The life and death of residential dissonants in transit-oriented development: A discrete time survival analysis

Abstract

Residential dissonants, residents who are not satisfied with land use patterns in their neighbourhood, are a threat to transit-oriented development (TOD) policy because of their unsustainable transport choices. However, it is not known if their level of dissatisfaction is reduced in TODs, and if so, the time duration it takes. This study tracks dissonance status of 98 TOD residents using five waves of panel data spanning over nine years from Brisbane, Australia. The residents were classified into TOD dissonant and TOD consonant (opposite of dissonants) groups and a discrete time survival analysis technique was applied to identify time-to-event for these groups. An event was recorded if a dissonant became a consonant, or vice versa. Two discrete time hazard models were estimated using binary logistic regression analysis (one for each transition) to identify socio-demographic and built environment characteristics associated with the occurrence of an event. Results showed that about 46% of the TOD residents were dissonants at baseline. The survival functions were significantly different between dissonant and consonant classes. About half of the dissonants took-on the characteristics of consonants in just four years. In contrast, TOD consonants remained consonants relatively longer (median survival duration is 9 years). Groups that were likely to become dissonants were those with low educational status, and people born overseas. The findings suggest that TODs have an autonomous effect on changing attitudes over time, which verifies the ‘reverse causality’ hypothesis, and therefore, TODs are likely to be dissonant free naturally presumably as residents experience the benefits of TOD living. The process could be sped up with targeted policy interventions (e.g., concessionary travel card, rent relief to bear the high cost of living in TODs) for those being as, or likely to be susceptible to become dissonant.

***Keywords*:**

Transit-oriented development; Residential dissonance; Residential self-selection; Reverse causality; Travel attitudes; Discrete time survival analysis; Discrete time hazard model; Travel behaviour; Brisbane

1. Introduction

The theory of cognitive dissonance is now increasingly being used in transportation research to explain travel behaviour outcomes (De Vos, 2018; Kah and Lee, 2016; Kajosaari et al., 2019; Manaugh and El-Geneidy, 2015; Tanford and Montgomery, 2015; van de Coevering et al., 2018). Cognitive dissonance is a state of mind involving conflicting attitudes, beliefs or behaviour (Festinger, 1957). For example, knowing the risk of cancer from cigarettes (cognition) and continuing smoking (behaviour) can be considered as a state of cognitive dissonance. Festinger (1957) has highlighted that individuals try to avoid discomfort from cognitive dissonance in three ways: a) altering attitudes, beliefs or behaviour; b) acquiring new information (e.g. new research shows that smoking is not that harmful); and c) reducing the importance of cognition (e.g. the pleasure of smoking is more important than the sufferings from cancer).

Schwanen and Mokhtarian (2004) have adapted the theory of cognitive dissonance in the context of urban form and travel behaviour research and referred to it as residential dissonance, which is the focus of this study. Yet, the theory has also been applied in other areas of transportation research such as in the context of travel attitudes and travel behaviour, which is denoted as travel mode dissonance (De Vos, 2018; Kroesen et al., 2017; Li, 2018; Thigpen, 2019; Ton et al., 2020; Ye and Titheridge, 2017; Zarabi et al., 2019). Residential dissonance is characterised as the discrepancy between preferred and actual land-use patterns in residential neighbourhoods whereas a congruency between them is referred to as residential consonance (Schwanen and Mokhtarian, 2004). Likewise, mismatched residents in a neighbourhood are defined as residential dissonants whereas residents with matched land use patterns are denoted as residential consonants.

Our review of the literature on residential dissonance, as elaborated in Section 2, shows that a large share of dissonants exist in a neighbourhood who are found to be a threat to sustainable transport and land use policy strategies (e.g. transit-oriented development). This is due to the fact that dissonants in transit rich neighbourhood exhibit an unsustainable travel behaviour (more reliance on the car and less on public transport) and they are unlikely to make a behavioural shift (e.g. from car to public transport) in order to be congruent with existing land use patterns (e.g. transit rich neighbourhood). Dissonants are also difficult to identify for policy interventions; and evidence on their adjustment of preferences to surrounding land uses has been scarcely reported and often inconclusive and incomplete. Against this backdrop, this study aims to examine the survival duration of residential dissonants/consonants in a neighbourhood in a natural experiment. In particular, the study seeks to answer the following three interrelated questions:

a) Do existing dissonants in a neighbourhood die (i.e. leave the neighbourhood and/or transition to become consonants), and if so, how long do they take to disappear?
b) Do new dissonants in a neighbourhood continue to form, and if so, how long does the process take for an existing consonant to transition to a dissonant?
c) Which of the dissonant/consonant groups die out in a neighbourhood?

An identification of the two durations would inform if policy intervention is needed at all to reduce the level of dissonance in a neighbourhood. For example, if dissonants die out in a shorter timespan compared with their birth, a neighbourhood would eventually be free of dissonants. Similarly, if certain groups of dissonants are less likely to die out compared with other groups, policy interventions can be targeted and tailored to these groups.

2. The processes of nullifying the discomfort from residential dissonance

A recent review article by De Vos and Singleton (2020) identifies that the literature on residential dissonance focuses on six key themes: a) an identification of the extent of residential dissonance in a neighbourhood; b) an assessment of the effects of residential dissonance on residential satisfaction; c) an evaluation of the impacts of residential dissonance on travel satisfaction; d) modelling the effects of residential dissonance on travel behaviour; e) effects of residential dissonance on residential mobility; and f) examination of the changes in preferences towards chosen neighbourhoods to reduce residential dissonance. In addition, our review shows that a few studies attempted to characterise residential dissonants based on their socio-demographic features. The findings from these studies provide important bases for addressing residential dissonance in order for sustainable urban and transport policies to be effective.

Available evidence shows that a large share of residents within a neighbourhood are dissonants, ranges between 23% and 60% in different types of neighbourhoods (Cao, 2015; Cho and Rodríguez, 2014; De Vos et al., 2012; Kamruzzaman et al., 2016a; Sanders et al., 2015; Schwanen and Mokhtarian, 2004). These mismatched residents possess a lower level of residential satisfaction (Cao and Wang, 2016), which leads to a reduced level of life satisfaction and psychological well-being (Fernández-Portero et al., 2017). Residential dissonance also reduces travel satisfaction for urban dwellers because their travel preferences (e.g. car use) are restricted by land use patterns (e.g. lack of parking) (De Vos et al., 2016). These dissatisfied residents try to minimise their discomfort (dissonance level) by altering attitudes, beliefs or behaviour as highlighted by Festinger (1957). As a result, the travel behaviour of dissonants has been identified to differ significantly from consonants (De Vos et al., 2012; Huang et al., 2016; Kajosaari et al., 2019; Schwanen and Mokhtarian, 2005a, b; Wolday et al., 2018). For example, despite living in the same transit rich area, consonants used more transit (104% and 114% for commuting and non-commuting activities respectively) than dissonants in the Oslo Metropolitan Area (Wolday et al., 2018). A one unit increase in dissonance level reduces an individual's propensity of switching to public transport by 50% in transit rich neighbourhoods (Kamruzzaman et al., 2013a).

The above findings are concerning for the promotion of sustainable travel behaviour, particularly because dissonants exist among all socio-economic groups and cannot be readily identified for policy interventions (Kamruzzaman et al., 2016a; Schwanen and Mokhtarian, 2004). As a way forward, Schwanen and Mokhtarian (2005b) suggest that residential dissonance could be reduced in two ways: a) dissonants relocate to their desired suburb to reduce their discomfort; and/or b) they change their preferences to adjust with existing land use patterns. Nevertheless, empirical findings supporting these hypotheses remain inconclusive. In terms of residential mobility behaviour, Kamruzzaman et al. (2013b) found that the share of residential relocation are nearly equal for dissonant and consonant groups from a neighbourhood. In addition, studies found that the travel behavioural adjustment of dissonants is very slow (Kamruzzaman et al., 2015; Kamruzzaman et al., 2013a). This finding works in the opposite direction of the hypotheses because travel behaviour often reinforces attitudinal response (Bagley and Mokhtarian, 2002; Reibstein et al., 1980; Tardiff, 1977). This means that a dissonant who inherently drive more in an urban environment is likely to continue developing pro-driving attitudes due to their driving.

The attitudinal adjustment to residential land uses is referred to as the 'reverse causality' hypothesis in the literature (Kroesen, 2019; van de Coevering et al., 2016; van Wee et al., 2019). The causality hypothesis is centred on the residential self-selection effect, which postulates that individuals with certain travel attitudes (e.g. pro-public transport) deliberately choose residential neighbourhoods with certain land use patterns (e.g. close to train station) that enables them to realise their travel attitudes (Guan et al., 2020; Handy and Clifton, 2001). This means that the effects of the built environment on travel behaviour can partly be credited to the residential self-selection effects (Mokhtarian and Cao, 2008). The reverse causality hypothesis, on the other hand, posits that the land use patterns of a residential neighbourhood (or travel behaviour) shape the travel attitudes of an individual (Bohte, 2010). If this hypothesis is to be true, it implies that a residential dissonant of an urban environment eventually becomes consonant over time.

Unlike the self-selection literature, studies on the reverse causality hypothesis is relatively scarce. In a cross-sectional study, Bagley and Mokhtarian (2002) found no impact of residential location on attitudes in the San Francisco Bay Area – i.e. attitudes did not change due to residential location. In contrast, Bohte (2010) found the evidence of reverse causality in the Netherlands. This study found that an increasing travel distance to a railway station negatively affected respondents' attitudes towards public transport. In another cross-sectional study, Lin et al. (2017) observed bi-directional relationships between the built environment and travel attitudes in Beijing, and the direction depends on the ability of the respondents to self-select residential location. These studies, however, failed to capture dynamic changes in attitudes due to cross-sectional nature of the data. Bagley and Mokhtarian (2002, p.294) highlighted that these can "best be identified with a longitudinal data set that measures attitudes, lifestyle, demographics, and travel behavior for a panel of households".

In a quasi-longitudinal study, De Vos et al. (2018) did not find a significant effect of residential neighbourhood on travel attitudes following residential mobility when the relocation involved little changes in the built environment (e.g. suburban to suburban, and urban to urban). However, the study found some evidence of attitudinal changes when a residential relocation was associated with a large change in the built environment (e.g. from suburban to urban or vice-versa). In another residential relocation study, Wang and Lin (2019) found inconsistent relationship between pre-move and post-move attitudes and concludes that individuals' travel preferences are susceptible to change. However, none of these studies have specifically investigated attitudinal adjustment of dissonants, and as a result, which of the different groups experienced an attitudinal change is unclear. In addition, the findings from these studies suggest that built environment interventions might have an effect on attitudes – not an existing built environment.

Our review of the literature finds two longitudinal studies that support the hypothesis that existing land use patterns of a neighbourhood can affect travel attitudes over time (Kroesen, 2019; van de Coevering et al., 2016). Kroesen (2019), using the Dutch mobility panel data, found that the built environment (distance to train station) and travel behaviour (train use and car ownership) in 2014 influenced the possibility for a person to remain in the same attitudinal class between 2014 and 2016. The study, therefore, questions the use of attitudinal data as an exogenous variable to address the residential self-selection bias in determining the effects of the built environment on travel behaviour. In contrast, van de Coevering et al. (2016), using a different dataset from the Netherlands, found that people who lived away from a train station in 2005 developed pro-car attitudes in 2012. Again, none of these studies measured attitudinal changes specifically for dissonant groups. However, in a later study, van de Coevering et al. (2018), using a transition matrix, showed that such changes occurred for a fraction of residents and that there is the highest possibility (86-100%) for different groups to remain in the same class over time, which corroborates the findings as reported in Kroesen (2019). Moreover, the study found that dissonants are unlikely to switch to consonants classes.

The above review of attitudinal adjustment process suggests that residents in general may or may not experience an attitudinal change. However, studies examining attitudinal adjustment process of dissonants are rare, and no such evidence is reported in the literature. More importantly, the questions that the literature yet to answers fully for attitudinal adjustment of residents are, "how many people, which kinds, how much, and how long does it take" (Bagley and Mokhtarian, 2002, p.294)? This study partially addresses this gap by examining the duration of attitudinal adjustment processes of dissonants and consonants.

3. Data and methods

3.1 Study context

This study investigates the three research questions in the context of TOD neighbourhoods. TODs are characterised by moderate to high population density, mix of land uses, well design road networks (e.g. connected), and centred on transit stations. TODs are chosen to study for two reasons: a) prior research has shown that a large share of TOD residents are dissonants (30%), which would enable investigation of whether dissonants in TODs disappear naturally (Kamruzzaman et al., 2016a); and b) TODs involve huge financial investments aimed at creating settings to prompt individuals to choose public and active transport services (Cervero et al., 2004); and contrasting to this aim, TOD dissonants are more likely to use private motor vehicles and less likely to use public transport compared with TOD consonants (Cao, 2015; Kamruzzaman et al., 2015; Phani Kumar et al., 2018). As a result, an evidence of survival duration for dissonants could inform whether policy interventions are needed or not to reduce the level of dissonance, and thereby, to bring greater certainty in TOD investments. TOD neighbourhoods are chosen from Brisbane, Australia as case studies due to TOD focused planning policies in this context (Queensland Government, 2009, 2010; Searle et al., 2014; Tanko et al., 2018; Yang and Pojani, 2017).

3.2 Sample and data

The research questions were investigated using the HABITAT (**H**ow **A**reas in **B**risbane **I**nfluence Heal**t**h and **A**ctivi**t**y) panel survey data from Brisbane. The survey applied a two-stage probability sampling method. First, the survey randomly selected 200 neighbourhoods (defined as census collection districts - CCDs) from Brisbane (Figure 1). A CCD contained, on average, 203 occupied private dwellings, and was the smallest administrative unit used by the Australian Bureau of Statistics when the sampling strategies were designed for the HABITAT survey. Second, adults, aged 40 to 65, from these neighbourhoods were randomly selected (Burton et al., 2009). The survey was administered in five phases, starting in 2007, and followed-up in 2009, 2011, 2013 and 2016. Data were collected from 11,035, 7,866, 6,900, 6,520, and 5,187 adults respectively. The initial respondents were refined for this study based on two criteria. First, individuals who relocated to their neighbourhoods prior to 2005 (i.e. more than two years ago from the baseline in 2007) were excluded. This exclusion ensured the selection of an unbiased analytical sample who developed residential dissonance due to an immediate experience of land use patterns of a neighbourhood – i.e. neither due to reverse causality as discussed earlier (i.e. attitudinal changes due to land use pattern over time) nor due to a longer stay in that neighbourhood. Schwanen and Mokhtarian (2004) found a positive relationship between the length of stay and dissonance level in urban neighbourhoods. Second, given the focus of this study, only those individuals were retained whose residential neighbourhoods were classified as TODs. These exclusions led to 98 participants at baseline (Figure 1). The characteristics of the participants in 2007 are shown in Table 1.

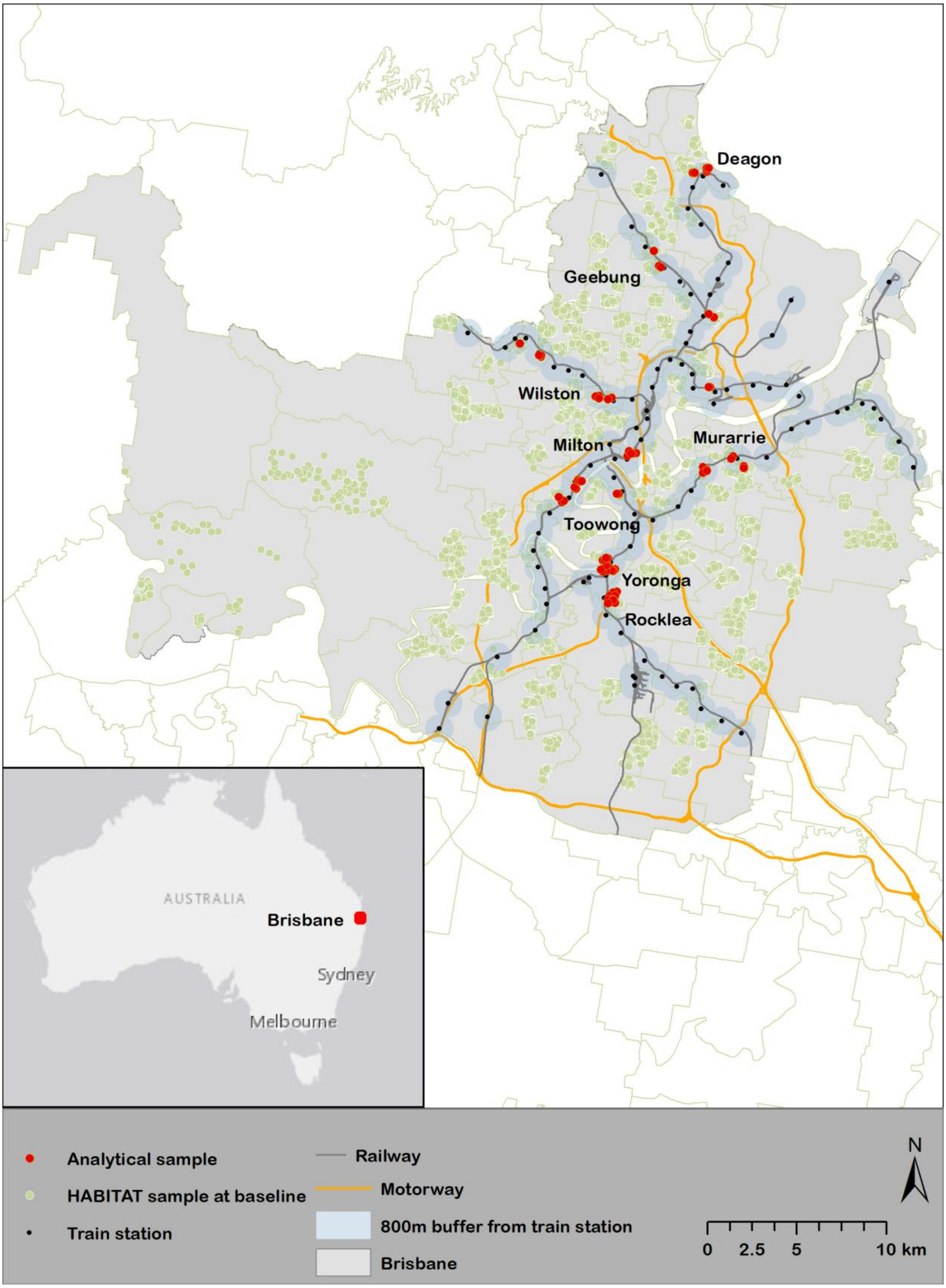


Figure 1: Distribution of HABITAT survey participants and analytical samples across Brisbane

Table 1: Sample description in 2007

Variables	Frequency	%	Mean	Standard deviation
Gender				
Male	37	37.8		
Female	61	62.2		
Age			51.0	7.1
Education				
Up to year 12	35	35.7		
Certificate/diploma	27	27.6		
Bachelor or higher degree	36	36.7		
Vehicle availability*				
Yes, always	83	84.7		
Other (e.g. sometimes/do not drive/not available)	15	15.3		
Employment status*				
Full-time employed	51	52.0		
Part-time employed	18	18.4		
Other (unemployed/retired)	29	29.6		
Country of birth				
Other	28	37.8		
Australia	61	62.2		
Self-reported health status (1-Poor to 5-Excellent)*			3.39	1.1
N	98			

* These covariates vary over time

3.3 Methods

Figure 2 outlines the methodological steps applied in this study to identify the survival duration of residential dissonants/consonants in TODs. These steps are discussed in detail in the following sub-sections. Briefly, the survey respondents were classified into TOD and non-TOD residents based on the built environment characteristics of their home location in 2007. The TOD residents were then classified into TOD consonants and TOD dissonants groups using their residential location choice data. The consonants and dissonants status of the respective groups were monitored in subsequent survey periods. A median survival duration was then calculated for each group.

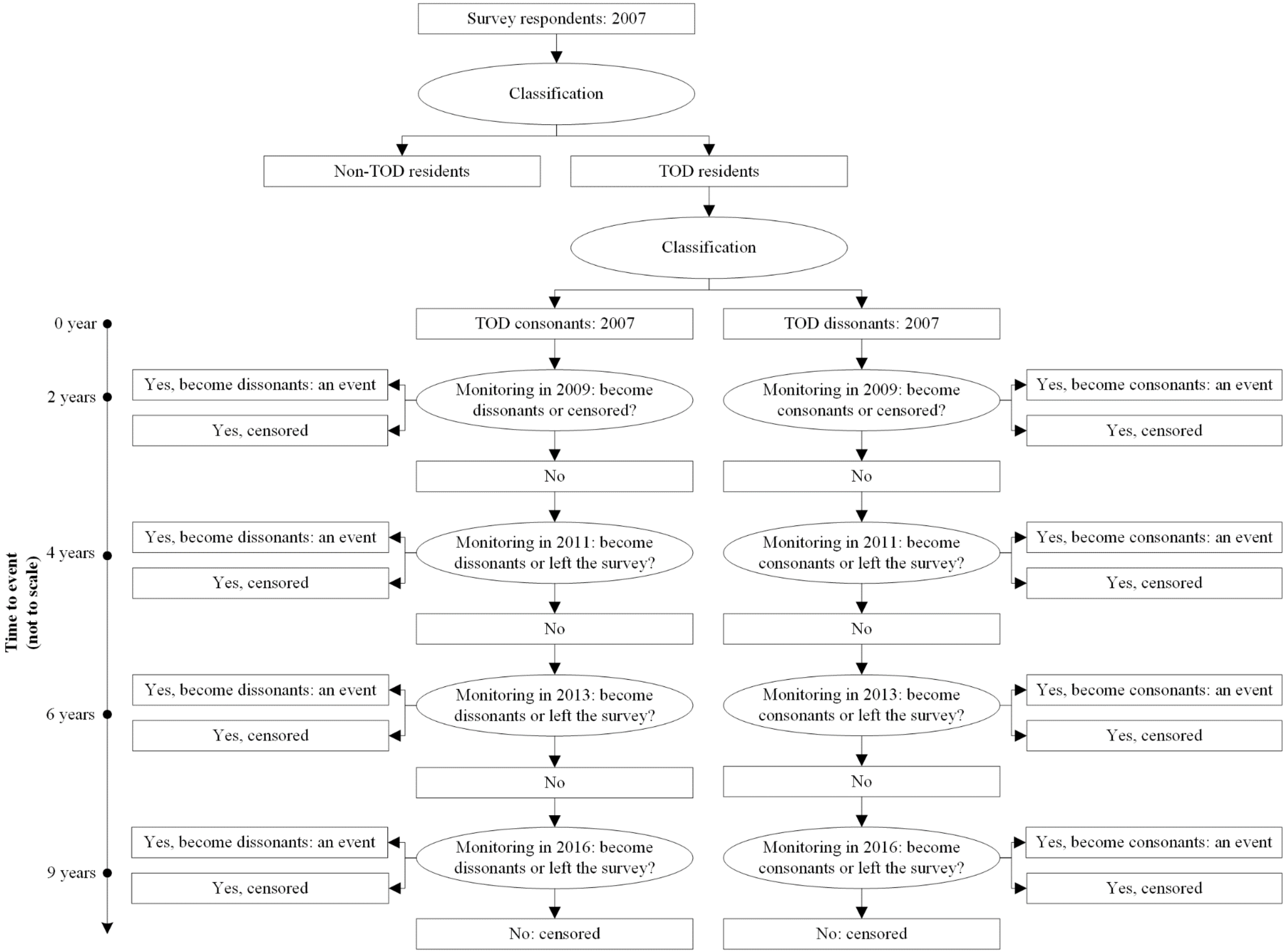


Figure 2: Schematic diagram of the methodology to identify survival duration of dissonants/consonants

3.3.1 Identifying TOD residents in 2007

A two-step process was followed to identify respondents whose living environments meet the characteristics of a TOD neighbourhood. First, an 800m network buffer was derived from all train stations in Brisbane and respondents whose home locations were located within the buffer were retained in the analytical sample (Figure 1). This procedure ensured that the selected residents had access to proximate public transport services. Second, three built environment factors (land use mix, net dwelling density, and intersection density) were derived for the selected respondents based on a 1000m network buffer centred on their home locations. These variables represent the 3Ds of a TOD neighbourhood (diversity, density, and design) (Cervero and Kockelman, 1997).

A two-step cluster analysis was conducted using these 3D factors, which resulted in a three-cluster solution (Figure 3). The main reasons for choosing the two-step cluster analysis method over other methods (e.g. K-means, are: its ability to automatically find the optimal number of clusters (the method does not require to pre-select cluster number manually); it combines BIC (Bayesian Information Criterion) and distance change criteria to select the optimum number of cluster, unlike other methods that use only a single criterion; the method can successfully handles both scale and categorical variables together, and is even more effective for scale variables (Kayri, 2007; Wendler, 2016).

The three clusters are distinguishable, among them Cluster 3 clearly represents the characteristics of a TOD in this context, as shown in the Description in Figure 3 (Queensland Government, 2009). The local policy also recognises that TODs are not 'one size fits all' and proposes various specification of TODs in terms of variations in density, diversity, and design (Queensland Government, 2010). From the perspective of these variations, the neighbourhoods that belong to Cluster 2 can also be considered as TODs. These two clusters contained 99 respondents; however, one respondent was excluded due to missing data on the factors affecting their residential location choice as discussed below in Section 3.3.2.

3.3.2 Identifying TOD dissonants/consonants in 2007

The 2007 survey asked respondents to specify which factors motivated them in selecting the current suburb of residence. They answered 17 statements on a 5-point Likert scale (1-strongly disagree – 5-strongly agree) (Appendix 1). Three of the 17 statements were used to identify if the 98 TOD residents moved to their chosen neighbourhoods due to TOD features. The three statements are: ease of walking to places, closeness to public transport, and wanted to live close to shops. It is likely that an individual who prefers to live in a TOD would rate highly all these features, while other statements do not unambiguously relate to living preferences for a TOD. The scores of the three items were used to classify respondents into two groups using the two-step cluster analysis method (Appendix 2). The cluster analysis clearly distinguishes the residential preferences of those 98 TOD residents. The average scores of Cluster 1 showed that these respondents chose TODs for their TOD-ness – these 53 respondents were referred to as TOD consonants. In contrast, 45 respondents in Cluster 2 did not rank these three factors highly, meaning that they chose the TOD neighbourhoods as a place to live for other reasons – this group of residents were defined as TOD dissonants. It should be noted here that, theoretically, there might be differences between reasons for choosing a neighbourhood and preference for living in a neighbourhood, however, our prior study shows that empirically these two theoretical constructs are highly correlated (anonymised).

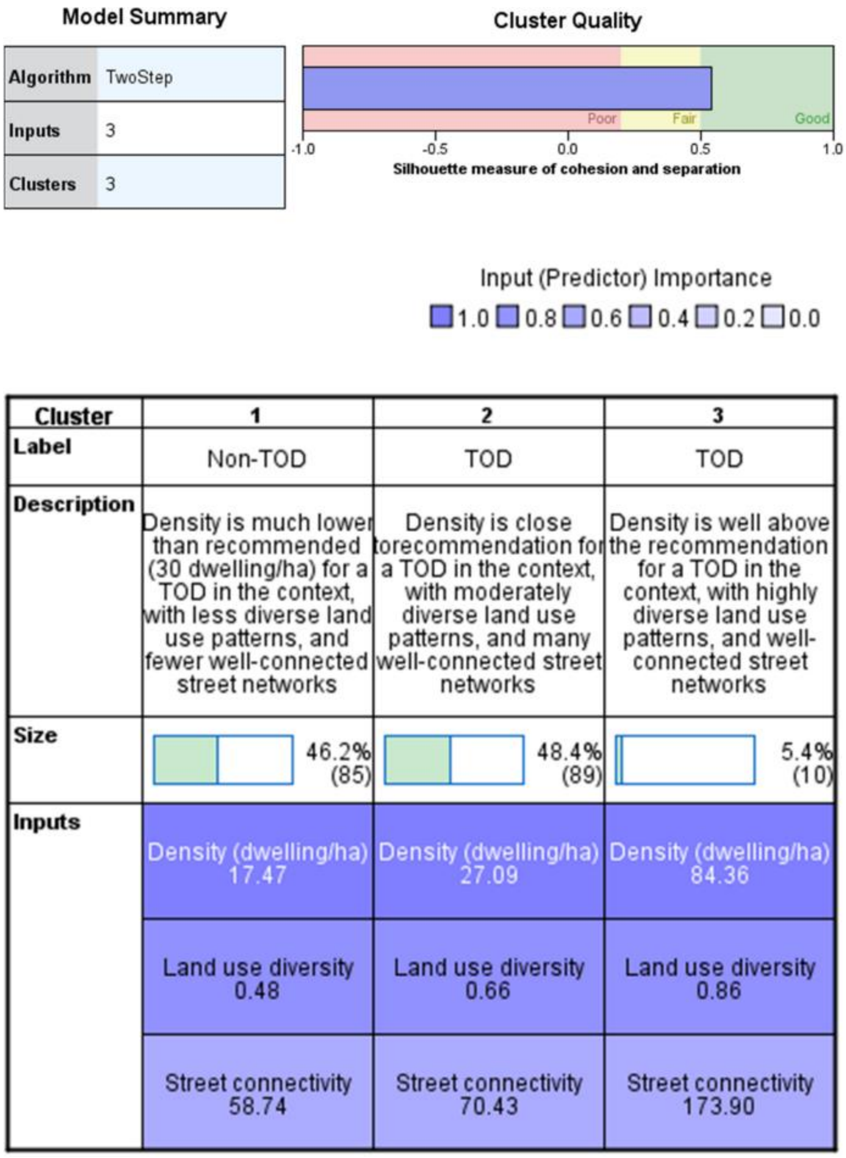
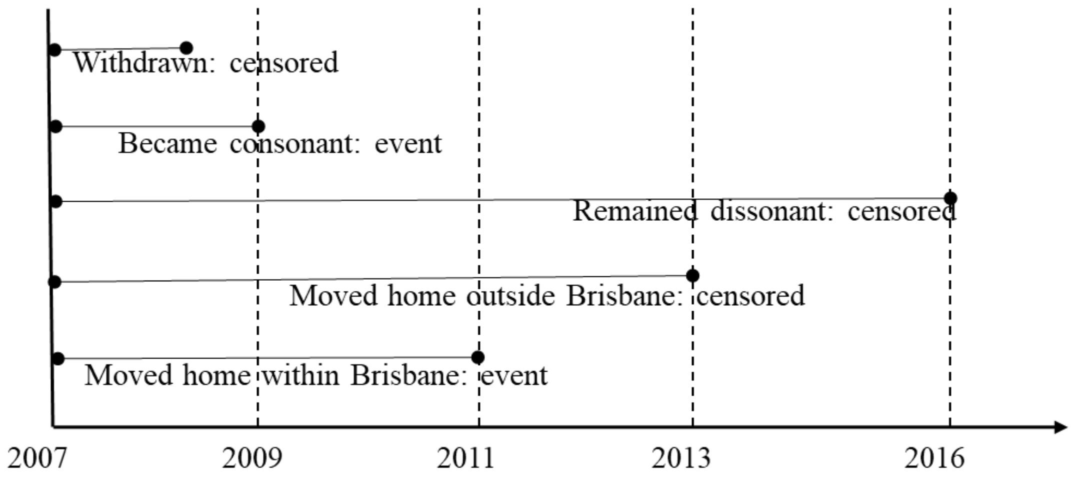


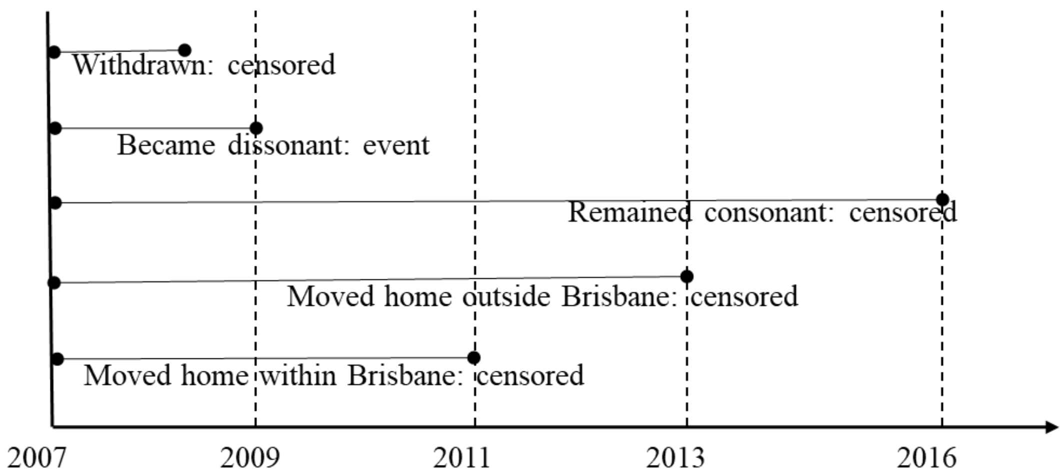
Figure 3: Cluster analysis of the three built environment factors to identify TOD neighbourhoods in Brisbane

3.3.3 Approach: survival analysis

This study's research questions required time-to-event data to be analysed – i.e. whether an event occurred and if so, how long (duration) it took to occur. This type of question calls for the application of survival analysis (Kepper et al., 2014). This method deals with censored cases appropriately compared with traditional methods – i.e. where time-to-event is unknown for a portion of the total sample because either they did not experience an event over the observation periods or they have left the study, and as a result, their complete event history data are not available (Masyn, 2014). Figure 4 schematically outlines the procedures applied to define an event, censoring, and time-to-event in this study. These are further discussed below.



For dissonants in 2007



For consonants in 2007

Figure 4: Schematic timeline diagram of event history documentation process

3.3.3.1 Event

As described in Section 3.3.2, the study classified the sample into two groups at baseline (2007): TOD dissonants and TOD consonants. An event was recorded separately for these two groups (Figure 4). For dissonants, an event was defined in two ways: a) if they changed their living preferences and became TOD consonants; or b) they moved residences to any other neighbourhoods in Brisbane. For TOD consonants, an event was recorded if they changed living preferences and became TOD dissonants but did not move. The event was defined differently for dissonants and consonants because dissonants could reduce their discomfort in two ways (relocation and changing attitudes) as hypothesized by Schwanen and Mokhtarian (2005b), whereas the residential location hypothesis does not apply to residential consonants. If a consonant relocates, this is not due to their discomfort with existing land use patterns – otherwise they would not be defined as consonants.

Respondents' living preferences in the follow-up survey waves were captured in a 7-item[1] question measured on a 5-point Likert scale (1-strongly disagree – 5-strongly agree) (Table 2). These items represent travel attitudes and preferences of the TOD respondents[2]. Given that public transport is a key

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[1] There are more items in the surveys, but these 7 items were found to be consistent across the periods

[2] Note that travel attitudes and preferences were used as surrogate measure of residential preferences. The statements capturing residential location choice data were collected only in 2007. On the other hand, travel attitudes and preference data were not collected in 2007.

mode in facilitating travel in TOD areas, it was hypothesised that residents would maintain a positive attitude to public transport if they remained TOD consonants. The dimensionality of data captured in the seven items were reduced through a factor analysis which resulted in a two-factor solution in all follow-up survey waves. The generated two factors are respectively interpreted as sensitivity to environmental externalities (F1) and perception about public transport (F2). The scores of the second factor were then used to determine dissonant/consonant status of the respondents. A positive score in F2 denotes a resident as a dissonant whereas a negative score defines a participant as a consonant. The dissonant/consonant status in the follow-ups were compared against the baseline status to identify if there was an event. The HABITAT survey also collected respondents' residential mobility data in each of the follow-up waves, which was used to identify if there was an event caused by residential mobility.

Table 2: Factor analysis results showing the pattern matrix of a 7-item question on travel attitudes and perception

Items	2009		2011		2013		2016	
	F1	F2	F1	F2	F1	F2	F1	F2
People need to walk and cycle more to reduce global warming	.945	.142	.800	-.092	.872	.071	.833	.143
People need to walk and cycle more to improve the environment	.910	.003	.958	-.118	.570	.020	.907	-.059
People need to walk and cycle more to reduce traffic congestion	.420	-.221	.588	.124	.779	-.079	.970	-.076
Travelling by public transport is not very pleasant	.023	.823	-.092	.730	-.077	.735	-.194	.576
Public transport is expensive	.095	.629	-.024	.333	-.056	.371	-	-
Public transport is inconvenient and unreliable	-.031	.602	-.078	.806	.207	.630	.085	.843
Using public transport takes too much time	-.075	.416	.182	.565	.045	.580	.119	.691
% of variance explained	31.1	19.6	29.4	22.2	28.5	17.2	41.9	25.8

Note: F1 - Sensitivity to environmental externalities, F2 – Perception about PT, - Excluded due to complex structure
Extraction method: Principal Axis Factoring, Rotation Method: Oblimin with Kaiser Normalistion
Software: SPSS

3.3.3.2 Censoring

Censoring refers to the treatment of respondents who did not experience an event. It was found that some respondents did not experience the events at all over the survey periods. They were censored in this study. In addition, as shown in Figure 4, a consonant is denoted as censored if any of the following conditions were met: a) remained consonant in the follow-ups but moved home within Brisbane; b) moved home outside of Brisbane; and c) discontinued participation in the survey. Likewise, a dissonant was recorded as censored if any of the following conditions were met: a) moved home outside of Brisbane, and therefore, it is unknown if the mobility was due to dissonance or other external factors (e.g. job); and b) discontinued participation in the survey.

3.3.3.3 Time-to-event

Previous studies have crudely classified time scales for events as either continuous or discrete (Masyn, 2014). Studies adopting a continuous time scale have precise information of the time of an event (e.g. death of a patient) or even if the time is measured in discrete intervals, they are sufficiently granular. A discrete scale is used in one of two situations: a) an event occurred at any point in time but the duration is recorded in interval (e.g. drop out from school may happen in any day but recorded only annually); and b) an event is recorded in discrete point in time (e.g. retention rate is measured at the end of a term). Given that the data were collected in different intervals in this study, the time-to-event data was recorded in discrete intervals in this study. The duration to an event was thus set as 0 years, 2 years, 4 years, 6 years, and 9 years respectively for the baseline (2007) and follow-up surveys in 2009, 2011, 2013, and 2016.

3.3.3.4 Discrete time survival analysis

Given that the time-to-event data was measured in discrete intervals in this study, as a result, the discrete time survival analysis method was applied to investigate the answers for the first two research questions

– i.e. to identify the survival duration of dissonants/consonants in TODs. Previously several studies in transportation have applied a continuous time survival analysis method (Anastasopoulos et al., 2012; Bergman et al., 2018; Grechi and Maggi, 2018; Louie et al., 2017; Rahimi et al., 2019; Zheng et al., 2019). However, an application of discrete time survival analysis method has rarely been reported in the transportation/planning literature. This study therefore applied the two most commonly applied techniques to analyse discrete time survival data – the hazard and survival probabilities (Tekle and Vermunt, 2012).

The hazard probability is a conditional probability, which is estimated for each time interval separately. It estimates the probability, for example, that a consonant will become dissonants (an event) in a certain time interval, given that the consonant did not experience it in a previous interval, and is denoted by:

$$\hat{h}(t_j) = \frac{d_j}{n_j} \tag{1}$$

where, $\hat{h}(t_j)$ is the estimated hazard probability during interval t_j, d_j is the number of observed events during the time interval t_j, and n_j is the number of individuals that are at risk during t_j.

The survivor function estimates probability of survival for any person selected randomly (i.e. the person has not experienced an event) past a certain interval. In contrast to the hazard probabilities, which are estimated for each interval separately, the survivor function calculates cumulative probability of survival for all preceding intervals. For example, the survival probability after the 1st interval is equal to the product of survival probabilities of the 0th and 1st intervals. Mathematically, the survival probability during the first interval is complementary to the hazard probability during the first interval. Therefore, the estimated survival probability after the time period t_j is given by:

$$\hat{s}(t_j) = \hat{s}(t_{j-1})[1 - \hat{h}(t_j)] \tag{2}$$

where, $\hat{s}(t_j)$ is the estimated survival probability after the time period t_j, $\hat{s}(t_{j-1})$ is the estimated survival probability after the time period t_{j-1}, and $\hat{h}(t_j)$ is the estimated hazard probability at time interval t_j.

This research estimated hazard and survival probabilities for both TOD dissonant and TOD consonant groups. In addition, a life table was prepared for both groups that summarises both hazard and survival probabilities in descriptive statistics (nonparametric) together with the number of individuals entering/at risk as well as experiencing an event at each interval. All these analytical methods were required to construct an event history database in which each individual was binary coded with 1 if they experienced an event, otherwise censored with a 0 (zero) value. A corresponding time indicator was created for each individual representing the time taken to experience the event (or time taken to be censored) from time zero.

Table 1 shows that some variables are fixed over time (gender) while others vary. As a result, to answer the third research question, the study estimated a discrete time hazard model comprising of both time-constant and time-varying covariates using binary logistic regression analysis, given by:

$$logit\left[h_{x_p}(t_j)\right] = \alpha_j D_j + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p + \gamma_1 Y_{1j} + \gamma_2 Y_{2j} + \gamma_3 Y_{3j} + \cdots + \gamma_q Y_{qj} \tag{3}$$

where, $h_{x_p}(t_j)$ represents conditional hazard probability at time interval t_j for an individual; having p time-constant explanatory factors X_1, X_2, ……,X_p; β_1, β_2,…., β_p are the parameters to be estimated that show the effects of the respective time-constant explanatory factors; and q time-varying covariates Y_{1j}, Y_{2j}, ……,Y_{qj}; γ_1, γ_2,…., $\beta\gamma_q$ are the parameters to be estimated that show the effects of the respective time-varying covariates on the logit hazard; D_j represents dummies of time intervals, α_j is the intercept parameter at time interval t_j.

The odds rations were calculated for the estimated coefficients for an easy interpretation. Thus, a time-constant covariate (gender) with an odds ratio of 2 for male, for example, can be interpreted as: males are 2 times more likely than female to experience an event (if at risk), controlling for the effect of other covariates in the model. This means that the interpretation of time-constant covariates is not attached to an interval of the time periods under investigation. In contrast, the interpretation of the effects of time-varying covariates is attached to specific interval in the time periods. As an example, an odds ratio of 2 for the dwelling density indicator suggests that, at every interval from 2007 to 2016, the odds of experiencing an event are 2 times higher for an individual who experienced a one unit change in dwelling density – i.e. the risk of experiencing the event increases only in those time intervals concurrent with, or subsequent to, the changes in dwelling density. However, unlike time-constant categorical covariates in which the membership of all individuals is fixed for all intervals (e.g. male or female), the membership of individuals in a time-varying covariate changes – e.g. from full-time employed to part-time employed to unemployed; and therefore, the effects cannot be contrast against a reference group for all periods, but be interpreted as interval specific. For example, an odds ratio of 2 for unemployed individuals indicates that whenever an individual changed their employment status from full-time employed (reference group) to unemployed, his/her odds of experiencing an event are 2 times higher.

All the factors, as shown in Table 1, were retained in the model irrespective of their significance level. Our aim is not to derive a predictive model but to identify dissonant/consonant groups that changed their status. In addition, our analysis shows that there were minor changes (some are statistically significant) in the built environment over the study periods (Appendix 3). As a result, the three built environment factors (dwelling density, intersection density, and land use diversity) were included in the models as time-varying covariates. A person-period database was created by reformatting the person specific database, in which one record was created for each person separately for each time period until they experienced an event or censored. Therefore, the number of records associated with different individuals vary depending on the number of time-interval they were under risk.

4. Results

4.1 Dynamics of dissonants/consonants in TODs

Table 3 shows the extent of residential dissonance in TODs over the study periods. The different sample sizes in different periods are mainly due to sample attrition. 58 respondents dropped out over the study periods. To investigate attrition bias, the research conducted two types of tests. First, a One-way ANOVA test result showed that on average the drop-out cases remained in the study for 4.12 years and 4.56 years respectively for those classified as consonants and dissonants in 2007. The difference is not statistically significant (F=0.40, p=0.53). Second, a Wilcoxon (Gehan) test was conducted to compare the survival functions of the drop-out cases by dissonant/consonant status. The test result showed that the survival functions of these two groups were not statistically different (Statistics of 12.24 with 1 degrees of freedom at the 0.165 significance level). Based on the tests results, it can be concluded that the drop-out samples did not affect the overall study findings. Similar methods were followed in previous studies to test the attrition bias in survival analysis (Choi et al., 2012).

Table 3: Classification of TOD residents in terms of their dissonant/consonant status over the survey periods

Classification of TOD residents	2007 (%)	2009 (%)	2011 (%)	2013 (%)	2016 (%)
Consonants	54.1	57.4	45.8	58.0	55.0
Dissonants	45.9	42.6	54.2	42.0	45.0
N	98	68	59	50	40

On average, about 46% of the residents in TODs were dissonants in 2007. The level of dissonance slightly reduced to 43% in 2009 but increased to a maximum of 54% in 2011. Table 3 outlines that the level of dissonants reduced again to 42% in 2013 but slightly increased again to 45% in 2016. These changes in the level of dissonance suggest that neighbourhood dissonance is not static. It also indicates that there were internal dynamics in a TOD meaning that dissonants might have transitioned to consonants and vice-versa, which justifies the need for this research.

4.2 Validity of the dissonants/consonants status

As indicated in Section 2.2.2, this study used a surrogate measure to identify residential dissonants in 2007 – i.e. neighbourhood preferences were identified based on reasons for choosing a TOD neighbourhood. As a result, it was necessary to verify if the TOD residents were correctly classified in terms of dissonants and consonants groups. Previous studies found that TOD dissonant group exhibits a higher rate of car use and a lower rate of public and active transport use. Therefore, the validation was conducted by examining their mode use behaviour. HABITAT participants reported their main mode of transport on weekdays (Table 4). Table 4 shows that the use of public transport was about three times higher for the TOD consonant group compared with TOD dissonant. Walking was also a dominant share (21%) of overall travel for TOD consonant. In contrast, TOD dissonants were twice as likely as to use private transport compared with TOD consonants. All these findings echo the previous findings on this topic, and therefore, indicate that the classification method as applied in this study has reasonably well categorised the TOD residents into dissonant and consonant groups.

Table 4: Modal share (%) of TOD residents in Brisbane - main mode of transport used in weekdays

Mode	**2007**	
	TOD consonant	TOD dissonant
Public transport	30.8	8.9
Car / motorcycle	42.3	80.0
Walk	21.2	6.7
Cycle	3.9	4.4
Other	1.9	0.0

4.3 Survival duration for dissonants/consonants in TODs

Table 5 shows the life table outlining survival duration for TOD dissonants/consonants in Brisbane. For the 98 TOD residents, the table shows whether the event of disappearing dissonance/consonance had happened (yes or no), and if yes, when it happened. The table outlines the results for TOD dissonant and consonant groups separately.

The time interval in the 2nd column of Table 5 is defined with traditionally used square brackets and parentheses format – they respectively denote that the initial time is included, and the end time is excluded from the interval. The 3rd column shows the number of TOD residents who entered into the analysis in each discrete time interval. The 4th column shows the number of residents censored in each interval. The 3rd and 4th columns were used to calculate the number of residents who were at risk during an interval (number entering minus half of those censored) in the 5th column. This method accounts for the effect of censored cases. As Gehan (1969) suggested, if there are no losses or withdrawals, then the number of individuals exposed to risk is equal to the number of individual entering the interval. However, if individuals are lost or withdrawn in an interval, they are credited with being exposed to the risk of an event for one-half the interval. The presumption is that the time of withdrawal/lost is uniformly distributed throughout the interval. The 6th column represents the number of TOD residents experienced an event (i.e. consonants became dissonants or dissonants became consonants) during the interval. The 7th column shows the proportion of residents terminating who were at risk during the interval (e.g. 6/40 = 0.15). The proportion surviving (8th column) is calculated by subtracting proportion terminating from 1 (e.g. 1 – 0.15 = 0.85). The 9th column in Table 5 represents the cumulative survival probability (e.g. 1.0 x 0.85 x 0.68 = 0.58 for the third row in TOD consonant groups). Unlike the descriptive hazard rate in the 7th column, the 10th column represents estimated hazard rate, given that they survived until the beginning of the respective intervals.

Table 5: Life table of TOD dissonant and consonant groups

1	2	3	4	5	6	7	8	9	10
TOD resident type	Interval (years)	Number entering interval	Censored - withdrawing during interval	Number exposed to risk	Number of terminal events	Proportion terminating (hazard)	Proportion surviving	Cumulative proportion surviving at end of interval	Estimated hazard rate
Consonant	[0-2)	53	0	53.0	0	.00	1.00	1.00	0.00
	[2-4)	53	26	40.0	6	.15	.85	.85	0.16
	[4-6)	21	4	19.0	6	.32	.68	.58	0.38
	[6-9)	11	4	9.0	1	.11	.89	.52	0.12
	[9-)	6	5	3.5	1	.29	.71	.37	0.00
Dissonant	[0-2)	45	0	45.0	0	.00	1.00	1.00	0.00
	[2-4)	45	12	39.0	19	.49	.51	.51	0.64
	[4-6)	14	3	12.5	5	.40	.60	.31	0.50
	[6-9)	6	3	4.5	1	.22	.78	.24	0.25
	[9-)	2	2	1.0	0	.00	1.00	.24	0.00

The estimated hazard rate is shown in Figure 5 over time. It shows that the risk of event occurrence is the highest in the 2nd year and 4th year for TOD dissonants and TOD consonants respectively. This means that most TOD dissonants became TOD consonants in 2009 – 19 out of 45 as shown in Table 5. Although the rate was the highest in the 4th year for TOD consonant, it is yet lower compared with the TOD dissonant group in this interval. Table 5 shows that six TOD consonants became TOD dissonants out of 21 entered in the interval whereas five TOD dissonants out of 14 entered in the interval became TOD consonants. The hazard rate reduced for both groups in the 6th year despite the rate remaining higher for TOD dissonant group. These findings suggest that the dissonant group experienced the event at a higher rate compared with the TOD consonant groups in all periods.

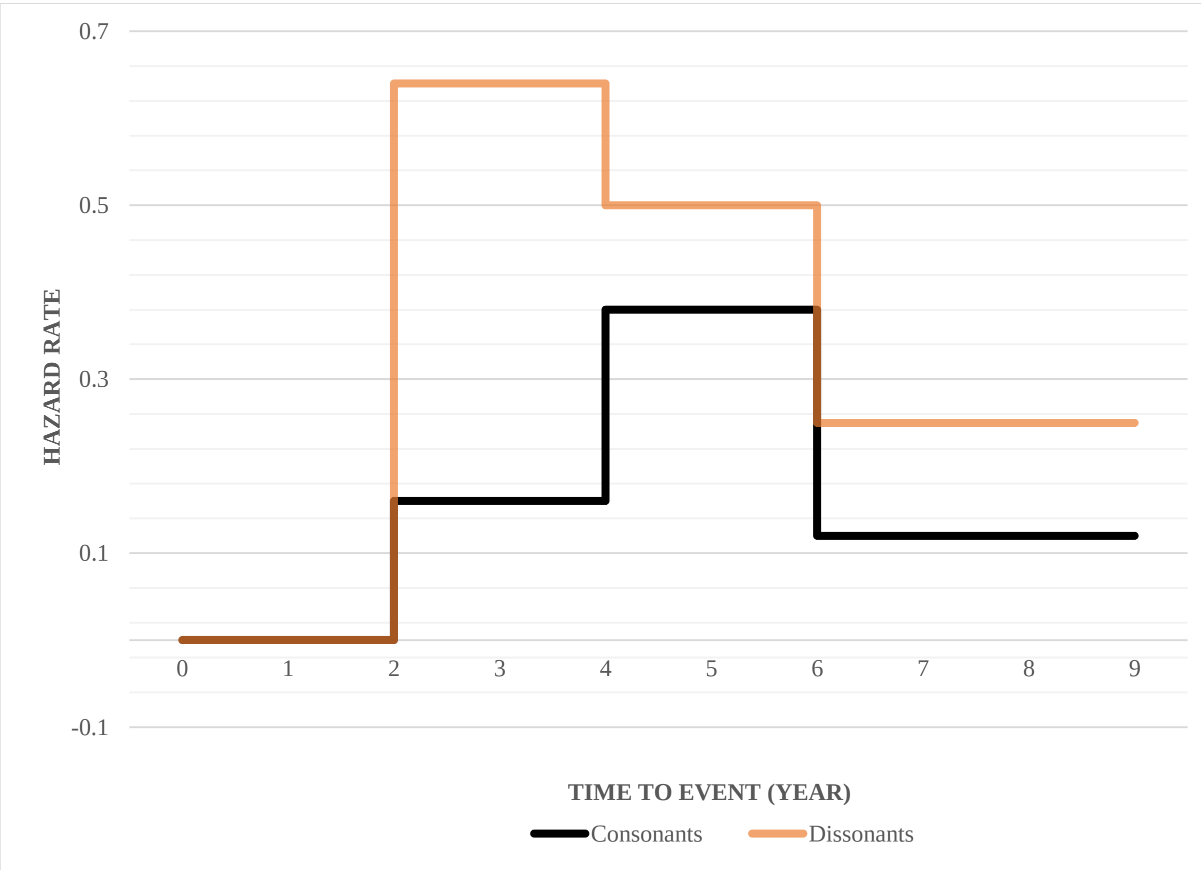

Figure 5: Estimated hazard functions for TOD dissonant and consonant groups

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Figure 6 visualises cumulative survival probabilities for TOD dissonant and consonant groups over time. A hazard curve may rise, decline, or remain stable over time, but the survivor curve never rises. The survival function remains steady if there is no event in an interval, it drops sharply or slowly depending on the hazard rate of an interval. Figure 6 shows that only 51% of the TOD dissonants survived after the 2nd year whereas the survival rate for TOD consonant was 85% after the 2nd year. The survival rate declined for both groups in the successive intervals despite the gaps between the groups remained in all intervals.

A visual examination of Figure 6 shows that TOD dissonants have the lower survival curve compared with TOD consonant. To confirm this finding, the Wilcoxon test was conducted, which compares the survival functions between TOD consonants and TOD dissonants. The test results returned with a Wilcoxon (Gehan) Statistics of 12.24 with 1 degrees of freedom at the 0.001 significance level. These statistics confirmed that the survival functions are significantly different between the two groups. To further assist in understanding, the median survival time was calculated for both groups – i.e. estimated time duration for the survival of 50% of the sample without the event. The results show that the median survival times for TOD dissonant and TOD consonant groups (i.e., the time taken to switch from dissonant to a consonant and vice versa) were 4.06 years and 9.0 years respectively.

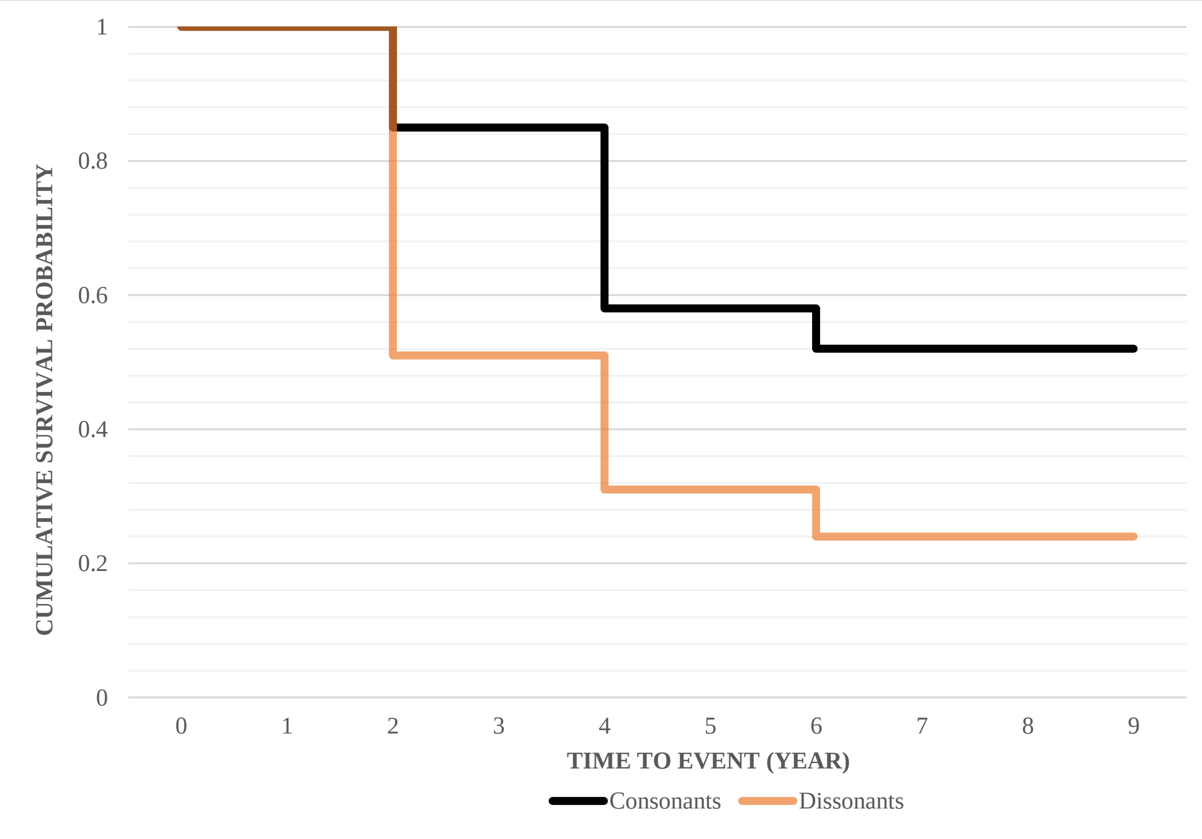

Figure 6: Cumulative survival probabilities for TOD dissonant and consonant groups

4.4 Factors affecting the duration of the events

This section presents findings from the two discrete time hazard models, one for TOD consonants and the other for TOD dissonants as shown in Table 6, aiming to identify the groups that were more likely to experience an event. The models were estimated using the person-period format of the data containing a total of 158 records (91 consonants and 67 dissonants). Odds ratios were calculated by exponentiating the coefficients (B) for an easy interpretation. In both models, the non-intercept option was chosen in SPSS software. As a result, the coefficients for the time dummies indicate the log odds for the reference groups in different time intervals.

Three covariates were found to be statistically significant in Model 1 (education, country of birth, and intersection density) using a more liberal approach (at the 0.1 level). Among these factors, two are time-constant (education and country of birth) and intersection density is a time-varying covariate. The odds ratios for the two education categories (certificate/diploma, and bachelor or higher degree) were found to be 0.08 and 0.02 respectively in Model 1, which mean that the odds for these two groups to become TOD dissonants were about 12.5 and 50 times lower to that for TOD consonant with relatively low educational status (up to year 12). In contrast, the odds of becoming a TOD dissonant was five and half times higher for those TOD consonants who were born in other countries compared with TOD consonants born in Australia. When the intersection density increased by one unit, the odds of residents to transition to TOD dissonants reduced by 3%.

Unlike Model 1, the overall model was not found to be statistically significant for Model 2 estimating the likelihood for a TOD dissonant to become a TOD consonant. In other words, none of the covariates were found to have a statistically significant correlation with the occurrence of an event (TOD dissonants becoming TOD consonant) in Model 2. Despite a higher rate of event occurrence and a lower median survival duration for the TOD dissonants, the statistical insignificance of the factors in Model 2 suggest that all groups experienced the event equally.

Table 6: Discrete time to event model showing the factors associated with the time-to-event for TOD dissonant and consonant groups

Covariates	Model 1: TOD consonants			Model 2: TOD dissonants		
	B	Sig.	Odds ratio	B	Sig.	Odds ratio
Interval: [2-4)	4.63	0.46	102.24	-0.18	0.97	0.83
Interval: [4-6)	7.11	0.26	1219.22	-038	0.93	0.68
Interval: [6-9)	4.36	0.45	77.83	-0.85	0.84	0.43
Interval: [9-)	6.08	0.34	437.71	-20.17	0.99	0.01
Gender: Male (ref: Female)	1.72	0.19	5.60	-0.42	0.58	0.66
Age	-0.02	0.79	0.98	0.02	0.67	1.02
Education (ref: Up to year 12)						
Certificate/diploma	**-2.53**	**0.09**	**0.08**	0.98	0.22	2.68
Bachelor or higher degree	**-3.80**	**0.02**	**0.02**	0.98	0.28	2.67
Vehicle availability: Yes, always (ref: Other)	2.34	0.12	10.42	-1.51	0.38	0.22
Employment status (ref: Full-time employed)						
Part-time employed	-1.60	0.19	0.20	0.39	0.66	1.48
Other (unemployed/retired)	-1.11	0.34	0.33	0.07	0.94	1.07
Country of birth: Other (ref: Australia)	**1.70**	**0.09**	**5.48**	0.10	0.90	1.10
Self-reported health status (1-Poor to 5-Excellent)	0.05	0.93	1.05	0.01	0.97	1.01
Residential density (dwellings/Ha)	0.02	0.30	1.02	0.02	0.57	1.02
Intersection density (number/Ha)	**-0.03**	**0.08**	**0.97**	-0.01	0.72	0.99
Land use mix (Entropy Index)	-7.79	0.12	0.01	-0.73	0.85	0.48
-2 Log likelihood	50.14			79.92		
Nagelkerke R Square	0.76			0.23		
Omnibus Tests of Model Coefficients (Chi^2)	76.01	0.01		12.96	0.68	
N	91			67		

5. Discussion and conclusion

To our knowledge, this is the first study that has conducted a survival analysis to examine the residential dissonance reduction processes in TODs. Residential dissonance is a threat to TOD policy because dissonant are more likely to drive a private motor vehicle rather than take advantage of the availability of proximate public transport. Despite a hypothetical understanding that dissonance might reduce naturally after experiencing the convenience of living in a TOD, empirical validation of this hypothesis has been lacking.

This study tracked the beginning and end of residential dissonance using five waves of panel data over nine years from Brisbane and verifies that residential dissonance is a dynamic process. In other words, existing dissonants will die out after living sometime in a TOD, but new dissonants are formed from those previously labelled as consonant. However, the critical finding is that TOD dissonants (comprised of 46% of all TOD residents) become TOD consonants faster than the formation of new dissonants. Hence, over time TODs will eventually become dissonant free: 50% of the TOD dissonants became TOD consonants in 4 years; in contrast, 50% of the existing TOD consonants became TOD dissonants over 9 years. A further analysis shows that 28% of the transitions from dissonants to consonants occurred due to residential mobility of the dissonants. It is expected that most of these vacancies will be self-selected by TOD consonants, given that there are more dissonants live in non-TOD areas compared with TOD areas in the context of a city (Kamruzzaman et al., 2016a). However, TODs are costlier to rent/own a house than that of in non-TOD areas (Noland et al., 2014), which may create a perceived barrier for the self-selection process to occur. Advocacy and wider dissemination of research findings are necessary to break this perceived barrier because studies found that TODs are more affordable than non-TODs because the lower cost of transportation offsets housing costs (Renne et al., 2016).

A faster rate of reduction of TOD dissonance is critical because groups that are likely to remain as dissonants in a TOD cannot be identified to speed up the dissonance reduction process. A shorter survival duration for TOD dissonants means that policy makers and practitioners do not need to worry about their dissolution. Nevertheless, dissonance levels could be reduced even faster by improving the quality (e.g., comfort, frequency) of public transport and infrastructure for active travel, intervening to change attitudes towards public transport, cycling and walking (e.g. temporary free public transport pass) (Abou-Zeid and Ben-Akiva, 2012; Fujii and Kitamura, 2003). In contrast, the study found that certain groups of TOD consonants (e.g. low educational status, people who born overseas) are likely to become TOD dissonants, and as a result, specific policy measures can be targeted at these groups to stop becoming a dissonant such as identifying their preferences in terms of land use patterns in TODs, providing concessionary public transport tickets, monetary incentive/rent relief to bear the high cost of owning/renting houses in TODs (Kamruzzaman et al., 2016a). The study findings also indicate the probable intervention periods for this group. Given that the riskiest period for a TOD consonant to become a dissonant is between 4 and 6 years, therefore, any intervention should be designed within the first 4 years of their living in a TOD.

Although the overall rate of transition was higher for dissonants (56% - 25 out of 45) compared with consonants (26% - 14 out of 53) over the nine years of study period, the study did not find any specific groups that are more likely to make a transition from dissonants to consonants. This means that the rate of transition is equal for all groups, and cannot be readily identified for policy interventions – e.g. to make the transition quicker for those who are likely to make a transition or to influence for making a transition who are less likely to make a transition. This finding is complementary to previous findings on this topic that dissonants are mixed-up with all socio-demographic groups and cannot be readily identified (Kamruzzaman et al., 2016a; Schwanen and Mokhtarian, 2004).

The findings from this study verify the 'reverse causality' hypothesis in two ways. First, about half of the TOD dissonants, who possessed an anti-TOD attitudes, developed a pro-TOD attitudes in just four years (except those who relocated to other neighbourhoods), irrespective of their socio-demographic status (age, gender) or irrespective of changes in their economic condition (e.g. employment, car-availability). This means that the built environment in TODs had an autonomous effect, building positive attitudes towards it. This finding is in line with findings reported in previous studies (Bohte, 2010; van de Coevering et al., 2016), but contradicts with findings reported in van de Coevering et al. (2018) that dissonants are unlikely to switch to consonants classes. Second and more importantly, a causal effect of the built environment on attitudes was evident in case of consonants. The periods that witnessed an intervention in the built environment (more connected street networks) reduced the rate of transition from consonants to dissonants. The finding corroborates with the findings as reported in De Vos et al. (2018) that a large change in the built environment is likely to change attitudes. However, some findings from this study work in opposite direction of the ‘reverse causality’ hypothesis. For example, a few respondents developed an anti-TOD attitudes despite living in TODs. A possible reason for such a transition could be that the built environment features of TODs (or the opportunities provided within these) were not enough to maintain the pro-TOD attitudes for some residents. Another possible explanation could be due to a change in the socio-economic conditions of the respondents that were not captured here (e.g. birth of a child, loss of a partner). An identification of these missing elements and including these in the TOD design principles would enhance the sustainability of TODs.

The study demonstrates an application of discrete time survival analysis technique in the context of TOD research. The application of this technique is relatively scarce in the transport planning literature, and therefore, the study has paved the way for other researchers to apply a similar technique in the field. However, the biggest challenge is the availability of panel datasets in transportation research (Bhat and Guo, 2007; Dargay, 2007; Kamruzzaman et al., 2016b). The HABITAT dataset as used in this study was originally collected to monitor health outcome of older adults over 40 years. As a result, the data suffers from a lack of representation of all age groups and a limited sample size for this study. In addition, given that the survey was not designed specifically for the analysis of residential dissonance, as a result, the study had to choose surrogate measures to identify residential preference indicator of TOD residents. These indicators again were not consistently applied over the study periods (e.g. the use of residential location choice statements in 2007 and travel attitudes in the subsequent periods), which might have an impact on the findings presented here. Due to the limitation in sample size, the study applied a conservative approach in determining its research question. Further questions that remain unanswered are: why a particular group experienced an event sooner compared with their counterparts and why a particular group never experienced an event? These could be answered by interacting time-interval with the covariates if the data were available to extract a larger sample size. Future studies should seek to find answers to these questions.

6. Acknowledgement

The HABITAT study has been funded by three Australian National Health and Medical Research Council (NHMRC) Project Grants [#339718, #497236, #1047453]. Author [anonymised] is supported by an ARC Discovery [DP200100952] and an NHMRC-UKRI [APP1192788] research grants. Author [anonymised] is supported by an NHMRC Senior Principal Research Fellowship GNT1107672. The authors would like to thank Prof. Kevin O’Connor (Associate Editor of the journal) and the two anonymous reviewers for their thoughtful comments and suggestion, which contributed to improve the quality of this paper.

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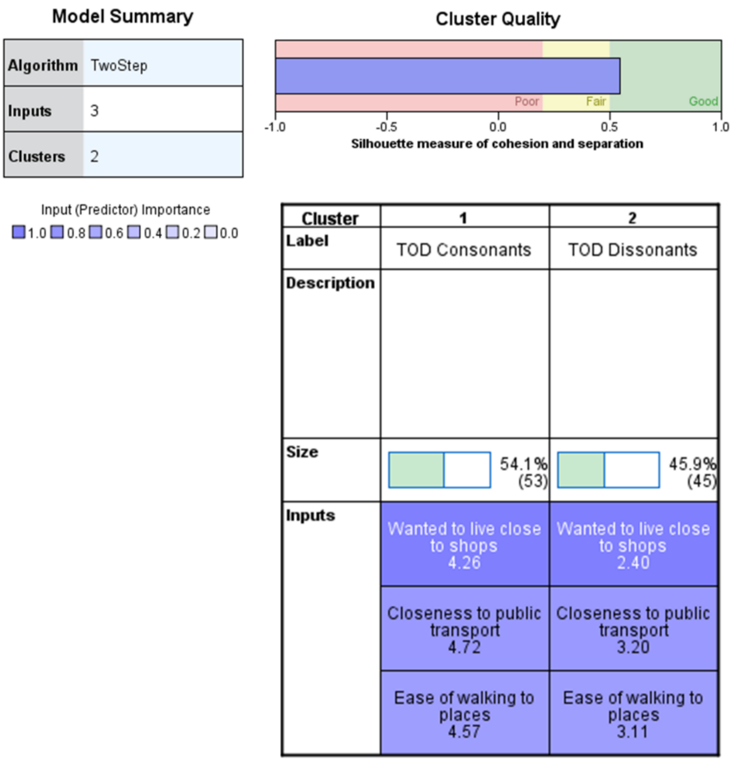
8. Appendices

Appendix 1: Items used to identify the reasons for choosing the current neighbourhood

#	Item description
1	Affordability of housing, land or rent
2	Investment potential
3	Closeness to work
4	Safety from crime
5	Closeness to schools
6	Ease of walking to places
7	Closeness to childcare
8	Closeness to the city
9	Near to green-space or bushland
10	Closeness to public transport
11	Closeness to open space (e.g. parks)
12	Wanted to live close to shops
13	Access to freeways or main roads
14	Closeness to recreation facilities
15	Moved in with my spouse/partner
16	Sense of community
17	Closeness to relatives

Appendix 2: Cluster analysis of the three residential location choice factors to determine TOD dissonants/consonants



Appendix 3: Changes in the built environment characteristics of the study neighbourhoods over the study periods*

Built environment factors	Measures					Changes in measures			
	2007	2009	2011	2013	2016	2009-07	2011-09	2013-11	2016-11
Net residential density (Dwelling/Ha)	26.27	27.34	28.59	29.06	29.30	1.07	1.24**	0.47	0.24
Intersection density (number/Ha)	70.55	69.95	73.95	74.40	74.14	-0.59	4.00**	0.46	-0.26
Average land use mix index	0.65	0.63	0.55	0.59	0.63	-0.01**	-0.09**	0.04	0.04**
N	24	24	24	24	24	24	24	24	24

* A consistent approach was used to monitor changes in built environment patterns by measuring these at the neighbourhood level. The 98 analytical samples lived in 24 neighbourhoods in 2007. The built environment changes of these 24 neighbourhoods are presented here. Although the indicators were derived at the individual level for the analysis, such indicators would not capture the changes because the number of samples reduced over time. An average based on the number of samples would not represent the changes properly because it can capture changes either due to real changes in the built environment or due to changes in the number of samples (and the consequent changes in individual buffers) or both.

** The differences are statistically significant at the 0.05 level based on a paired *t*-test, which takes into account the correlations of the values between the years as they were derived for the same neighbourhoods over the time periods.