The equity and spatial implications of transit fare

Abstract:
Availability of new open/big data (NOBD) such as smartcard and General Transit Feed Specification data has provided unprecedented opportunities for transit planners and policy-analysts to conduct analyses that are highly challenging and even infeasible where only traditional data (e.g., censuses/surveys) are in presence. In this study, we first review and summarize discrete and scattering existing studies on (a) society and justice, (b) transportation/space and justice, and (c) transit fare and justice. We consider (c) as a subset of (b) and (b) as a subset of (a). We then illustrate how NOBD can supplement traditional data in the studies of the equity and spatial implications of transit fares via an exploratory study of Brisbane, Australia. Specifically, we propose and implement methods or procedures such as "trajectory rebuilding", "fare matching", "segment tagging", "desired line/stop visualization", "commuter identification" and "scenario analysis" to show why and how transit fares could have important equity and spatial implications. In addition to empirical findings and policy recommendations, we offer some transferable methods and procedures for visualizing and concretizing the aforementioned implications.

Key words: non-traditional data; equity; space; distance-based fare; Brisbane

Introduction

In the domain of transit, fare is a basic element of transit system operations. In the short run, it influences the overall ridership and financial condition of a transit agency. In the long run, it affects the form and development of central cities, their surrounding areas and suburbs (Vuchic, 2005). Planning and deciding transit fares are not easy tasks, which require analyses of many trade-offs among objectives, satisfaction of different requirements and considerations of various constraints. Thinking more broadly, transit fares involve problematizing and even reforming existing institutions, decision-making mechanisms, planning processes, policy evaluations and monitoring practices (e.g., see Martens, 2016; Soja, 2010). In other words, transit fares can be a lens through which we can understand better (a) if citizens are given proper and equal rights, especially decent transit accessibility to opportunities in their respective cities and (b) if transit services in general and transit fares in particular have facilitated or discouraged citizens to enjoy cities as "the place of simultaneity and encounter and of rights to be given content through struggle" (Lefèbvre, 1993, p. 428; Martens, 2016). Those rights are "an aspect of social relatedness rather than as an inherent and natural property of individuals" (Holston and Appadurai, 1996, p.197).

In the real world, transit fares have direct equity and spatial implications for transit riders. Planners and decisions-makers should carefully evaluate these implications so as to ensure or improve "environmental justice", "spatial justice" and "social inclusion". In terms of "environmental justice", all people are supposed to be treated fairly and to have meaningful involvement, with respect to the development, implementation, and enforcement of laws, regulations, and policies (EPA, 2017). "Spatial justice" requires that most if not all people can benefit from "the fair and equitable distribution in space of socially valued resources and the opportunities to use them" (Soja, 2008, p.2). It also desires that "[the transportation system] provides a sufficient level of accessibility to all [users] under most circumstances" (Martens, 2016, p. 215). In the public transport sphere, "social inclusion" means that few people and even no one would be excluded socially because of unaffordable transit fares/services that contribute to or constitute "the inability to fully participate in the economic and social activities that are necessary to maintain a reasonable quality of life" (Lucas, 2004, p. viii).

In the context of the US, both the White House and different cabinet units have issued executive orders to require environmental justice be considered in all phases of planning, policy-making, and projects since the 1990s. As the leading agency in the transportation field, US Department of Transportation (USDOT) has also compiled various references, datasets and tools for different stakeholders to best consider environmental justice (USDOT, 2016). Of those recommended materials or tools, however, few have touched on emerging new open/big data (NOBD) such as on-line General Transit Feed Specification (GTFS) data and data generated by smartcard swipes ("smartcard data" for shorthand hereafter). Traditionally, both travel demand models and land use models do not have replicable components and efficient procedures to consider justice in the transportation domain (c.f., Alsnih and Storper, 2003). Can NOBD be used to facilitate better considerations of transit fare's equity and spatial implications in the public transport domain? If so, how to do that and what are the recommended procedures that are the most efficient? What new insights into, or findings about transit fare's equity and spatial implications can we generate with the extra help of NOBD?

In this study, we attempt to address the above three questions via a case study of the transit fare system in Brisbane, Australia. Based on a combination of census data and NOBD (i.e. local on-line GTFS and smartcard data, our study proposes and implements methods or procedures such as "trajectory rebuilding", "fare matching", "segment tagging", "desired line/stop visualisation", "commuter identification" and "scenario analysis" to show why and how transit fares could have important equity and spatial implications. In addition to empirical findings and policy recommendations, we offer some transferable methods and procedures for visualizing and concretizing the aforementioned implications.

The ensuing text is organized as follows. The ensuing section (Section 2) provides a review of existing literature, which is categorized into three main streams: Society and Justice, Transportation/Space and Justice and Transit Fare, Justice and Social exclusion. Section 3 is an empirical study of the transit fare system in Brisbane, Australia. Section 4 synthesizes the findings of both the literature review and the empirical study. Section 5 concludes and discusses future research directions.

Literature Review

Society and Justice

Many scholars have long been interested in society and justice. Their work laid down the theoretical foundation regarding how we should define and pursue justice in principle. Justice, to them, should be a goal and pursuit of any modern/democratic societies. Only a few, however, had directly studied on justice in the domain of transportation. Their work therefore may only indirectly inspire those who work on transportation-related justice. Among the theories on society and justice, Rawls' theory of justice, despite of being a-spatial, is arguably one of the most inspiring and influential, at least in the west. According to this theory, there are two core elements of justice. One is the procedures that people use to derive the principles of justice. The other is the set of principles of justice after those procedures have been executed properly. An "original position" (also called "the veil of ignorance", Rawls [1971], p.118) helps establish the principles of justice. Such a position assumes that there are free, equal, mutually disinterested and rational persons who only care about their own interests. These persons are impartial in social lives. This would generate necessary moral principles that shape the basic structure of society. Such structure is composed of the major political, social and economic institutions that distribute fundamental rights and duties and that determine the benefits and burdens of social cooperation.

Rawls (1971) further defined five types of primary social goods:
(1) Basic rights and liberty.
(2) Freedom of movement and free choice of occupation against the backdrop of diverse opportunities.
(3) Powers and prerogatives of offices and positions of responsibility.
(4) Income and wealth.
(5) The social bases of self-respect.

Justice in the domain of transportation could be one that is related to (2). Based on Rawls (1971), a just society would be the one in which everyone receives a fair share of primary social goods. Such share compensates for the arbitrariness embodied in the natural lottery: vigor, intelligence and imagination. To promote and maintain a just society, Rawls (1971) suggested that three principles be in effect:
(1) Citizens enjoy equal basic liberties.
(2) Citizens have fair equality of opportunity.
(3) The difference principle: It holds that inequalities in the distribution of the primary goods are permissible only when they benefit the least well-off of society.

Partially built on Rawls' ideas outlined above, Dworkin (2000) proposed that (a) resources can be an alternative to primary social goods when considering society and justice; (b) the market force and individual preference and discretion should be accounted for and exploited to promote justice. A just society, according to Dworkin (2000), is one that (a) has an envy-free distribution of a wide range of goods (or resources) that are available in a society from the outset; (b) members of the society then have their respective discretion to dispose goods allocated to them in a functioning economic market. In terms of how to dispose of goods or income among members of society, Dworkin (2000) was in favor of various insurance schemes that a performing market would generate and that members of the society can freely choose from. One, for instance, buys an insurance scheme in advance to mitigate the risk or cost of not being given a prime location in her/his city. Of course, depending on particular risks or costs, there are not necessarily insurance schemes generated by the market. When there were, it should be members of the society who decide whether to buy and what to buy. The society, based on the collective opinions of its members, can also design and offer some insurance schemes to guarantee its members who encounter some brute bad luck to enjoy some minimum level of assurance or benefits.

To create a justice society, comparisons are of crucial importance besides the market, individuals' discretion and insurance schemes. They help us conceptualize and identify just arrangements. Sen (2006) argued that transcendental theories should be developed to guide us to do those comparisons. The primary aim of such theories is to provide principles and guidelines for one to properly conceptualize and identify perfectly just arrangements. According to Sen (2006), it is unwise to identify and compare all the alternatives when deciding the perfectly just arrangements. It is wiser to find a fairer alternative based on particular pairwise rankings. Such rankings often inform us regarding what would and how to enhance justice or reduce injustice.

If we tentatively overlook individual scholars' specific views (or theories) about society and justice highlighted above, we can categorize their views into two camps: the utilitarian perspectives and the deontological views (Johnson, 2011). One is concerned with a goal and derive a conception of justice from that goal or objective. It attempts to explore and exploit those principles, rules, and institutions that are instrumental to realization of justice. Rawls (1971) thus belongs to this camp. The other believes that justice is a matter of strict duties that cannot be overridden by any other considerations. Ancient philosophers such as Hume, Beccaria, Smith, and Bentham more or less embrace such idea (for more details, see Johnson, 2011). Built on the two camps, Johnson (2011) upheld that justice is about the character of relationships among persons instead of a single pre-eminent goal or on a set of strict duties and that justice is based heavily on the concept of reciprocity.

The above ideas may look abstract on the surface. But they have many inspirations for those who want to consider justice in a particular domain like transportation. Most notably, Rawls' original position, Dworkin's insurance schemes, Sen's ideas about comparisons and a fairer alternative and Johnson's character of relationships have all enlightened the ensuing case study of Brisbane. For instance, the distance-based fare scheme was proposed as a fairer alternative as compared to the current zone-based fare scheme.

Transportation/Space and Justice

Unlike those scholars cited above, neo-Marxism scholars like Dikec (2001), Harvey (1996), Soja (2008, 2010) and Young (1990) have more or less increased spatial awareness/sensitivity in the discourse of society and justice. This has enabled them to more directly and consciously touch on transportation/space and justice, which has inspired this manuscript more directly and substantially. To Harvey (1996), uneven development in space dominates today's primary mode of production (i.e., capitalism), which in turn determines the social construction of principles of justice and even the form of injustice. Young (1990) showed that many people had tendency of overlooking the concepts and existence of oppression and domination when examining injustice affairs. To her, injustice has more to do with oppression and domination than distribution (space). Dikec (2001), being somehow different from Young (1990), believed that injustice in the city is characterized by the domination of urban space, which is socially and spatially manifest. If we could not address causes of the domination (e.g., capitalism dominance), injustice in the city could be produced or reproduced socially and spatially.

In the last few decades, one of the compelling real-world cases showing the relevance of space (transportation) and justice is arguably the "the Bus Riders Union (BRU) decision" in the US. In this case, local bus riders in Los Angeles with the help of BRU successfully won a lawsuit against the Metropolitan Transportation Authority (MTA), the local transit agency, in 1996. As a result of the case, MTA had to invest more generously and wisely into the local bus system, providing more environment-friendly, secure, affordable, and comfortable bus services to local bus riders, which greatly outnumbered local rail riders. Before the decision, it was found that MTA spent disproportionately more on rail transit lines that served wealthy communities than on the local bus system. Interestingly, the lawsuit was triggered by MTA's decisions to eliminate the local monthly bus passes and to raise bus fares. It was dug out later that MTA's had excessive expenditure on rail transit and paid much higher subsidy per rail transit rider as compared to a bus rider. The above case has been intensively referred to by different courts in the US to judge other cases related to transport/spatial justice since 1996 (Soja, 2010).

Partly inspired by the above case, Soja (2010) became a seminal book on spatial justice and public policy. He used the above case to illustrate how spatial injustice in the domain of transportation could occur in the real-world settings and how different people had reacted (or should react) to it. To him, a location in space, including transport services to and from it, always has some degree of relative advantage or disadvantage. These differences sometimes are inconsequential and/or unintended and other times are oppressive and/or intentional. Soja (2010) contended that scholars and decision-makers should consider both differences, especially the existence, severity, causes and cures of the latter.

Compared to Soja, Martens (2016) adopted a slightly different approach to (spatial) justice in the transportation domain. Based on a review of transportation planning and policy practices in the past five decades or so, he argued that those practices had focused on the performance of transportation systems and related methods or models to improve it while overlooking users or those who cannot use the systems for various reasons. For concrete transportation system improvements, not all would equally benefit from them. Even worse, some would suffer from those improvements, i.e., there was environmental injustice. He suggested that a transportation system is fair, if, and only if, it provides a sufficient level of accessibility to all under most circumstances. How to define "sufficient" in the real-world setting? He argued that it can be defined through collective deliberation and selection processes in a democratic society. In an empirical study of Amsterdam, he illustrated that accessibility can be measured by indicators such as jobs within certain travel time (i.e., a cumulative opportunity indicator) by different units of analysis (e.g., traffic analysis zone). In addition, Martens (2016) developed four general guidelines for one to consider (in)justice in the domain of transportation:

(1) Injustice emerges if a person experiences insufficient level of accessibility.
(2) All persons should be entitled to various insurance schemes so that they can enjoy a sufficient level of accessibility.
(3) Proceeds of the above insurance schemes should be used to address insufficient accessibility experienced by citizens.
(4) Interventions into the transportation domain can only be justified if they do not increase the number those citizens who suffer insufficient accessibility or make them worse off.

Based on the above, Martens (2016) treats (spatial) justice in the transportation domain as a mobility discourse that cultivate spatial sensitivity toward injustice and a spatial culture to fight against it.

Almost in parallel to Martens (2016), Pereira et al. (2017) reviewed key theories of justice and argue that accessibility should be considered as a human capability. They recommended that public policies should:

(1) Contain some minimum standards of accessibility to key destinations;
(2) Respect individuals' rights and prioritize the disadvantaged;
(3) Reduce inequalities of opportunities;
(4) Mitigate transport externalities.

In the political sphere, governments' attention to justice or equity in the transportation domain originated in the US in the 1970s (Alsnih and Storper, 2003). Initially, the primary focus was on direct impacts of transportation investments on connectivity and mobility. Later, the focus expanded greatly, covering extra issues such as impacts of transportation investment on urban economic growth, job accessibility, and even the cost/subsidy of public transport per capita (Transportation Research Board [TRB], 2002).

In the European context, “justice” or “environmental justice” (as a technical term) are less frequently used than “social inclusion” in the transportation domain. Scholars like Lucas (2004) Preston and Raje (2007) tended to believe that the three terms can be used interchangeably or have much overlap. Lucas (2004, p. viii and ix), for instance, defines that environmental justice is “policies and programs to address unequal impact of development on minority and low-income communities” and that “social exclusion” is “the inability to fully participate in the economic and social activities that are necessary to maintaining a reasonable quality of life”, and “social inclusion” is policies and programs to address social exclusion. Thus, if we assume that certain groups (e.g., minority) or places (e.g., low-income communities) are more likely to be subject to environmental injustice and social exclusion than other groups or places, then environmental justice and social inclusion policies and programs would actually often deal with the same groups or places.

Despite of the above, improvements in environmental justice, however, do not necessarily lead to more social inclusion and vice versa. A low-income community, for instance, can equally benefit from a new real estate project like its adjacent communities because of the introduction and execution of proper environmental justice policies or programs. But it could still be subject to social exclusion because of (a) insufficient level of accessibility to jobs or to transit services, (b) the lack of, or infrequent transit services and/or (c) prohibitively expensive transit fares for the poor.

There have been quite a few publications and documents on social exclusion and (environmental) justice in the transportation domain since the late 1990s (e.g., European Commission, 1998; Hine, 2003; Hine and Michell, 2000, 2003; Raje, 2004, Lucas, 2004; Donaghy et al., 2005; Stanley and Vella-Brodrick, 2009). Given the above-mentioned connections between social exclusion and (environmental) justice, some of those materials address environmental justice and social inclusion simultaneously (e.g., Lucas, 2004). Within the UK government, a Social Exclusion Unit within the Cabinet Office was created to deal with social exclusions in different fields, of which transportation is just one. Funded by this unit and other governmental agencies, a series of research projects have been executed to examine how accessibility, mobility and social exclusion are interconnected and how governments can tackle some of the social exclusion identified based on case studies (Preston and Raje, 2007). Of course, many public agencies are aware that transportation-related social exclusion is only one of the various forms of social exclusion. In addition, to best address transportation-related social exclusion, different stakeholders such as the public, NGOs, governments and associations should cooperate (European Commission, 1998). New information technology can help too (Hine, 2003).

In Australia, where the ensuing empirical case is embedded, scholars have examined how both environmental justice and social exclusion can inspire local professional practices and scholarly studies (e.g., Alsnih and Stoper, 2003). They have also conducted case studies to evaluate the status quo of transportation-related environmental justice and social exclusion in particular cities or areas. Currie (2004, 2010) and Currie et al. (2009), for instance, studied gaps in public transport supply and needs, which could contribute to transportation related social exclusion in different Australian states and capital cities. Those residents and/or workers in Australia’s urban fringes can face poor levels of public transport services (Hurni, 2006). Thus, if we assume the right to use the city center as a necessary condition for residents or workers to fully participate in urban social life, those urban-fringe workers and/or residents could face significant mobility disadvantages and even mobility-related injustice if their primary mode of travel is public transport (c.f., Lefèbvre, 1993; Martens, 2016).

As a whole, the above studies have highlighted the importance of linking transportation/space to justice, which has long been a-spatial in the eye of scholars such as Rawls (1971), Dworkin (2000), Sen (2006) and Johnson (2011). Despite that most of these studies still look at transportation/space and justice at the theoretical level, several of them (e.g., Martens, 2016 and Pereira et al. 2017) have started illustrating ideas regarding how to evaluate and/or promote transportation/spatial justice in the real-world settings. Across countries, different entities have also paid attention to justice, equity or social inclusion in the transportation domain. Little has been done, however, on how NOBD can be used to facilitate the studies on transportation/space, justice and/or social exclusion.

Transit Fare, Justice and/or Social Inclusion

Compared to transportation/space and justice, transit fare and justice or social inclusion have not been examined intensively before. In existing studies, most authors only examined transit fare, justice and/or social exclusion at the theoretical level. Few empirical studies have been conducted to embody how transit fare, justice and/or social exclusion are related to one another in reality. At the theoretical level, Church et al. (2000) offered an analytical framework to relate social exclusion and transportation. In this framework, fares can result in one of nine types of social exclusions: fare-based exclusion. Similar to Church et al. (2000), TRB (2002) pointed out that like job accessibility and community quality, the cost of public transport per capita can be an important aspect of environmental justice in the domain of transportation. The cost of (public) transport influences one's level of mobility and accessibility, which can in turn contribute to social exclusion or inclusion (Stanley and Vella-Brodrick, 2009). In reality, even if the government or transit operators have provided discounted schemes to reduce costs of (public) transport, not all citizens could equally take advantage of these schemes if measures were not taken to engage and empower all citizens. Mitchell (2000, 2003), for instance, examined socio-demographic, mode of travel and transport expenditure characteristics of the social groups in the UK that are vulnerable to transportation-related social exclusion. They found that relatively few members from these groups used reduced fares and budget ticketing. However, residents and socially-excluded communities are often not given sufficient opportunities to participate in decision-making about the operation and management, including pricing, of the transportation system (Hodgson and Turner, 2003). This reminds us of Djkec (2001), which stressed that injustice as outcomes of socioeconomic processes cannot be alleviated or removed if we did not deal with the root reasons (e.g., capitalism-dominated urbanization).

In practice, fare is primarily treated as a tool to entice more use of public transport rather than something that can have equity and spatial implications (e.g.., Zhang et al., 2014; Sharaby and Shiftan, 2012; Brown et al., 2003). Nuworsoo et al. (2009) was the only existing study that we identified in existing studies that stresses on equity/justice implications of transit fare. But it focuses on exploring five alternative proposals rather than examining the current fare system and its spatial and equity implications. Plus, it was purely based on traditional data--on-board surveys.

All in all, the above review of existing studies by no means is exhaustive. But it somewhat indicates that transit fare, space and (spatial) justice are important issues but they have been mostly studied at the theoretical level. Few studies have been done on these issues based on empirical data. According to our best knowledge, no existing studies on these issues have been based on NOBD such as smartcard data. NOBD has three advantages as compared to traditional data. First, it covers a very large and usually representative sample of the population, which could in theory minimize the risk of biased sampling. In our ensuing study of Brisbane, for instance, Go card data record nearly 90% of all transit trips (TransLink, 2016). Second, NOBD is usually collected and updated continuously, which makes studies on the population across various temporal units feasible (c.f., Batty, 2012). Third, because of the above-mentioned characteristics, NOBD can be used to divide the population (or more accurately, a good sample of the population) into different meaningful segments and examine their respective attributes of relevance. The following empirical analyses will be based primarily on NOBD. They attempt to show (a) how transit fare, space and justice are related to one another in the real-world settings; (b) how smartcard data can be processed to quantify and visualize the above relationships.

Empirical Studies

Based on data of smartcard swipes from TransLink, the local agency tasked to provide public transport services in Southeast Queensland (SEQ), we conducted exploratory studies to show how NOBD, in combination with other data can help improve studies on (environmental) justice and transit fares in the transportation domain.

The site and data

The study site for this research is SEQ, Australia. SEQ occupies an area of about 22, 240 square kilometres in the eastern portion of Australia. Within SEQ, there are eleven local government areas with an estimated population of 3.27 million, accounting for 70.2 percent of the total population in Queensland (Queensland Treasury, 2015). Since August 2012, TransLink has been responsible for the delivery of passenger transport services across Queensland, including SEQ. Public transport remains a popular way to get around in SEQ, with over four million passenger trips each week (TransLink, 2016). Nearly all local passengers and most visitors to SEQ use a smartcard, the "Go card", to pay their fare when using the system, which consists of buses, ferries and trains. The Go card is a more popular option amongst both local and foreign passengers because TransLink charges up to 63% extra fees for those using paper tickets. Because of this, Go card data record nearly 90% of all transit trips (TransLink, 2016). To accurately charge their fares, TransLink requires that Go card users tap their card for both boarding and alighting. These taps automatically generate the following information:

- Trip ID (a unique ‘‘leg’’ of a journey) and journey ID (stop of origin–stop of destination, based solely on fare rules),
- The stop information for trip origin and destination,
- Boarding and alighting time, and
- Unique card number and card type (concession card or regular card).

The information is instantly sent to and stored in TransLink's central server. TransLink defines a journey as the set of trips taken on one fare basis. TransLink considers consecutive transactions linked into a single journey if the time gap between alighting and subsequent boarding is less than 60 minutes. The fare is discounted for transfers, and a maximum of three transfers are allowed for a journey.

The data used in this study covers a full-day's Go card swipes across SEQ. The day is 4 March, 2013, which was a Monday and a typical workday with normal weather. We follow procedures such as "trajectory rebuilding", "fare matching", "segment tagging", "desired line/stops visualisation", "commuter identification" and "scenario analysis" to examine:
(1) Where transit riders/commuters travel to and from on a typical weekday,
(2) What kinds of trips/riders would contribute the most or the least to the fare box revenue,
(3) What happens to the fare of different transit riders/commuters/trips if local fare system changes from a zone-based system to a distance-based one.
(4) Where might be environmental injustice in the domain of transit fare.

We also used data from Australia Bureau of Statistics (ABS) in this study for us to understand the characteristics of riders and their origins and destinations. ABS data are aggregated at different predetermined geographic levels such as Statistical Area Levels 1, 2 and 3 (SA1, 2 and 3). Linking origin and destination of public transport trips to ABS data thus enables us to better understand where (e.g., SA1) trip makers go to and come from and which social group these trip makers might belong to. In this study, we decided to use ABS data by SA1, which is the smallest geographic unit for the ABS data. Each SA1 contains an average of 400 persons, with a minimum of 200 and a maximum of 800. Within the urbanized core, SA1 is usually smaller than one square kilometre. Within the boundaries of the City of Brisbane, for instance, the average size of SA1 is only 0.52 square kilometres.

Trajectory rebuilding

The Go card swipes we obtained alone did not allow us to know the trajectory/route a trip maker actually took. The Online Passenger Information Application(OPIA)(https://translink.com.au/about-translink/open-data) by Translink was used to rebuild the trajectory of passenger journeys.
OPIA is an open API which provided access to journey planning and schedule information for developers. For example, the Google Map developers use this API to develop journey planner for their end-users. For a short period of time between 2015 and 2016, TransLink allowed authorized developers to access OPIA for free. We seized this golden opportunity to derive the necessary information regarding trajectory rebuilding for this study. The inputs for OPIA included trip origin, destination, and boarding time information. These inputs were directly in the smartcard data that we already had access to. After "talking to" OPIA，it returned all of the bus route options that meet these input criteria with detailed information including fares, stops and shapes in ESRI-JSON format. The bus route was then selected based on the actual bus route that the passenger chose (recorded by smartcard). Finally, the shape of route trajectory were converted to .shp file using Python programming embedded in ArcGIS 10.3.

Fare matching

While the trajectory was rebuilt, our API also consulted with GTFS data to obtain the fare for each journey given the zone-based fare rules set up by TransLink, which divided SEQ into 23 zones (Figure 1). TransLink's GTFS data were still available online as of this manuscript was drafted (August 2018), but it no longer provided the fare information (for more information, see https://goo.gl/eBjUkm). In other words, unless TransLink gave us special permissions, we can no longer retrieve the historical fare information even if we have Go card data from the past.

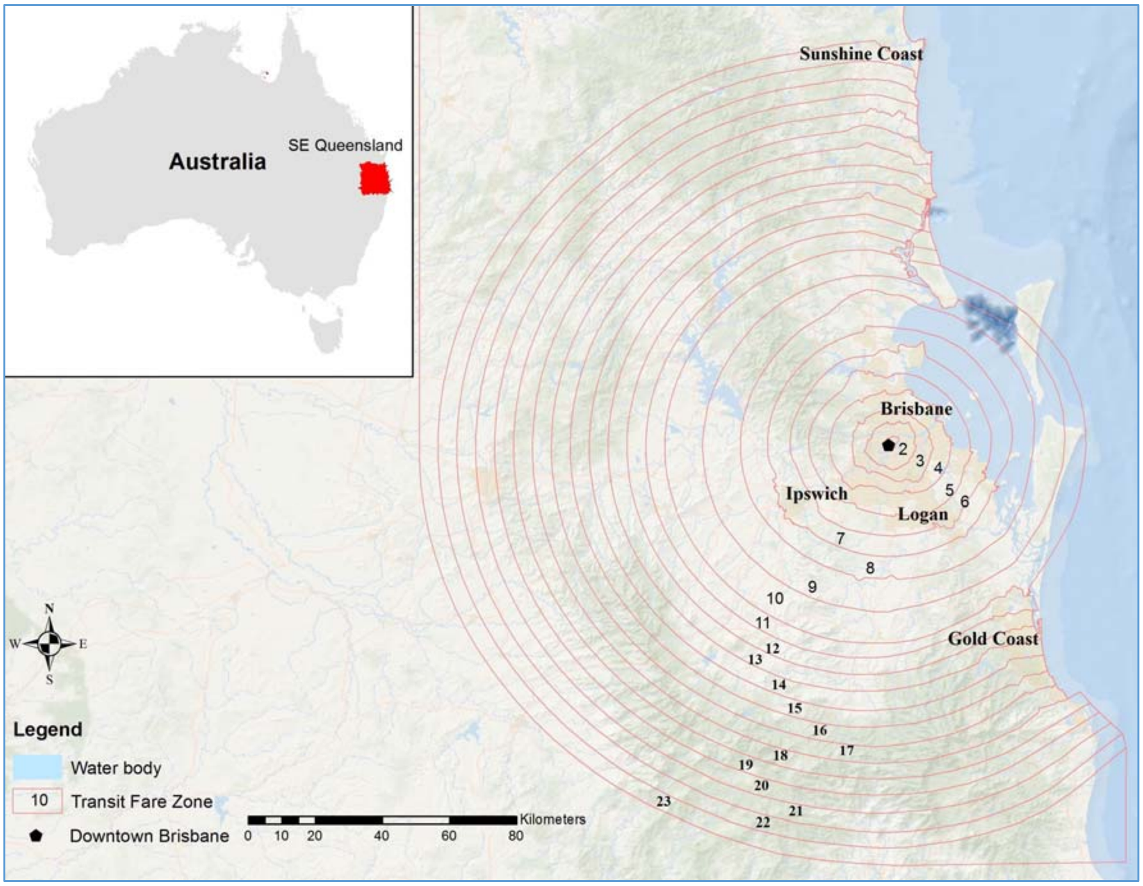

Figure 1: Fare Zones of TransLink

According to TransLink, all fares are charged based on the number of zones a trip maker travels through on one journey, which can consist of a series of linked trips. Linked trips are defined as multiple consecutive trips occur within two hours. Each trip contains one tap-on and tap-off. The above two hours mean the time between the first tap-off and the last tap-on of a journey. Fare prices vary depending on if a trip maker travels:

- During off-peak or peak times,
- Using a Go card or paper ticket,
- Using which type of Go card (regular vs. concession).

Given that concession Go card users (e.g., seniors and pensioners, children, tertiary students, asylum seekers) enjoy varied discounts and even free schemes, and that their transportation-related justice (if any) could be more complicated than regular Go card users (e.g., disabled, senior and concession Go card users would like to have special van to travel door to door), we therefore in this study focus exclusively on the regular Go card users who pay the full fares for their journeys. In addition, in light of the findings that most rail transit users travel across the boundaries of the City Council of Brisbane and that only a small percentage (less than 1%) of Go card users can be detected beyond Zone 8 designated by TransLink on the day we had smartcard data, we excluded rail transit users and Go card users tap on and off outside Zone 8 from our analyses too. Admittedly, because of the above handlings, our studies were about a subset of the population. They can be enhanced in the future by focusing on those users we had excluded. Of course, this means that we need to (a) be granted access to TransLink's on-line GTFS data with fare information via API again and (b) given complete smartcard data that cover more days so that we do not miss those traveling infrequently.

Segment tagging
After rebuilding trajectories of all regular Go card users, we constructed the so-called "desired lines" via travel demand modelling. Desired lines show where trip makers go to and come from and how many of them are along different routes (or their segments). The rebuilt trajectories we obtained from the trajectory rebuilding procedure described above do inform us about where Go card users went to and came from and which route they travelled along. But they cannot be used to make corresponding desired lines directly as the ridership by route has not been separately counted. We used the tag function in *TransCAD*, a travel demand modelling package to count the above ridership. In the *TransCAD* environment, this function uses the rebuilt trajectories and local transit routes as input and automatically aggregates ridership by route.

Desired line/stop visualisation
Once segment tagging has been completed, desired lines/stops can be visualized in the ArcGIS environment. Using the symbology function in ArcGIS, line segments and rectangles in different widths or colours can be used to create the desired lines/stops of all regular Go card users.

Commuter identification
One of the drawbacks of Go card data is that it does not contain sociodemographic information about users. This requires one find innovative ways to link Go card data with other traditional data, e.g., censuses. In this study, we assume it is outgoing riders and/or commuters in the morning peak that could help us establish the desirable linkage between the Go card data and the ABS data, the local censuses contain much useful sociodemographic information about small areas (e.g., SA1) and about residents/workers therein. Our conventional knowledge tells us that a significant share of residents/workers would be outgoing riders and/or commuters in the morning peak. If we assume that residents/workers are rather homogeneous in a specific small area, then we can use the ABS data to estimate sociodemographic characteristics of the outgoing commuters in the morning peak. Specifically, by interviewing a handful of local transport planners/workers in Brisbane by referring to Alsger et al. (2015), who studied riders' origins, destinations and transfer behaviours in the context of SEQ, we came up with the following conditions for us to single out Go card commuters from other Go card riders:

- Condition 1: Those riders (R1) who swiped Go card for the first time as soon as the local transit services started their weekday operations (usually 6am) until 9am, when most employers required or desired their employees to report for duty at worksite. Such riders would then have two spatiotemporal tags after they completed a journey: a boarding time (B1) and stop (or station) (S1) and an alighting time (A1) and stop (S2).
- Condition 2: R1 who swiped their Go card again at S2 or one of the stations within 800 meters of S2 at a time (B2) (c.f., Alsger et al., 2015, who reported 10 minutes of transfer time between alighting and the next boarding stop for most riders, which is about 800 meters' walk) that was at least six hours later than A1. Now, we have a new group of riders (R2), which were only a small subset of R1.
- Condition 3: R2 who completed the second journey of the day by alighting at S1 or one of the stations within 800 meters of S1 (c.f., Alsger et al., 2015). Now, we have

a new group of riders (R3), which were again a small subset of R2, or even a smaller subset of R1.

In the study, we treat R3 as a typical sample of the local commuters by transit.

Scenario analyses

In order to fathom the equity and spatial implications of transit fare, we have designed a new policy scenario about the local fare system with respect to the baseline scenario that has a zone-based fare system. The new policy scenario, according to Sen (2006), is not necessarily the perfect arrangements. But it enables us to have pairwise comparisons. Such comparisons then can inform us regarding what would and how to enhance or reduce justice in the base scenario. Bearing the above in mind, in the new scenario, we assume that:

(a) All regular Go card users would still have to make the journeys they made in the baseline scenario.

(b) There is a new fare system (policy scenario), which is distance-based. This new system is in general fairer than the zone-based one, if the logic remains that a rider's fare is supposed to be positively related to how many zones or how much distance s/he travels.

(c) The rate per kilometre of the new fare system is designed in a way that the overall fare-box revenue equals to that of the baseline.

(d) Riders residing in socioeconomically disadvantaged small areas should not pay a higher fare for the same distance travelled than other riders regardless of the policy scenarios. If they do, there could be indications of environmental injustice.

Studies on costs of different Go card users and their spatial patterns for each scenario, and comparisons of the costs and patterns between the two scenarios enable us to gain some interesting insights into the equity and spatial implications of transit fare.

Specifically, through the above analyses and comparisons, we hope to answer the following questions:

(a) Whether Go card users/commuters from or to certain small areas (e.g., SA1s), travelling across certain zones, or along certain corridors or segments contribute more to the overall fare-box revenue than others per kilometre? In other words, whether some Go card riders/commuters would pay a lower fare in the distance-based fare system? If so, who were them, where do they travel to and from, and which routes they are most likely to take?

(b) For the outgoing commuters/riders whose fare per kilometre is higher than the average of all outgoing commuters ("overpaying outgoing commuters/riders"), how many of them started their journey to work from socioeconomically disadvantaged small areas? Is there a pattern for these small areas? Answers to these, we think, would shed lights on environmental injustice in transit fare.

(c) Regardless of the socioeconomic situations of the small areas, which small areas have the most and fewest overpaying outgoing/incoming commuters/riders?

(d) Among small areas that have different shares of overpaying riders, whether they are significantly different in socioeconomic status? In other words, whether overpaying riders concentrated in certain small areas that have lower socioeconomic status?

(e) In light of answers to the above questions, what findings or insights can we obtain about equity and spatial implications of transit fare paid by all the riders and the commuters?

Results and findings

Percentage of revenue and journey distance: Fifty percent of fare-box revenues were generated by riders whose journey distance is less than 17 kilometres. These riders account for 91% of all the riders.

Fare by distance: As a whole, the fare per kilometre for all riders is $0.35. On average, those making journeys shorter than 12 kilometres experience a higher fare per kilometre travelled than the rider population.

Who paid more? Table 1 shows the fare distribution by zone travelled. The Go card riders who travelled only one zone paid the highest average fare per kilometres ($0.78/km). If we assume that it is fairer for riders to pay a similar or the same fare for the same unit of distance travelled (i.e., the new policy scenario described above), these one-zone riders were "overpaying riders", who paid a higher cost for the same distance travelled as compared to all other riders. Financially, overpaying riders cross-subsidized other riders using TransLink.

Table 1: Fare Distribution by Zone Travelled

Zones Traveled	Total Fare	Total Journeys	Fare/ journey	Total Dist. (km)	Fare/km	Dist./ journey (km)
All	$766,723	205,578	$3.73	2,189,955	$0.35	10.65
1 zone	$192,478	64,285	$2.99	246,924	$0.78	3.84
2 zones	$284,569	79,103	$3.60	690,947	$0.41	8.73
3 zones	$149,780	34,805	$4.30	579,268	$0.26	16.64
3+ zones	$139,699	27,385	$5.10	672,817	$0.21	24.57

Where are they to and from? Figures 2 and 3 show the overpaying outgoing/incoming riders and commuters by SA1 regardless of the number of zones they travelled across. Here, if a rider starts her/his journey from one SA1 (origin) to the other (destination), s/he is defined as an outgoing rider relative to this origin. Otherwise, s/he is an incoming rider relative to this origin. Since we use SA1 to aggregate journeys and riders, we cannot differentiate outgoing or incoming riders who complete their whole journey within a SA1. There are, however, very few such riders because SA1's are usually very small, as mentioned earlier.

Interestingly, SA1's in or around Downtown Brisbane (areas in between West End and Teneriffe in Figures), where there are more jobs, activity centres and high-end apartments than elsewhere in SEQ see a large number of outgoing/incoming riders and commuters. Compared to SA1s that contained the overpaying outgoing riders, however, SA1s that contained overpaying outgoing commuters tended to concentrate more along certain corridors. In the north and in the southwest, for instance, there were still some SA1's that contained overpaying outgoing riders. But there were few such SA1's that contained the overpaying outgoing commuters.

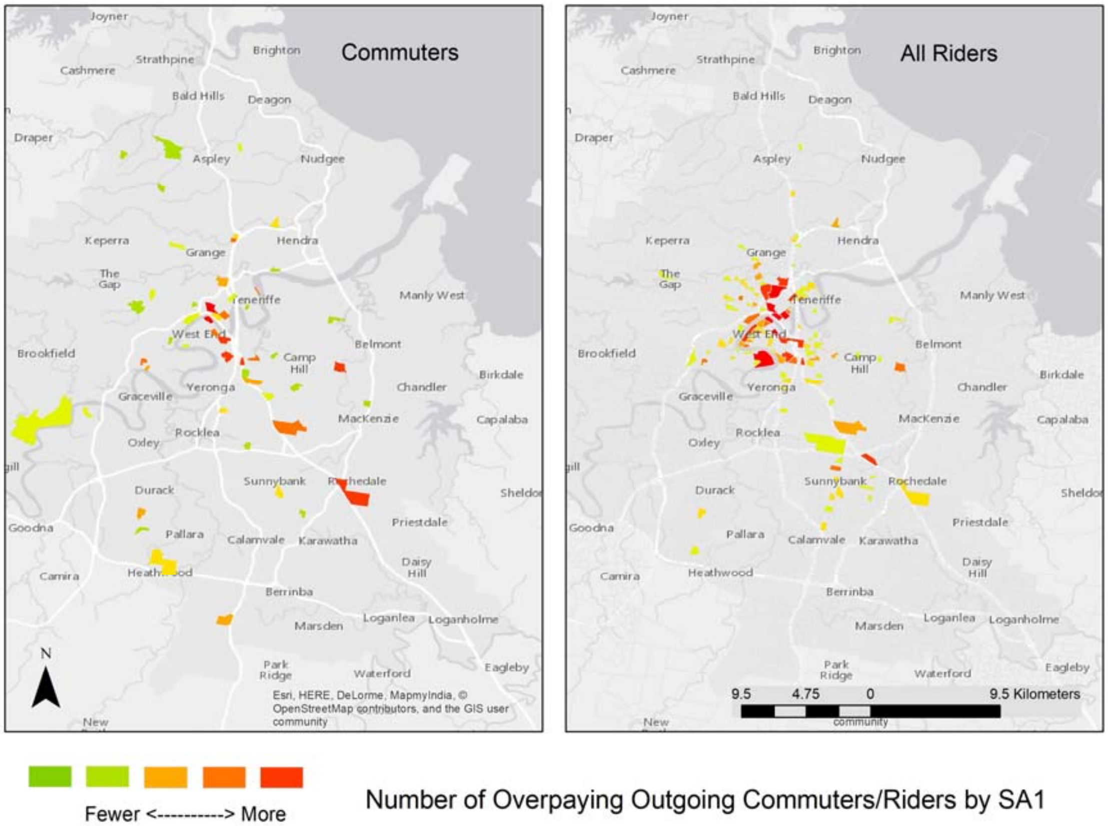

Figure 2: Number of Overpaying Outgoing Commuters/Riders by SA1

In terms of incoming riders/commuters, SA1's that contained the overpaying incoming commuters again scattered widely in the region. SA1's that contained the most overpaying incoming riders, not surprisingly, clustered in and around Downtown Brisbane. Interesting, SA1s in and around St Lucia (the red spot south to West End in the right panel of Figure 3) saw many overpaying incoming riders too. Those SA1s have University of Queensland, which is one of the largest employers and is one of the most popular destinations in SEQ.

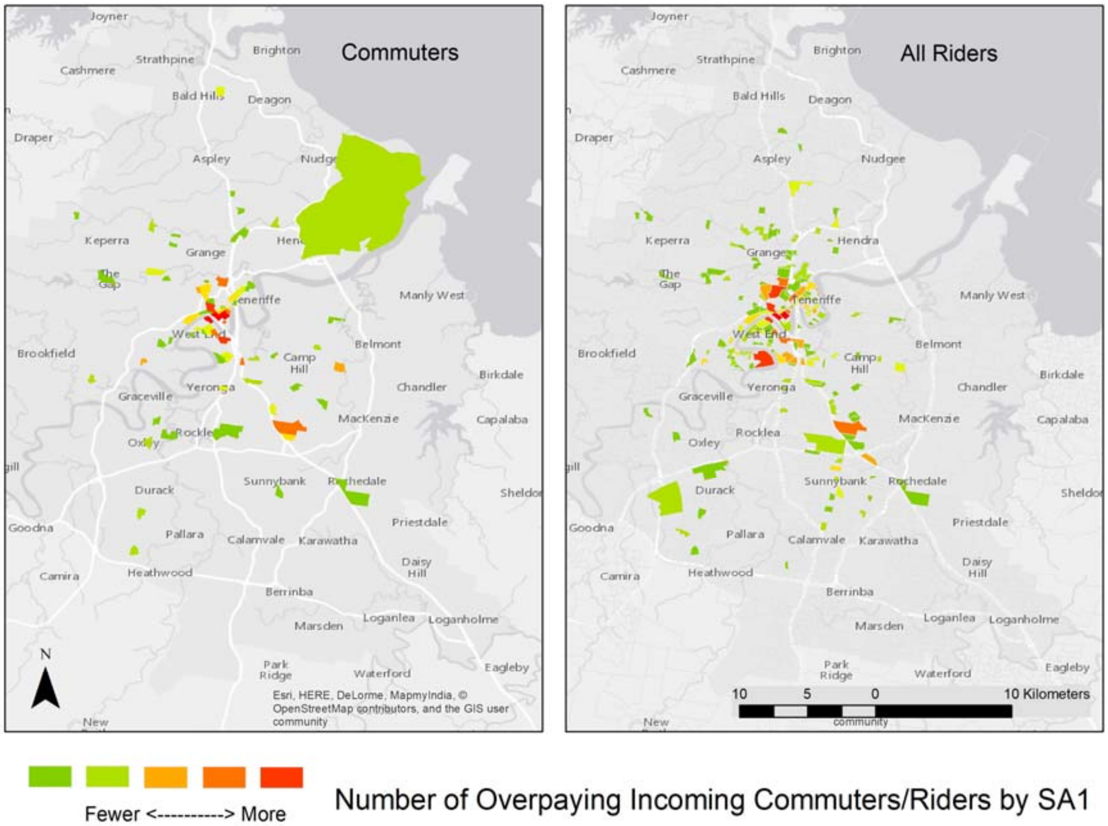

Figure 3: Number of Overpaying Incoming Riders/Commuters by SA1

Where are likely to be (residential) areas subject to environmental injustice in transit fare? ABS uses the Index of Relative Socio-economic Advantage and Disadvantage (IRSAD) to rank SA1s' overall socioeconomic status. A low score indicates a less favourable status or condition at a SA1. Based on the IRSAD, riders' or commuters' fare/km in the new policy scenario and the number of outgoing overpaying riders/commuters by SA1, we drew Figures 4 and 5 for us to identify SA1's (most likely to be residential areas for commuters) where there could be environmental injustice in transit fare (c.f., Martens, 2016).

In Figures 4 and 5, the origin of the two axes is the means of fare/km for all the commuters or all the riders and the IRSAD of all SA1s, respectively. Thus, for those outgoing commuters or riders from SA1's in Quadrant II (the upper left corner in the figure), they not only paid a higher fare/km than the mean and are residents of SA1s with a low IRSAD value. For these commuters or riders, they could suffer from environmental injustice in transit fare. Similarly, for those commuters or riders from SA1's in Quadrant IV (the lower right corner) of Figures 4 and 5, they were actually "beneficiary" of the zone-based fare scheme if the distance-based fare scheme is regarded as being fairer. In the zone-based fare scheme, their fare/km was lower than the mean of all the riders/commuters.

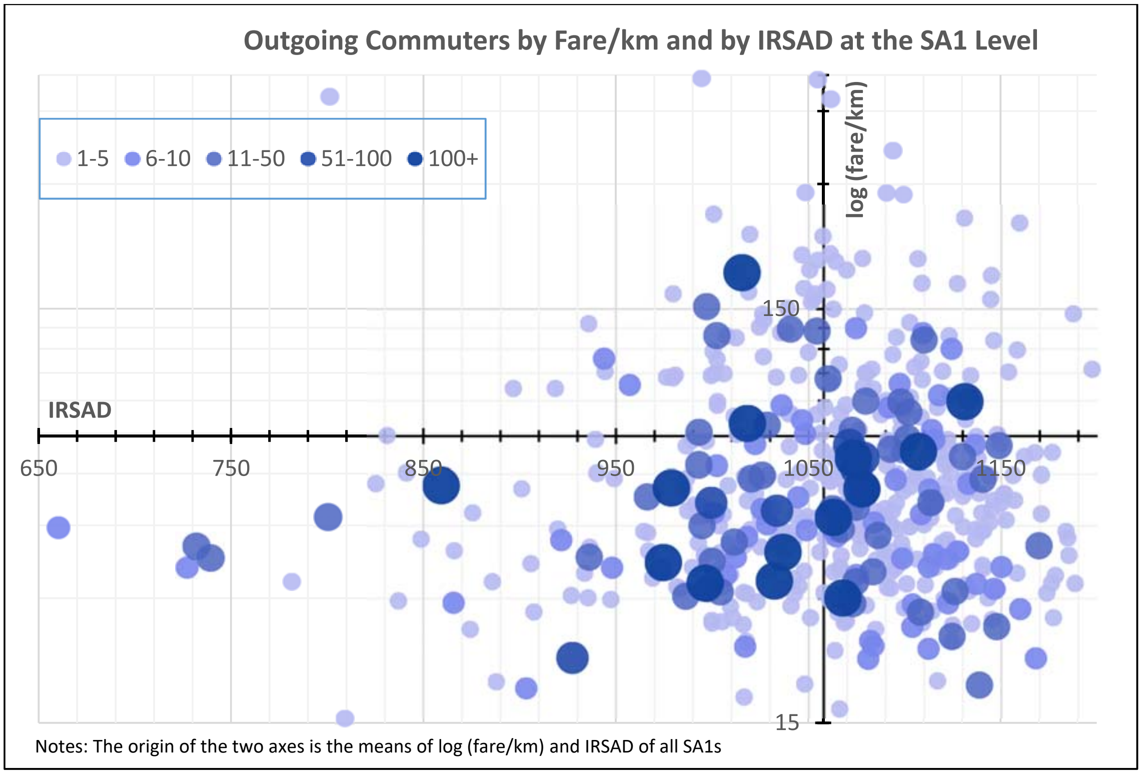

Figure 4: Outgoing Commuters by Fare/km and by IRSAD at the SA1 Level

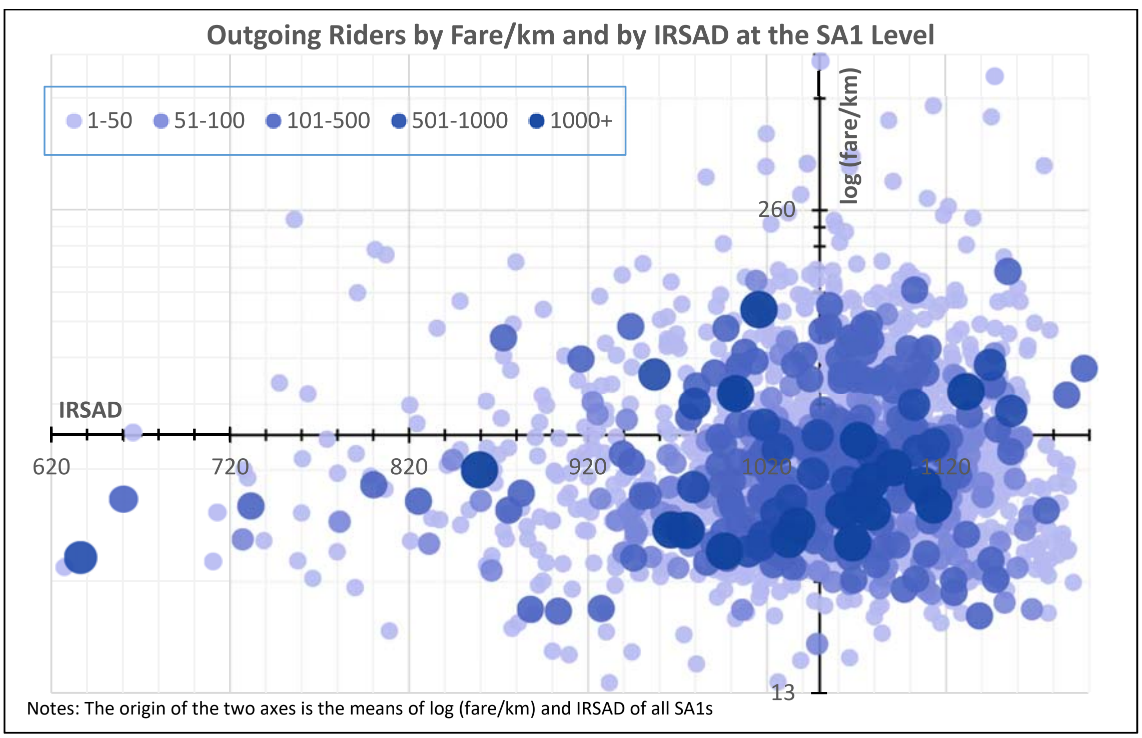

Figure 5: Outgoing Riders by Fare/km and by IRSAD at the SA1 Level

After identifying SA1's where there were incoming or outgoing commuters or riders probably suffering from environmental injustice or benefiting from the zone-based fare system, we drew maps to see whether those SA1's have some spatial pattern. Figure 6 is a sample of such maps. It shows where those SA1's that simultaneously appear in Quadrant II of Figures 4 and 5 are in space and how many overpaying outgoing commuters there were in each SA1. Two SA1's in Downtown Brisbane and three SA1's in the south, southwest and southeast (relative to the downtown) had the most commuters that probably experienced environmental injustice.

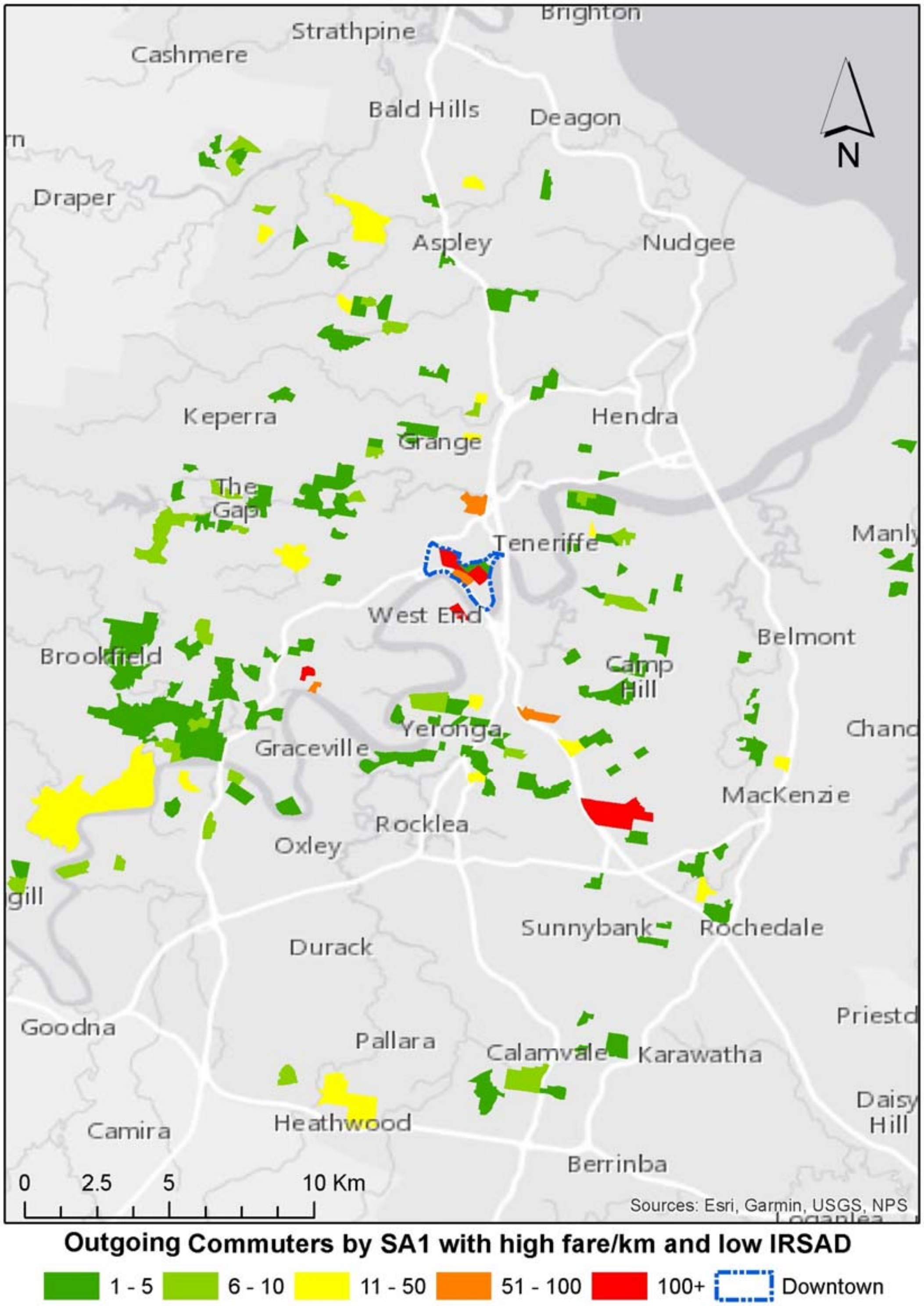

Figure 6: SA1's with Low IRSAD and Overpaying Commuters and Riders

Which corridors (routes) did they travel along the most? TransLink categorizes bus routes into inbound ones and outbound ones relative to Downtown Brisbane. Our rebuilt trajectories can be aggregated by transit corridor, by direction, by overpaying commuters and by overpaying riders. Figure 7 is a sample of the aggregated rebuilt trajectories, which show which inbound bus routes or route segments are most popular among the overpaying riders. To verify how the rebuilt (visualised) trajectories of overpaying riders in Figure 7 matched the recorded journeys by route in the Go card data, we calculated the correlation coefficient of the two for Routes 1 to 200, the most well utilized routes in SEQ. We got a correlation coefficient of 0.82, which indicates that the rebuilt trajectories matched satisfactorily with the recorded journeys. It should be noted that when we derived/visualised the rebuilt trajectories we assumed that riders always took the direct route between any two stations while the recorded journeys in Go card data reflected how riders travelled in reality. Of course, Go card data only informed us about the origin and destination of each trip and that was why we must rebuild the trajectory of each journey, which can consist of multiple trips by accessing exogenous GTFS data via API.

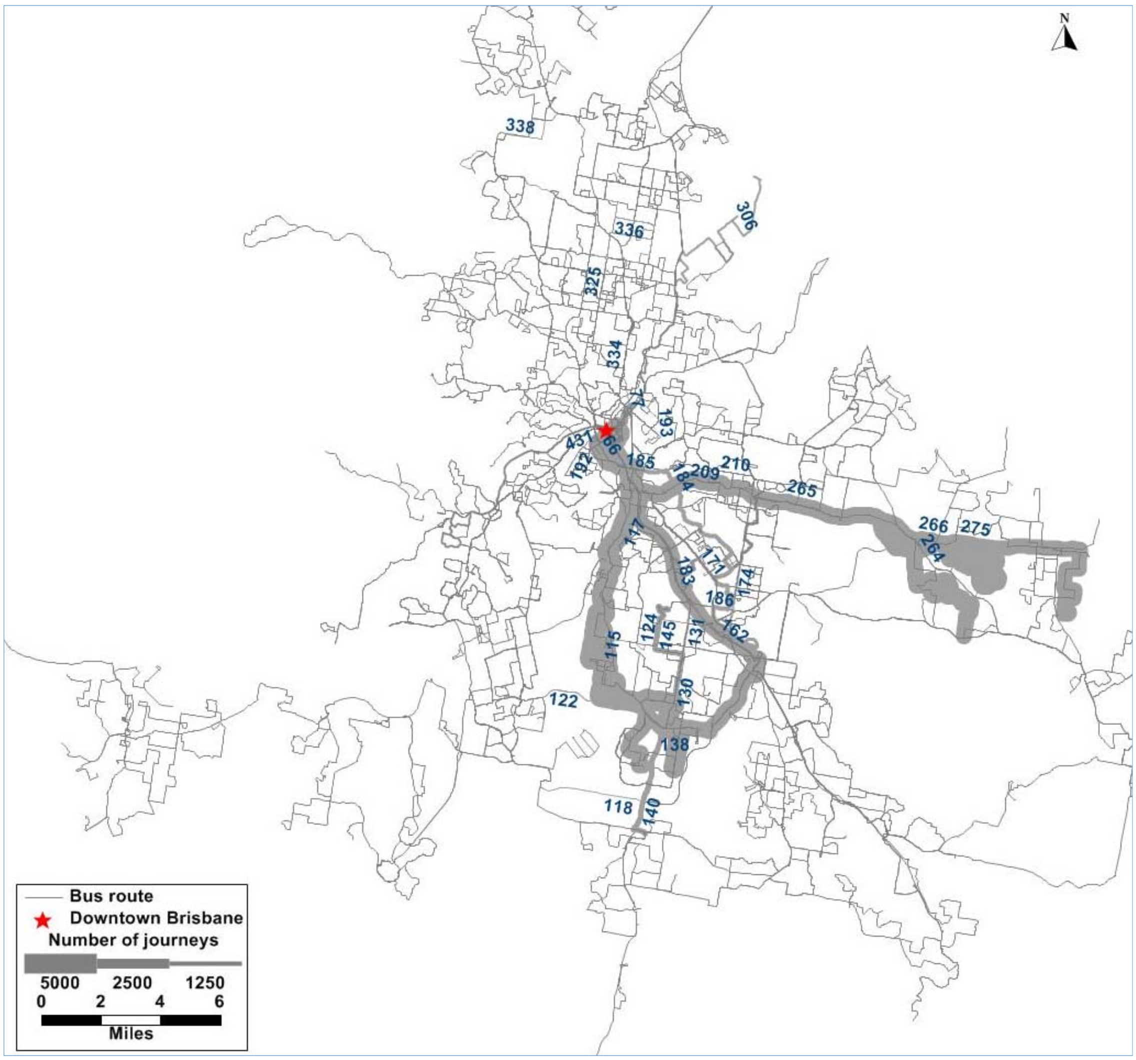

Figure 7: Popular Inbound Corridors among the Overpaying Riders*
*Route number is shown on the corridor.

For inbound journeys, the overpaying riders are most likely to travel along those routes (route segments) from areas in the south and southeast of Downtown Brisbane, notably, Routes 138, 183, 115, 162 and 117. For outbound journeys, the overpaying riders are most likely to travel along those routes from Downtown Brisbane to areas in the south as well as a few routes in the areas southeast of Downtown Brisbane. For both inbound and outbound journeys, the overpaying riders are less likely to travel along routes in areas north or west of Downtown Brisbane.

Sociodemographic characteristics of overpaying areas (commuters)

One of the drawbacks of smartcard data is that they do not contain sociodemographic information about riders. Thus, in addition to on-line GTFS and smartcard data, we also used local census data so as to better understand spatial and socioeconomic characteristics of overpaying riders. We linked popular origins and destinations of riders (based on Go card data) to a reasonable unit of analysis (i.e., SA1) in which local censuses have collected various sociodemographic information of residents or workers therein. Eventually, the socio-economic variables to be tested for the variances of the most/least popular origins or destinations by SA1 include total population ("Population"), the rate of people younger than 15 years old ("Student_15"), the rate of people older than 65 years old ("Age_65"), the rate of commuters traveling to work by bus ("Commuters_Bus"), the rate of people who have college or higher degree ("College_Rate"), the rate of people who speak English very well ("English_Well"), high income rate ("High_Income"), the rate of people who were born in Australia("Australian_Born"), the rate of married people ("Married_Rate"), employment rate ("Employment_Rate") and Socio-Economic Indexes for Areas (SEIFA). SEIFA is a product developed by the ABS that ranks areas in Australia according to relative socio-economic advantage and disadvantage. It comprises of Index of Relative Socio-economic Advantage and Disadvantage (IRSAD), Index of Relative Socio-economic Disadvantage (IRSD), Index of Economic Resources (IER) and Index of Education and Occupation (IEO). Those indices can be used to perform functions such as:

- Determining areas that require funding and services
- Identifying new business opportunities
- Investigating into the relationship between socio-economic disadvantage and various health and educational outcomes.

More information about these indices is summarized in Table 2.

Table 2: ABS Socio-Economic Indexes for Areas*

Index	Meaning	Notes
IRSAD	Summarising information about the economic and social conditions of people and households within an area, including both relative advantage and disadvantage measures.	A low score indicates a less favourable status or condition.
IRSD	Summarising information about the economic and social conditions of people and households, including only measures of relative disadvantages.	
IER	Focusing on the financial aspects of relative socio-economic advantages and disadvantages, by summarising variables related to income and wealth.	
IEO	Reflecting the educational and occupational level of communities.	

*Authors' compilations based on: http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/2033.0.55.001~2011~Main%20Features~The%20Indexes~10003, accessed 2 May, 2017.

T tests were used to determine if and how the socioeconomic characteristics of the most and least popular origins (for outgoing riders) and destinations (for incoming riders) were significantly different from each other. In this study, we first rank all origins or destinations by SA1 by the number of overpaying riders. The first quartile of origins or destinations by SA1 that produced or attracted the most riders were defined as the most popular ones. The fourth quartile of origins or destinations by SA1 that produced or attracted the fewest riders are regarded as the least popular origins or destinations, respectively.

Tables 3 and 4 present the t-test results of the most and least popular origins/destinations among overpaying commuters, a subset of riders we felt more confident when linking ABS data to Go card data, especially at the origins. Before performing t test, Levene's Test was first conducted to test the assumption of equality of variances, as we were unsure about the variances in different socioeconomic variables measuring the two types of origins/destinations.

Table 3: t-test Results of the Most and Least Popular Origins (by SA1)

Variable Name	Mean		t-test for Equality of Means
	Least Popular (n=137)	Most Popular (n=137)	Sig. (2-tailed)
Population	427.527(145.270)**	453.263(216.316)	0.236
Age_18*	0.260(0.062)	0.208(0.081)	0.000
Age_65	0.136(0.078)	0.108(0.076)	0.002
Commuters_Bus	0.099(0.069)	0.139(0.073)	0.000
College_Rate*	0.662(0.164)	0.747(0.113)	0.000
English_Well_Rate*	0.863(0.134)	0.881(0.081)	0.184
High_Income_Rate	0.163(0.081)	0.200(0.085)	0.000
Australian_Born*	0.876(0.090)	0.839(0.108)	0.002
Married_Rate*	0.502(0.114)	0.384(0.129)	0.000
Employed_Rate	0.596(0.069)	0.618(0.072)	0.009
IRSAD	1049.127(95.788)	1054.214(81.217)	0.618
IRSD	1040.808(94.720)	1043.546(79.376)	0.785
IER	1031.401(101.265)	979.693(98.776)	0.000
IEO*	1054.891(89.660)	1099.128(79.917)	0.000

Notes:
*Levene'stests for equality of variances indicate that two samples have equality of variances (p-value <= 0.05) and so t-test assuming equal variances are run. For the other classifications, t-tests are run assuming unequal variances.
** Standard Deviations are in parentheses.

As seen in Table 3, the results of t-test indicates that the most popular origins are significantly different from the least popular ones in many socio-economic characteristics, most notably, "Age_18", "Age_65", "Commuters_Bus", "College_Rate", "High_Income_Rate", "Australian_Born", "Married_Rate", "Employed_Rate", "IER" and "IEO" (Sig.(2-tailed)<0.05). In other words, commuter riders are more likely to pay a higher fare per kilometre when they travel from SA1s that have the following socio-economic characteristics:

- Lower percentage of young residents and senior residents
- Higher percentage of bus commuters
- Higher percentage of people who have college or higher degree
- Higher percentage of high income people
- Lower percentage of Australia-born residents
- Lower percentage of married families
- Higher percentage of employed people
- Smaller IER but bigger IEO.

Table 4: t-test Results of the Most and Least Popular Destinations (by SA1)

Variable Name	Mean		t-test for Equality of Means
	Least Popular (n=80)	Most Popular (n=80)	Sig. (2-tailed)
Population	428.520(156.419)**	449.375(239.319)	0.519
Age_18	0.227(0.092)	0.197(0.091)	0.046
Age_65*	0.133(0.137)	0.092(0.053)	0.015
Commuters_Bus*	0.094(0.071)	0.143(0.081)	0.000
College_Rate*	0.679(0.175)	0.754(0.123)	0.002
English_Well_Rate*	0.827(0.184)	0.871(0.068)	0.045
High_Income_Rate*	0.171(0.099)	0.185(0.081)	0.335
Australian_Born*	0.852(0.114)	0.783(0.149)	0.001
Married_Rate	0.445(0.129)	0.351(0.124)	0.000
Employed_Rate	0.608(0.083)	0.615(0.091)	0.585
IRSAD*	1035.352(93.135)	1045.774(63.669)	0.417
IRSD	1024.368(87.979)	1032.670(64.422)	0.510
IER	991.226(100.866)	943.748(95.597)	0.003
IEO*	1063.433(94.318)	1106.800(66.796)	0.001

Notes:
*Levene’s tests for equality of variances indicate that two samples have equality of variances (p-value <= 0.05) and so t-test assuming equal variances are run. For the other classifications, t-tests are run assuming unequal variances.
** Standard Deviations are in parentheses.

The t-tests for equality of means of socio-economic characteristics between the most and least popular destinations (Table 4) produce similar results as the popular origins in several aspects. Therefore, the most popular destinations for commuter riders share many socio-economic characteristics with the most popular origins, including:

- Lower percentage of young residents and senior residents
- Higher percentage of bus commuters
- Higher percentage of people who have college or higher degree
- Lower percentage of people who speak English very well
- Lower percentage of Australia-born residents
- Lower percentage of married families
- Smaller IER but bigger IEO.

Notably, the most popular destinations for commuter riders were associated with a statistically significantly lower percentage of people who speak English very well compared to the least popular destinations. But unlike the most popular origins, the most popular destinations do not to have a higher percentage of high income people and a higher percentage of employed people.

Conclusions and Discussion

Existing literature has well informed us about generic theories of society and justice and transportation/space and justice. But it has only provided us with limited and discrete knowledge about transit fare, justice and social inclusion. In this exploratory study, we have summarized some of the above theories. We have also demonstrated how new open/big data (NOBD) such as GTFS and smartcard data can be utilized to increase our knowledge about transit fare and justice. Based on the empirical studies of Go card riders/commuters, we have produced some findings and insights about environmental injustice in the local context.

As a whole, we think we have produced some transferrable lessons, experiences, procedures and/or methods that may benefit other scholars or professionals who want to do more based on our explorations. **First**, we confirm that transit fare does have spatial and equity implications. In SEQ, for instance, commuters into or out of downtown from the southeast were more expensive fare per kilometre than other riders in the zone-based fare system. There were also some SA1’s and commuters probably were experiencing environmental injustice in transit fare (See Figures 4 to 6). **Second**, in combination with traditional data such as census data, NOBD can help us more accurately identify areas/riders that probably experience environmental injustice (and even social exclusion) (Figures 3 to 6). In addition, the combination can help us understand differences or similarities between those areas or riders (Tables 3 and 4). **Third**, we illustrate that such methods or procedures as “trajectory rebuilding”, “fare matching”, “segment tagging”, “desired line/stop visualization”, “commuter identification” and “scenario analysis” can be used to embody why and how transit fares could have important equity and spatial implications in a specific context.

In the long run, this study as well as other transit fare and justice studies can be improved should extra tasks as follows are undertaken. The first is to establish some common keys that both traditional data and NOBD share, for instance, unique but anonymous smartcard ID. Currently, the traditional data and NOBD do not have such a common key and use different units of analysis. In the case of SEQ, for instance, the units of our analyses are SA1 for census areas and individual rider for local smartcard data. A lot of information is lost when we aggregated individual riders by SA1. A second task is to develop the fair fare baseline. In this study, we simply assume that distance-based fare is fairer than zone-based fare. In reality, it can be much more complex to derive a fair fare system. In existing studies, for instance, Nuworsoo et al. (2009) argued that three criteria must be simultaneously considered when we design a fair fare system: the benefit criterion, the cost criterion and the ability to pay criterion. Different transit lines, especially for subways or elevated heavy/light rails, could have substantially different construction costs due to land costs and terrain constraints. It might be fair for riders on these lines to pay slightly higher fare per kilometer to compensate for the higher construction cost per kilometer. In addition, transit riders living in more remote areas might be enjoying a disproportionately lower land price as the land bid rent curve is non-linear. While taking advantage of cheaper housing costs, it is not necessarily unfair from a transit fare perspective that they incur higher per-km transportation costs (i.e. fare-per-km). In this regard, surveys of local stakeholders such as residents, riders, operators and experts are needed for us to establish a fair fare baseline.

The last task is that we need to find ways to better understand the price elasticity of transit riders and capture those simply cannot afford to use the most expensive part of local transit services. In this study, in order to find the fair fare baseline, we simply assume that all riders would still travel by the local transit system as they used to despite of the fare changes. But this may not be true. Litman (2017), for instance, showed how transit fare changes can increase or decrease the transit ridership for different transit services in different countries. This task, which definitely requires interdisciplinary collaborations, is about how to connect more theories of justice and social exclusion to real-world transit services in general and transit fare in particular. Rawls (1971/1999), for instance, argued for procedures for people to derive principles of justice. What should be such procedures in the domain of transit? As scholars such as Djkec (2001) rightly pointed out, we need to appropriately address the root of injustice. Otherwise, it is highly likely that the injustice we observed or measured can reproduce itself socially and spatially.

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