Leveraging GTFS data to assess transit supply

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Abstract

This is the abstract.

It consists of two paragraphs.

Keywords: keyword1, keyword2

1. Introduction

"If you can't measure it, you can't manage it" is often miss-attributed to Deming (1993), who was trying to make the opposite point (**?**). Regardless, service level indicators are important in researching, managing and seeking to improve transit operations (Fielding, 1987; Ryus et al., 2003). Many indicators already exist including, for example: those in the Transit Capacity and Quality of Service Manual (TCQSM)(Kittleson & Associates et al., 2013) and the Transit Score metric (Walk Score, 2023).

However, practitioners, researchers and advocates using such metrics may face two inter-related challenges: (1) calculating the metrics themselves for a specific location and service pattern; and (2) explaining the metrics, their meaning and importance to those who are not specialists in transit For example: the TCQSM metrics might be difficult to calculate without specialist software and data, but, they use an A to F scoring system and there is an entire guidebook explaining each;

in contrast, entering an address into the Transit Score website will return a score out of 100 reflecting the quantity of transit available, but the methodolgy and algorithm is not publicly available, so these cannot be calculated independently.

Previous research by Currie and Senbergs (2007) developed a transit Supply Index (SI) that appears to be both relatively easy to calculate and explain to non-transport professionals. It is obtained by calculating the number of transit arrivals at each stop within an area of interest, with an adjustment made to account for the typical walking distance catchment of transit stops and stations. Higher SI scores indicate areas with higher frequency services and/or better coverage.

Unfortunately, the SI does not appear to have been widely used, perhaps in part because at the time it was first published timetable data was not publicly available in a standardized and machine-readable format. The scores reported in Currie and Senbergs (2007) were calculated directly from a database of services provided by the transit authority in Melbourne, Australia. Since then, however, the General Transit Feed Specification (GTFS) has developed as a way to publish timetable data in a standardized format.

More than 10,000 agencies are now providing GTFS feeds[4] (MobilityData, undated), and many visualization,

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[4]There are two forms: GTFS-static consisting of the timetable data (the scheduled services); and GTFS-realtime, which includes vehicle arrivals and departure times based on real-world position data. This paper and project uses only the GTFS-static (timetable) format.

processing and analysis tools are now available.

A gap, however, is that there is not yet a tool to calculate SI scores directly from GTFS datasets. This provides the motivation for the research reported in this paper, in which a new R package (gtfssupplyindex) specifically developed to calculate SI scores is presented. The remainder of this paper is structured as follows: the next seciton outlines the background to this research, including the original formulation of the Transit Supply Index, and an explanation of the GTFS. Section 3 then describes the study methodology, followed by a brief presentation of results in Section 4. Section 5 discusses the results, outlines directions for future research and provides a conclusion.

2. Background

2.1. Transit metrics

Even a brief search reveals many metrics available for benchmarking transit services. Examples include: (1) those in the Transit Cooperative Research Program (TCRP) Report 88, which is an extensive guidebook on developing a performance-measurement system (Ryus et al., 2003); (2) online databases provided by the Florida Transit Information System (FTIS) (Florida Transit Information System, 2018) and International Association of Public Transport (UITP) (2015); (3) those used in the extensive annual benchmarking program undertaken yearly by the Transport Strategy Centre, which includes over 100 transit providers around the world (Imperial College London, undated); and (4) a recently developed methodology to calculate 'blank spots' within an area, being those places beyond 400/800 metre walking distances to/from bus and tram stops/train stations (Alamri et al., 2023).

The Fielding Triangle (Fielding, 1987) provides a framework for understanding how such metrics combine service inputs, outputs and consumption.
to describe cost efficiency and effectiveness; and service effectiveness. At a larger scale, Litman (2003) and Litman (2016) discuss some of the traffic, mobility, accessibility, social equity, strategic planning and other rational decision-making-based perspectives underling such transit metrics, while Reynolds et al. (2017) extends these into models of how institutionalism, incrementalism and other public policy analysis concepts might apply to decision-making processes. Further examples include: (1) Guzman et al. (2017), who develop a measure of accessibility in the context of policy development and social equity for Latin American Bus Rapid Transit (BRT) networks; and (2) the street space allocation metrics based around 10 ethical principles introduced by Creutzig et al. (2020).

However, many of these metrics appear difficult to calculate, complex to explain or understand, and likely not well suited to communication with those who are not transit planners or engineers, or other technical specialists. Where pre-calculated metrics are immediately available it may not be possible for practitioners, researchers or advocates to independently generate metrics for proposed system changes. Sometimes it is not even possible to know precisely how scores for the existing services levels are calculated.

For example, Transit Scores for locations with a published GTFS feed are readily available on the Walk Score (2023) website, eliminating the need for any calculations. The meaning of these Transit Scores appears easy to explain, as the highest possible score of 100 represents what might be experienced in the centre of New York. However, the Transit Score algorithm is patented and effectively a black box. It is not possible to calculate Transit Scores scores independently. Nor can Transit Scores to be generated for proposed changes to networks. The Transit Score metric, therefore, fails the first of the aforementioned challenges, as practitioners, researchers and advocates can only use those scores provided online. The metric is simple to explain: the closer to 100, the better; but, because it is based on a patented algorithm it may not be easy to understand or explain the connection between real-world conditions and the Transit Score, or what might need to be done to improve the score (and service levels). As such, it might partially pass the second of the aforementioned challenges, as it is simple to understand, yet may not withstand scrutiny.

In contrast, the TCQSM, specifies Levels of Service (LOS) between A and F across a range of factors[5].

[5]Including service span, frequency, speed, the proportion of the population serviced, competitiveness of travel times to car-based travel, and many more.

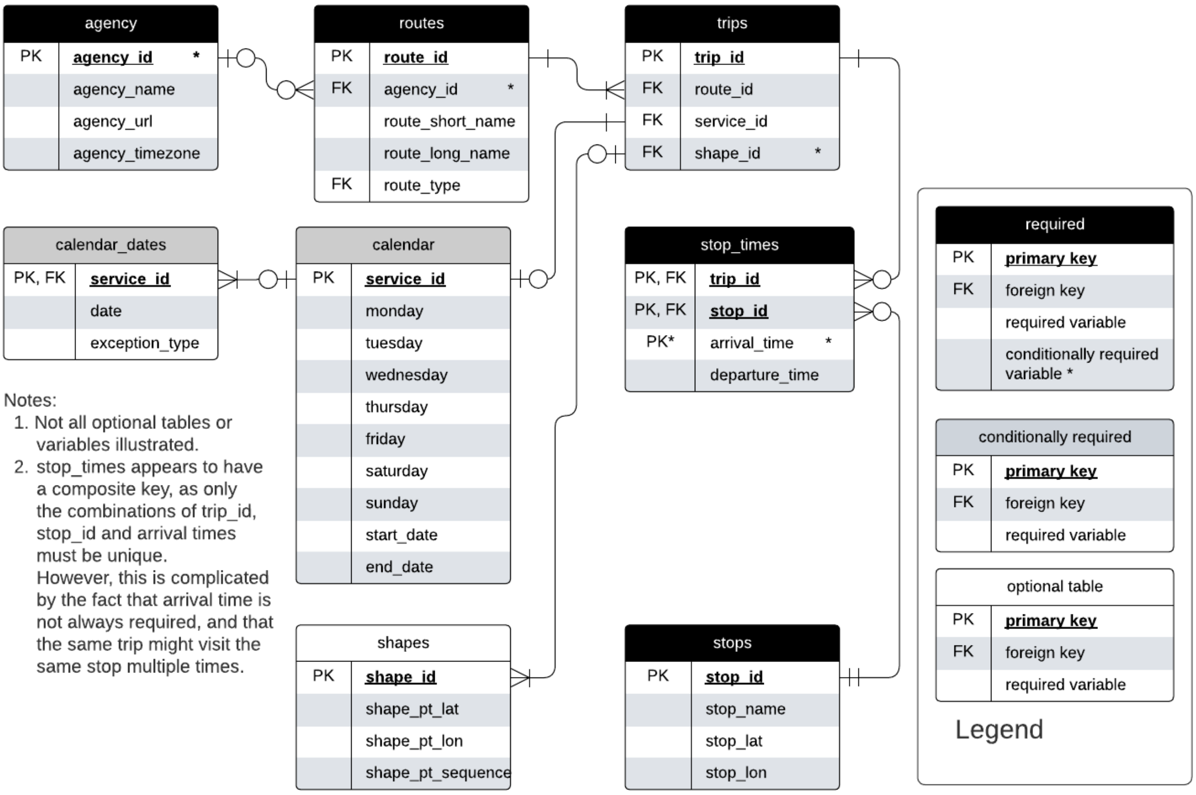

Figure 1: GTFS entity relationship diagram. Source: adapted by author from Alamri et al (2023) and the GTFS Schedule Reference (16/11/2023 revision).

This scoring scheme appears relatively simple to explain[6] and matches that often used in traffic capacity analysis. Detail within Kittleson & Associates et al. (2013) provides a resource for anyone wanting to better understand what the scores mean. However, calculation of many of TCQSM metrics may need specialised software and datasets[7] and it might be challenging to explain the detail of these measures or how to improve them to non-technical decision-makers, stakeholders or others involved in transit management or advocacy.

2.2. GTFS

The introduction of the General Transit Feed Specification (GTFS) and widespread release of schedule data in this format, however, has helped towards making transit metrics more broadly available and usable. GTFS is an open, text-based format that was developed originally to allow transit information to be included in the Google Maps navigation platform (MobilityData, undated).

Figure @ref(fig:GTFS_ERD) shows an Entity Relationship Diargram (ERD) of the GTFS data structure. Each box represents a database table in the GTFS, with table rows indicating the variables (columns) included in each[8]. Relationships between the tables are indicated by the connecting lines, and Primary Key

[6] A is good and F is bad.

[7] For example, the Service Coverage Area metric in the TCQSM (pp. 5-8 to 5-21) may require GIS or other analysis, on top of accurate data about population densities, stop locations and service schedules.

[8] For example, each record in the 'stops' table includes a value for stop_id, stop_name, stop_lat and stop_lon.

(PK) and Foreign Key (FK) designations[9]. ‘Crow’s feet’ indicate the relationships between each table[10].

GTFS now provides a mechanism for including individual transit systems in many online products and analysis, including the Transit Score metric itself. Wong (2013) provides another example of what can be done with GTFS data, having developed code to calculate of some of the TCQSM metrics[11] for 50 transit operators. While the Wong (2013) open-source code is readily available[12] this is now 11 years old and does not appear to be currently maintained. Future research may involve reviewing this code and using it to analyse modern GTFS feeds. However, in this paper the aim is more modest, being to use GTFS data to calculate Currie and Senbergs’ (2007) SI.

2.3. The Transit Suppy Index

A generalized form of the Transit Supply Index (SI) is shown in Equation 1[13].

$$SI_{area,time} = \sum \frac{Area_{Bn}}{Area_{area}} * SL_{n,time}$$

In Equation 1:

(1) $SI_{area,time}$ is the Supply Index for the area of interest and a given period of time;
(2) $Area_{Bn}$ is the buffer area for each stop (n) within the area of interest. In Currie and Senbergs (2007) this was based on a radius of 400 metres for bus and tram stops, and 800 metres for railway stations;
(3) $Area_{area}$ is the area of the area of interest; and
(4) $SL_{n,time}$ is the number of transit arrivals for each stop for a given time period.

An advantage of the SI is that it is a relatively simple number to calculate, understand and explain. It describes the number of transit arrivals at stops within an area of interest and time frame, multiplied by a factor accounting for the proportion of the area of interest within typical walking distances of each stop. Hence, more services, more stops and higher frequencies increase the score. However, the SI does not incorporate service span, speed or other elements of a transit service. While these may be important to passenger experience, they might add considerable complexity.

Simplicity is also helped by the way that the SI is additive, in that $SI_{area,time}$ scores can be aggregated to calculate an overall score across multiple time periods or for a region encompassing multiple areas of interest.

3. Methodology

This study developed a package with tools for calculating the SI from GTFS data. R (R Core Team, 2023), a widely used and readily available statistical programming language, was adopted for code development. The package development setup and workflow described by Wickham and Bryan (2023) was adopted in this study. Various existing packages were relied upon including: the sf package (Pebesma, 2023) for geospatial analysis; the tidyverse (Wickham et al., 2019); gtfstools (Herszenhut et al., 2022); and tidytransit (Poletti et al., 2023). Some code was adapted from examples, vignettes and other documentation in the tidytransit, gtfstools and other packages.

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[9] For example, stop_id appears in the ‘stops’ and ‘stop_times’ tables as a Primary Key and Foreign Key.

[10] See https://i.stack.imgur.com/fxaAq.png for guide to the symbols. But, for example, the stops table is required, with the stop_id field providing a unique (primary) key for every stop. Within the stop_times table (which is also required) the stop_id field is a foreign key. Each unique stop_id can appear many times in the stop_times table, but can appear only once in the stops table. In the stop_times table each combination of trip_id, stop_id and arrival time must be unique (although see note 2!) meaning that these fields together represent a composite key.

[11] Daily average headways, route length and stop numbers.

[12] https://github.com/jcwong86/GTFS_Explore_Tool

[13] Currie and Senbergs’ (2007) focus was the context of Melbourne’s Census Collection Districts (CCD) and calculations based on a week of transit service. CCDs predate the introduction of Statistical Areas 1, 2, 3, and 4 (SA1, SA2, SA3, SA4), and other geographical divisions currently used by the Australian Bureau of Statistics (ABS), which may be more familiar to readers from down under.

Two cases where used during the code development and testing such that results might be generated for real GTFS data.
These cases were the Mornington Peninsula Tourist Railway GTFS feed and the Public Transport Victoria (PTV) GTFS feed, both in Victoria, Australia. Both were selected primarily for convenience, given that the authors are familiar with the typical service patterns and geography. Further cases were selected as leading, representative and contrasting examples for the results reported here.

3.1. Mornington Penninsula Tourist Railway

The Morning Peninsula Tourist Railway is located in the outer south-eastern suburbs of Greater Melbourne. It runs on Sundays and Wednesdays between Mornington (southwestern-most station) and Moorooduc, with an intermediate stop at Tanti Park[14]. A GTFS feed from 2018 was selected for the purposes of tests and demonstrating the code and output. Australian Bureau of Statistics (ABS) data was also used, primarily through the strayr and absmapsdata packages (Mackey et al., 2023). The Mornington Peninsular Statistical Area 3 (SA3) zone and the Statistical Area 1 (SA1) zones contained within it were adopted as the areas of interest. These are shown in Figure @ref(fig:mornington_map_ABS), together with the locations of the three railway stations.

3.2. Public Transport Victoria (PTV)

Larger scale testing was performed using the Victorian GTFS feed, published by Public Transport Victoria (PTV), sourced via Transit Mobility Data, (2023) for historical feeds. Again, ABS data was used for the areas of interest.

3.3. Extensions??

Hourly "Manhattan- and London-ised Indexes"

Tidytransit includes a sample GTFS feed from New York's MTA (including the subway!), and so this was used for code tests were appropriate.

4. Results

4.1. Code structure and output

Developed code is available and documented on github (Reynolds, 2024). The structure of the package and the functions developed to generate each table are shown in Figure @ref(fig:SI_ERD). This indicates how the package takes input from three files: a gtfs feed (gtfs.zip); a sf object describing the geometry of the areas for which the SI is to be calculated; and a csv file defining the buffer zone distances (in metres) for each route type[15].

The ultimate output is a si_by_area_and_hour table (Figure @ref(fig:SI_ERD), bottom right), which reports the SI score for each hour of the day across dates specified by the user. The various functions and their output and explained in the following, using the Mornington Peninsula GTFS as an example.

4.2. Step-by-step: Mornington Peninsula

This section presents outputs of the various functions for December 30th, 2018, using the Mornington Penninsula Tourist Railway GTFS feed and SA1 zone boundaries. The individual steps involved in using the gtfssupplyindex package are:

(1) loading the gtfs.zip file - the gtfs_by_route_type function loads the gtfs data and splits it into a list (by route_type) of tidygtfs objects, using the filter_by_route_type function from the gtfstools package (Herszenhut et al., undated).

[14] https://transitfeeds.com/p/mornington-railway/806/latest/stops
[15] This file is included in the package.

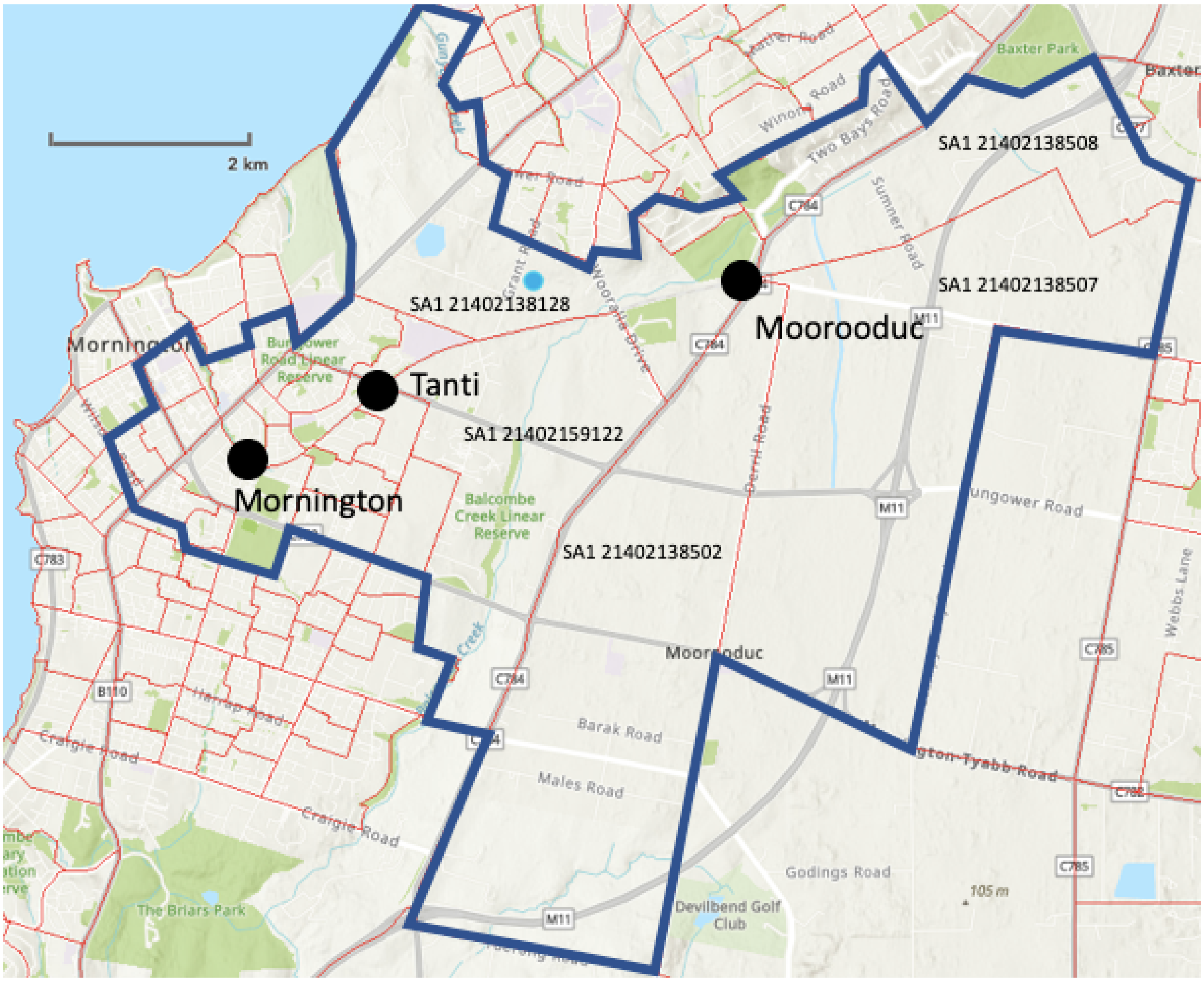


Figure 2: SA1 zones and location of Mornington Tourist Railway Stations.

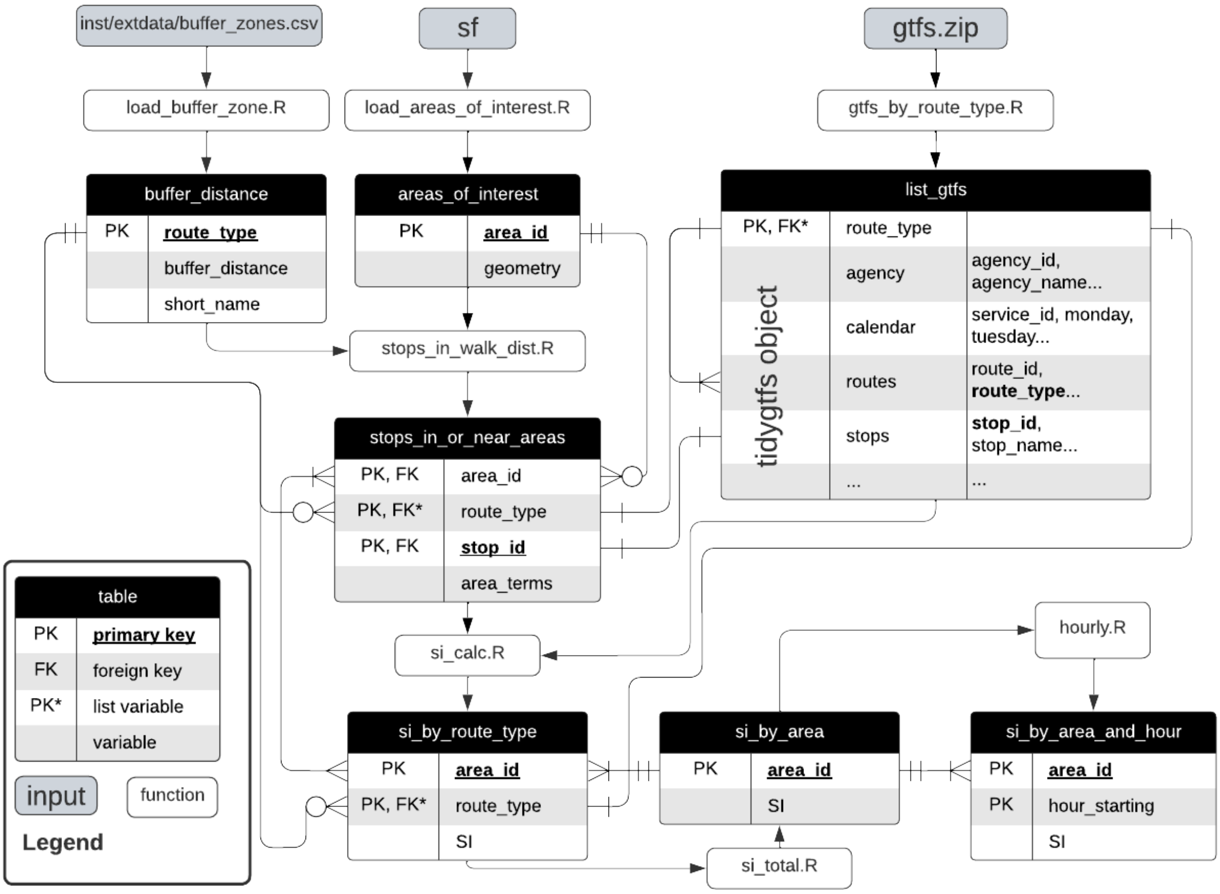


Figure 3: Entity Relationship Diagram (ERD) showing the data structure and functions related to the gtfssupplyindex package

Table 1: 'Rail' element of the stops in or near areas list for the Mornington Pennisula datasets, first six entries

stop_id	area_id	area_terms
1388695887	21402159101	0.7999912
1388695887	21402159102	0.0168220
1388695887	21402159105	0.6779951
1388695887	21402159107	0.6453927
1388695887	21402159111	0.2011127
1388695887	21402159113	0.1081424

(2) loading geometry information about the areas of interest - geographical data about the areas of interest are loaded by the load_areas_of_interest.R function into an sf object, using the sf package (Pebesma, 2023) . The resultant areas_of_interest table contains each area_id and its associated geometry. Data about buffer zones, specifically the walking distance threshold assigned to each route_type (mode) is then loaded, again through a function (load_buffer_zone.R). The package includes this information in a csv file, in which the buffer zone is defined in metres.

(3) calculating which stops are within the catchment walking distance of which areas, which is achieved using the stops_in_walk_dist function. However, this is complicated by the need to have different buffer distances for each route_type, and to only include those parts of the walking catchment that are within each area of interest. The calculation involves: (1) looking up the buffer_distance_length specific to each route_type; (2) transforming from latitude and longitude into metres and determining the area; (3) drawing circles around each stop, with the radius equal to the buffer distance, and intersecting these with the areas_of_interest (see Figure @ref(fig:calculate_stop_in_or_near_areas_verbose)); (4) calculating the $area_{Bn}$ terms are for each combination of stop_id and area_id; and then reporting the overall area terms for each area_of_interest ($Area_{Bn}/Area_{Area}$), as shown in Table **??**(tab:calculate_stop_in_or_near_areas).

```
stops_in_or_near_areas <- gtfssupplyindex:::stops_in_walk_dist(
  list_gtfs = list_gtfs,
  areas_of_interest = areas_of_interest,
  EPSG_for_transform = 28355,
  verbose = TRUE
)
```

(4) Calculating SI scores for a given time period, using the si_calc.R function. This adapts code from an article included in the tidytransit package (Poletti, undated) to calculate the number of arrivals in a given time period, and then combines this with the area terms to calculate the SI score. The si_total.R function aggregates the SI scores across all modes, although the Mornington Penninsula example presented here only includes rail services. Hourly values can likewise be generated using the hourly.R function which runs , giving the results shown in Table @ref(tab:SI_mornington_20181230_output)and mapped in Figure @ref(fig:SI_mornington_20181230_output).

The ultimate output, showing the SI scores for each hour, isshown in Table @ref(tab:SI_mornington_20181230_output) and mapped in Figure @ref(fig:SI_mornington_20181230_output).

The results meet expectations, with higher scores for SA1 zones closer to the three stations. Hand calculation for SA1 21402159136, which is close to the Mornington Station, to confirm the results is relatively trivial. By inspection, all of SA1 21402159136 (shown in purple in Figure @ref(fig:calculate_stop_in_or_near_areas_verbose) is within an 800 metre walking distance of Mornington Station, meaning that $Area_{Bn}/Area_{area} = 1$. The SI scores for each hour are therefore equal to the number of arrivals in each hour. Table @ref(tab:mornington_hand_check)

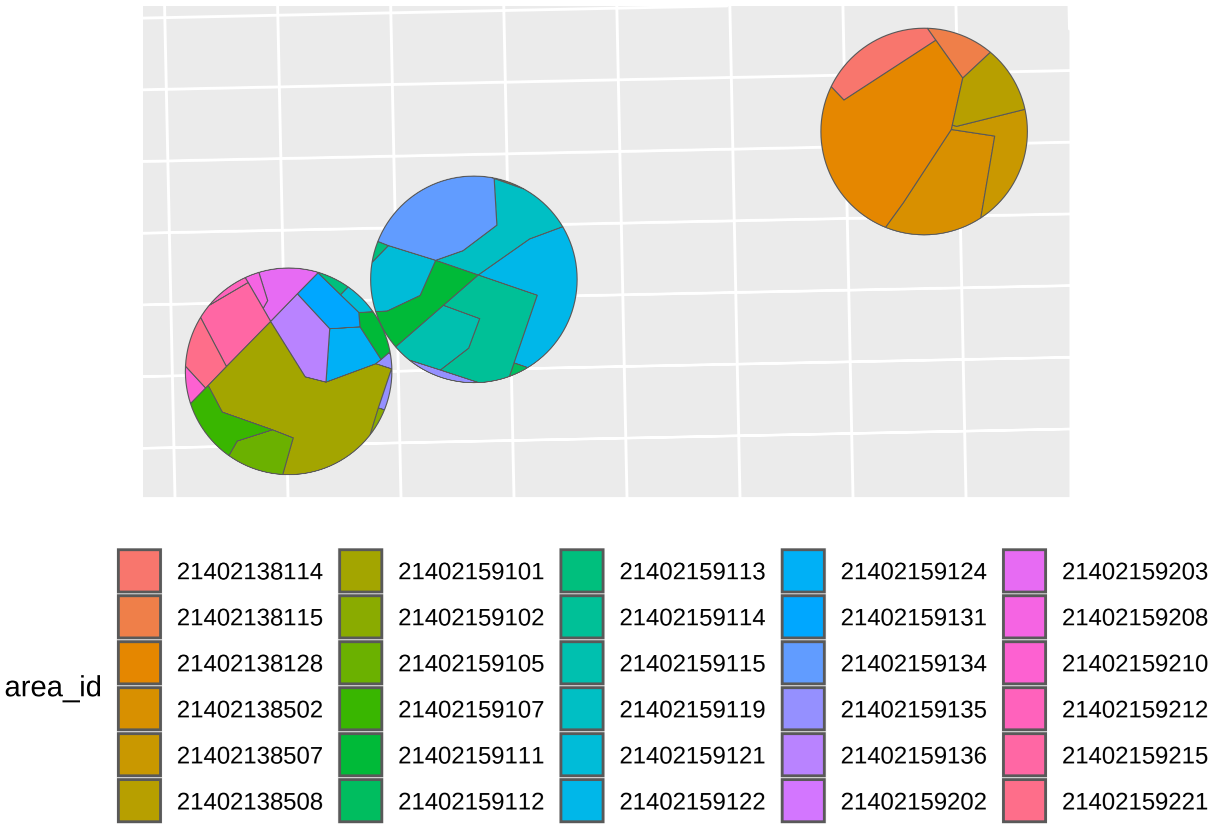


Figure 4: Step 3, part 4, stop catchments for the Mornington Penninsula Tourist Railway, showing intersections with SA1 zones

Table 2: Mornington Penninsula Tourist Railway hourly SI values for December 30, 2018, for first 6 SA1 zones

area_id	10:00	11:00	12:00	13:00	14:00	15:00
21402138114	0	0.5	0.5	0	0.5	0.5
21402138115	0	0.1	0.1	0	0.1	0.1
21402138128	0	0.2	0.2	0	0.2	0.2
21402138502	0	0.0	0.0	0	0.0	0.0
21402138507	0	0.0	0.0	0	0.0	0.0
21402138508	0	0.0	0.0	0	0.0	0.0

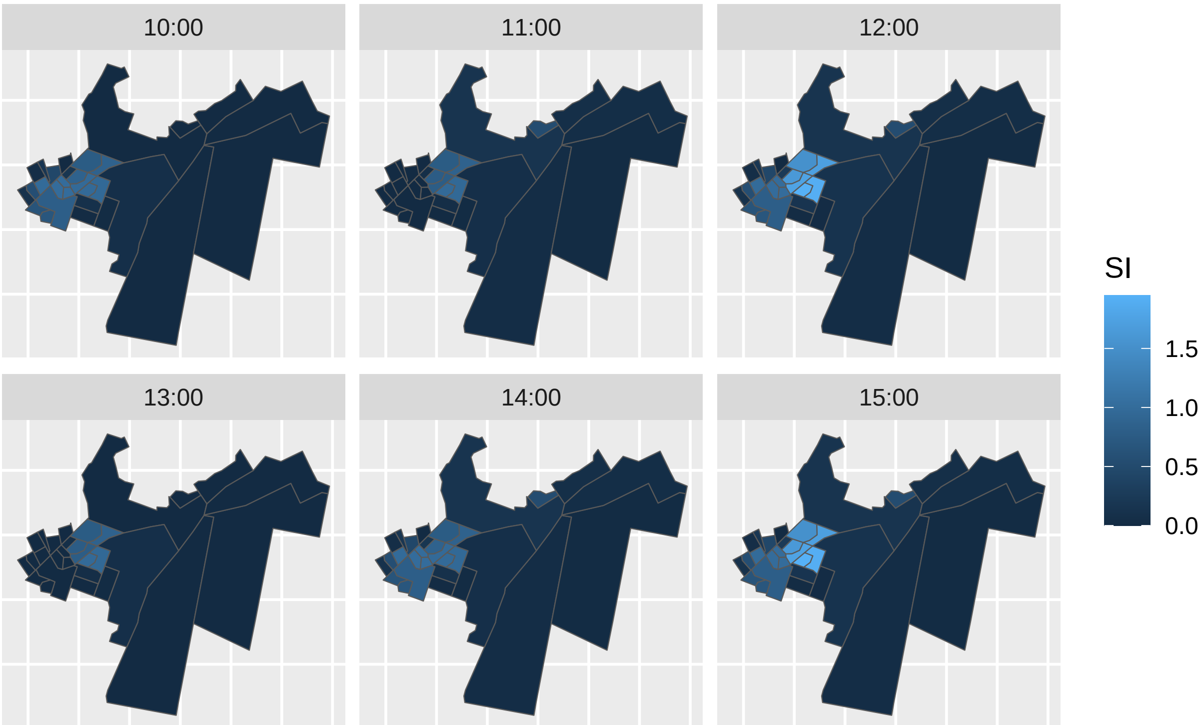


Figure 5: Mornington Penninsula Tourist Railway hourly SI values for December 30, 2018

Table 3: Mornington Penninsula Tourist Railway hourly SI values for December 30, 2018, for SA1 zone 21402159136

area_id	10:00	11:00	12:00	13:00	14:00	15:00
21402159136	1	0	1	0	1	1

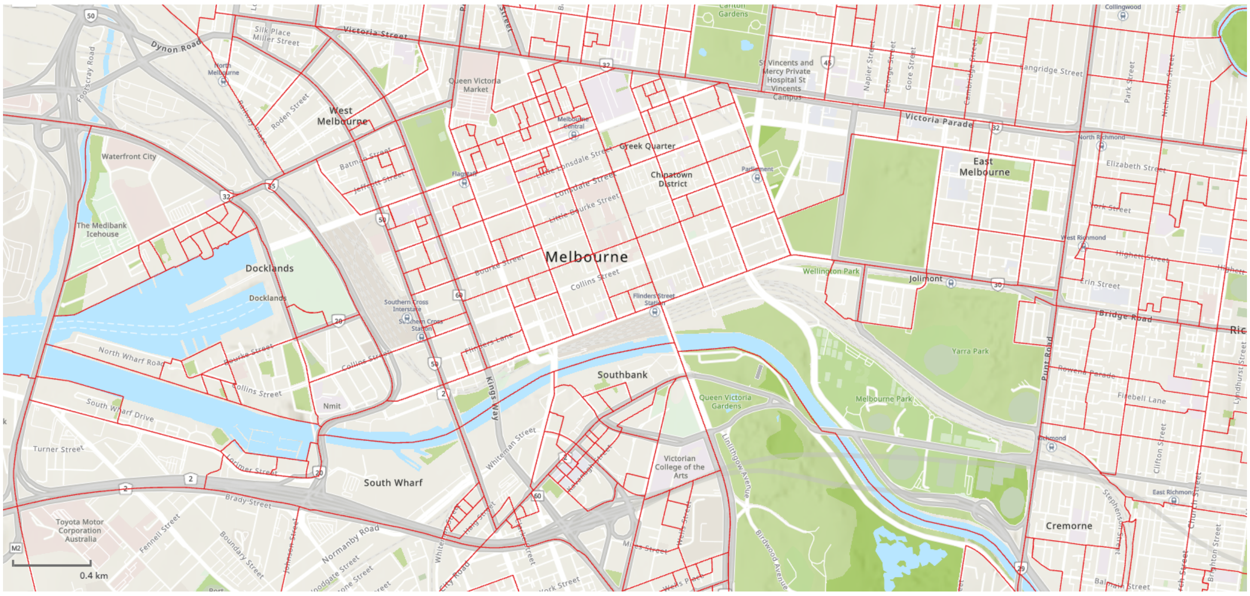


Figure 6: SA1 zones and location of Mornington Tourist Railway Stations.

shows the scores calculated by the function, which matches the pattern of arrivals at 10:47am, 12:12pm, 2:02pm and 3:27pm[16].

4.3. Greater Melbourne - October 2023

As a further example, hourly SI scores were calculated for all SA1 2021 zones within Greater Melbourne on Tuesday 10th, Saturday 14th and Sunday 15th October, 2023. These dates were selected so as to match the typical census timing of a Tuesday early in October, although 2023 is not actually a census year. GTFS data was obtained from Transit Mobility Data, (2023), with the October 6, 2023 dataset selected[17]. SI scores by hour for SA1 zones in the centre of Melbourne (shown in Figure @ref(CBD_map)) on Tuesday 10th October are shown in Figure @ref(Melbourne_CBD_map_231010),

The results shown in Figure @ref(Melbourne_CBD_map_231010) meet expectations, with higher SI scores shown in the Central Business District (CBD), where there are the five stations that make up the City Loop[18], and where many tram and bus routes converge. The SI scores are highest during the day, especially in the morning and afternoon peak periods around 7-9am and 4-7pm, reflecting the typical service peaks.

4.3.1. By mode

SI scores were also obtained for each mode separately. Scores for the whole day on Tuesday October 10th, 2023 are shown in Figure @ref(Melbourne_231010_by_mode).

[16] See https://transitfeeds.com/p/mornington-railway/806/latest/stops
[17] Minor adjustments were made to this dataset to remove duplicate stop_ids from the stops.txt file
[18] Flinders Street Station, Southern Cross Station, Flagstaff Station, Melbourne Central Station and Parliament Station.

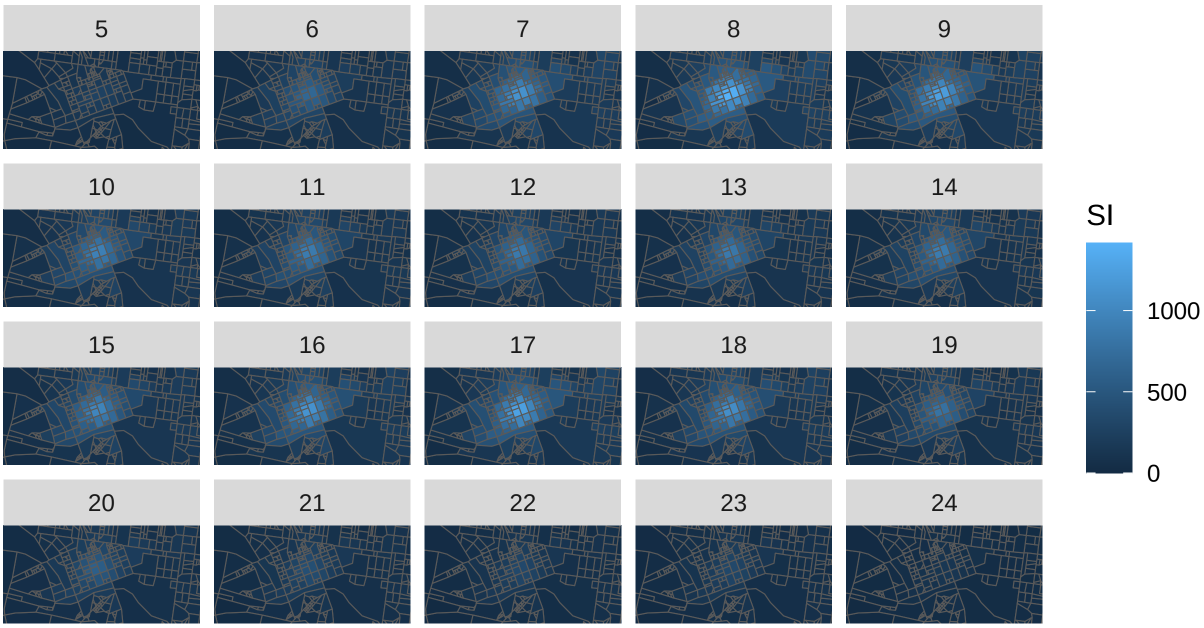
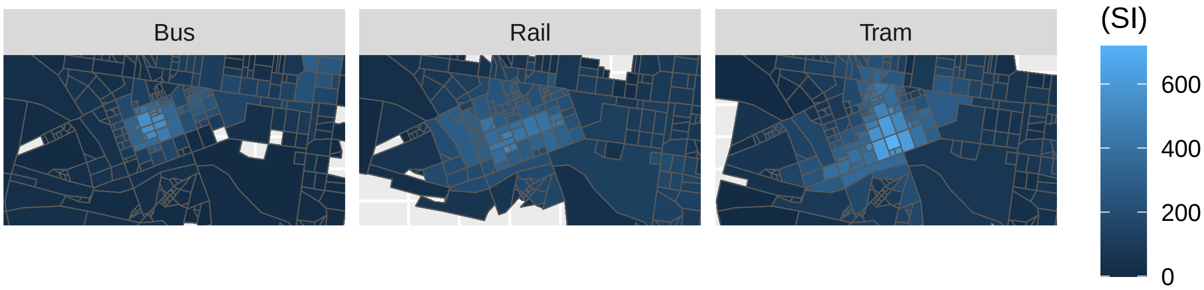
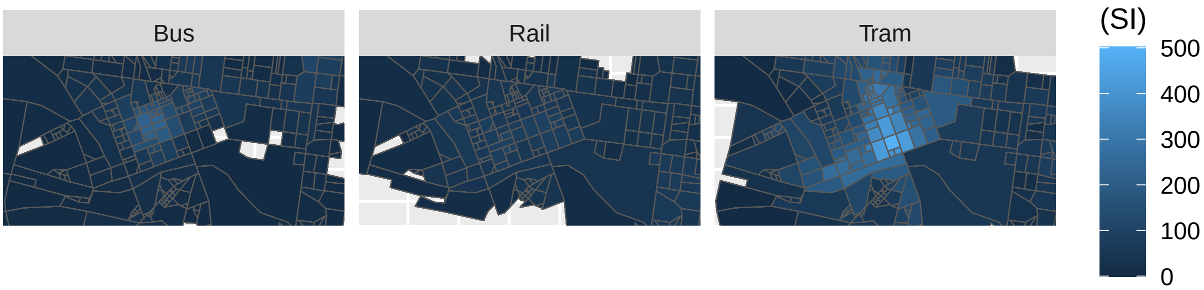


Figure 7: Victorian GTFS and SA1 zones near the Melbourne CBD, SI values for October 10, 2023, by hour between 5am and 1am

Figure @ref(Melbourne_231010_by_mode) indicates how the central city is serviced by: - buses that mostly travel along the Latrobe and Queen Street corridors, many of which travel east-west along Victoria Street to/from the north-east; - rail services stopping at City Loop stations; and - tram services, most of which running north-south along the Swanston Street corridor.




Bus
Rail
Tram
(SI)
500
400
300
200
100
0

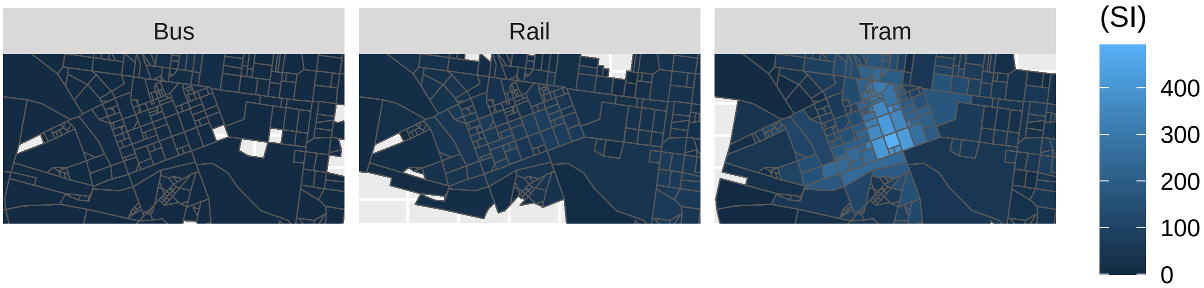


Figure @ref(Melbourne_231015_by_mode) shows a similar plot, but for Sunday October 15th, 2023. However, in this case the bus scores appear very low. While Sunday bus services in the CBD are generally much less frequent on Sundays than on other days, further investigation suggests that strike action had been planned around that time by transit workers(Hannaford, 2023). While it is unclear what normal services had been officially cancelled around that time, it appears likely that Sunday bus services may have been cut so as to have some replacement bus capacity available on other days. Regardless, this suggests that the October 2023 services reported above may not actually be representative of typical conditions in Melbourne. Hence, in the following section a similar analysis is shown for July 2023 instead.

4.4. Greater Melbourne - July 2023

4.4.1. Central Business District (CBD)

4.4.2. Clayton

4.4.3. Local Government Areas

4.4.4. Patterns

4.4.5. Trends

5. Extensions

5.1. Melbourne CBD Index

5.2. New York Index

5.3. London Index

6. Discussion and conclusions

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