small compared to the one between the London and Paris networks. Except for the walking time connectivity measure, Auckland PT's network was seen to perform poorly in the other measures, and this is reflected in Auckland's average single-path time indicator being the highest of the three cities. This finding has revealed Paris's network to have the best connectivity among the three cities, based on the quantitative measures.

Qualitative Measures Comparison

For qualitative measures, the interpretation of the values is that the higher the value, the better the quality of services. Table 6 suggests that the transfers undertaken in the Auckland network are "less smooth" compared to those made in the London and Paris networks. A possible reason for this is the reliance of the Auckland network on surface transit. Auckland PT users are more likely to be exposed to weather conditions, which could create discomfort. The city's hilly topography also assists in reducing the ease of making transfers. Paris and London have a greater proportion of underground railway systems in their network, which means that users of the London and Paris networks are able to benefit more than Auckland PT users from provisions such as shelters and escalators/stairs when making transfers. The fare system in Paris is fully-integrated, allowing users to use a single ticket for a trip on all PT modes (Syndicat des Transports d'Ile-de-France 2003). Transport for London's initiative for fare system integration produced the "Oyster" smartcard, which can be used on all PT modes (Graham 2013). Only particular lines in Auckland are integrated; users, depending on the path, need to buy separate tickets for a route involving transfers (Chowdhury and Ceder 2013).

TABLE 6.
Qualitative Measures of Connectivity

	Average Smoothness of Transfer (rating out of 5)	Average Availability of Information (rating out of 9)
Auckland	2.95	6.33
London	3.42	8.20
Paris	4.64	8.18

Table 6 shows that Auckland's network has the lowest average availability of information connectivity value, and the value for London and Paris is the same. Despite Auckland Transport's recent efforts to develop an integrated PT system, Auckland's network suffers from a number of companies operating individually. The lack of information integration in all three stages of a trip requiring a transfer creates confusion for the users (Chowdhury and Ceder 2013). A majority of the bus stops with shelters are equipped with route maps and timetables and a smaller proportion with real-time displays. Provisions such as direct customer service and announcements on vehicle arrival delays are available only at key interchanges. Transport agencies in London provide users with websites that offer an integrated source of passenger information for trip planning. PT users are also able to attain real-time information regarding vehicle arrivals on their mobile devices. London Buses' "Countdown" system is one of the world's largest real-time passenger information systems, with more than 2000 stops equipped with real-time displays (Caulfield and O'Mahony 2007). Route maps can be obtained easily from the Transport for London's website (Transport for London 2013). Similarly, in Paris, users are provided with websites that offer multi]modal information that is fully integrated (Syndicat des Transports d'Ile-de-France 2003). Metro lines have detailed network maps and show the connections of these lines with other parts of the network in-vehicle. Stations have clear way-finding signage, route maps, and real-time displays (Parisinfo 2013).

Overall, the comparison has shown that Paris's network has the best connectivity among the three cities. This finding suggests that Paris's PT users are able to make intermodal and intramodal transfers with ease. A possible explanation for this outcome is that transport agencies in Paris—Société des Transports Intercommunaux de Bruxelles (STIB) and the Régie Autonome des Transports Parisiens (RATP)—have developed a framework that successfully maintains customer-focused PT systems. The service quality certification is undertaken on a line-by-line basis (Liekendael, Furth et al. 2006). The high level of integration among the operators also contributes towards the services being of good quality. The surprising result was the average walking time per path in Paris was the highest of the three cities.

Conclusion

The aim of this study was to assess and compare connectivity of PT networks in different cities using Google Transit as an alternative data source. Google Transit provides both spatial and network data that are sourced directly from transport agencies. Such features of the journey planner allow it to be an efficient tool for retrieving the data required to measure connectivity. A case study was undertaken in Auckland, London, and Paris. Analysis focused on the morning peak period (7–9 AM) and, therefor,e one destination, the main business district, was chosen with several origins. This study contributes to previously-developed methodologies for determining connectivity by including qualitative measures, which are smoothness of transfer and information availability, along with quantitative measures. Quantitative measures consist of ride, waiting, and walking time.

The results have shown that the overall connectivity of the Paris network is better than the London and Auckland networks. The measures that contributed significantly towards the comparatively better overall connectivity were small variances in ride and waiting time and low average waiting time. A possible reason for this outcome is the high level of integration among PT operators in Paris. Of the three cities, Auckland had the poorest connectivity values. The measure that contributed most towards this result is the variance of ride time. London's network performed well for the measures of average walking time, variance of ride time, and information availability. Findings suggest that Auckland's network would benefit from more integrated services. PT operators are encouraged to improve their service quality, particularly the reliability of journey times. Some of the connectivity measures for London's network were similar to Auckland's, despite having more sophisticated PT systems, which suggests that transport agencies in London need to focus on methods for improving the interconnectivity among routes to provide users with more "seamless" transfers.

In summary, the methodology developed in this study can be adopted by any urbanized city to analyze the connectivity of its PT network. This can be used as a tool by PT planners to perform analysis of their current service and to compare their service with those of other cities. Future research can comprise case studies and improvements in the methodology developed. The selection of the OD pairs can be automated using Google's API to allow quicker comparisons and to perform sensitivity analysis. Detailed information on the inventory in the stations chosen can improve the qualitative analysis developed. Survey data also can assist in eliminating some of the assumptions made, such as the initial waiting time, reliability of timetables, and perception of security.

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