A Long Term Analysis of the Mechanisms Underlying Children's Activity-Travel Engagements in the Osaka Metropolitan Area

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Abstract: Using a series of conventional large-scale household travel surveys conducted in the Osaka metropolitan area of Japan in 1980, 1990 and 2000 this study examines the mechanisms underlying children's activity and travel engagements and how these mechanisms have changed over time. The results from a structural equation model show that, in the last two decades, children's trip patterns in the Osaka metropolitan area have become more efficient through greater trip chaining. At the same time, the results also show that boys have become less mobile and their non-school activities tend to be in fewer locations than those of girls. Further, Japanese boys are the ones who travelled by car more frequently than girls. Denser built environments, accessibility by rail transport, and a higher number of school trips have constantly reduced the amount of children's private car trips in the last three decades. Moreover, private car availability did not significantly increase the amount of children trip chaining in any observed year. This finding goes against the commonly held belief that public transport is less suitable for trip chaining. This is presumably due to the travel environment created by the well developed transit networks and dense land use in the study area.

Keywords:
Children, travel behaviour, over time changes, SEM, the Osaka metropolitan Area

Research Headlines:

- Children's trip chains becoming more efficient over time.
- Trip patterns evolve differently depending on children age and development stage.
- The difference in non-compulsory trips between boys and girls has narrowed.
- In comparison to older children, younger ones have become more travel active.
- Holistic model explores children's activity and travel behaviour changes over time.

1. INTRODUCTION

In the past few decades there has been a significant amount of study of adult travel patterns and how these are influenced by their socio-demographics, built environment conditions, preferences and attitudes. Those studies produce a general consensus that the denser the urban structure, particularly in combination with a mix of land uses in close proximity, the lower the dependence on the car. A mixed and denser urban structure would have densities that are high enough to support good public transport services and would encourage greater levels of walking and cycling, and enable residents (both adults and children) to make fewer car trips and trips of shorter distances (Waygood and Kitamura, 2009; Ewing and Cervero, 2010). At the same time, some previous studies (e.g. Kitamura et al., 1997; Handy et al., 2005; Susilo and Maat, 2007; Mercado and Paez, 2009; Cao et al., 2009; Susilo, 2010) also found that although land use characteristics, such as urban form, have some significance in explaining travel behaviour, individual attitudes are often more strongly associated with travel behaviour than land use policies which promote higher densities. It is evident that land use policies promoting mixed use, higher density developments may not have a material effect on travel demand unless individuals' attitudes are also changed (Bagley and Moktharian, 2002; Susilo et al., 2010).

Previous research has also shown that travel behaviour itself is not built within a day, but is a learning process over one's whole life (Baslington, 2008; Hjorthol and Fyhri, 2009). How we grow up will influence the way we travel, including our perspectives on travel modes and our habits (Lanzendorf, 2003). Age, education and job changes are consistently reported as significantly influencing decisions of residential moves and changes in travel modes throughout an individual's life course (e.g. Courgeau, 1985; Hollingworth and Miller, 1996). Simma and Axhausen (2003) found that the use of a particular travel mode positively influences the usage of the same mode for the rest of an individual's life course and the usage of other modes negatively. In line with these findings, Naess (2006) argued that children who have used bicycles in their childhood would be more likely to cycle as an adult than their counterparts who grew up travelling predominantly by car. Therefore, in order to understand and predict our travel behaviour in the future, it is important to understand the evolution of our travel behaviour from our childhood period and how we have modified it over time and why. Unfortunately, whilst children's health and their physical activity participations have received significant attention from sociologists, psychologists, and public health researchers (e.g. Bianchi, 2000; Sjolie and Thuen, 2002; Timperio et al., 2004), our knowledge of the mechanisms of children's travel and trip making behaviour over a longer time period is very limited.

Most of the recent children's travel behaviour studies only focus on their journey to school or how their activity time influences their parents' activity travel patterns. For example, using data from the 2001 US National Household Travel Survey (NHTS) McDonald (2006) shows that 36% of children's trips of less than one mile to school were by private car (an increase from 7% in 1969) with the percentage of walking and bicycle trips being 55% within that same distance (a decrease from 87% in 1969). Whilst the scope is rather limited, there is a general consensus among previous studies (e.g. Sjolie and Thuen, 2002; Lin and Chang, 2010) that shows strong links between children's school trip characteristics with the school travel distance, the quality of the urban form in the neighbourhood and also with the availability of safe routes between home and school locations. For example, based on self-reported travel diaries of daily travel in the US, Frank et al. (2007) found that a higher

residential density was associated with more walking among 9–11 year olds. For 16-20 year olds short distances to a commercial area and a higher intersection density were associated with more walking. A study in Toronto, Canada found that the residential built environment had more influence on the mode to school than the built environment of the school (Mitra et al., 2010). A study from Taiwan by Lin and Chang (2010) showed that high shade-tree density and high sidewalk coverage encouraged children to walk to school independently, while large city block sizes and increased numbers of intersections discouraged children from walking to school independently.

Furthermore, whilst urban form and density are important in influencing school travel mode, they may not be the only important factors that influence school travel mode. Waygood and Kitamura (2009) reported that the cultural expectation of children walking to school in Japan trumped all other factors, as all children in the study from the Osaka metropolitan area were reported to walk to school despite some living in rural areas that resulted in long walks. In the US, McMillan (2007) pointed out that social environment factors, such as poverty and social cohesion, had a larger influence than urban form. Similar findings are also echoed by McDonald (2007), Alton et al. (2007) and Timperio et al. (2007) studies from the US, England and Australia, respectively.

Given that the built environment conditions, parents' activity-travel engagements, and their preferences and attitudes are all constantly changing over time (Hillman et al., 1990; Valentine and Kendrick, 1997; Susilo and Kitamura, 2008), it is reasonable to expect that children's travel will adapt and modify accordingly – not only changing the way they go to school but also the rest of their activity-travel engagements on a given day. For example, there has been a substantial increase in the number of women in the labour force, household sizes have decreased, and the population has been aging in many developed countries. These changes have changed not only adult travel patterns, but also children's (Bianchi, 2000; Copperman and Bhat, 2007; McDonald, 2008). However, to the authors' knowledge, there has not been a study which explores in a systematic way how children's activity-travel engagements have changed over time.

Most previous studies have only focused on children's school trips as a discrete activity and ignored how the changes of this particular trip purpose have influenced other children's activity-trip engagements. Given that the potential for an individual to engage in events and processes are constrained and depend on a set of circumstances linked to the individual as well as to his/her environment (Hägerstrand, 1970; Jones, 1979; Susilo and Axhausen, 2007), it is important to understand how this particular trip purpose influences and shapes children's daily activity engagements and time spent on those activities given their internal and external constraints. This would help us to not only provide a better prediction of children's future travel patterns, but would also provide insight on how we can intervene and influence children's future travel behaviour. Therefore it is important to understand the mechanisms underlying children's daily activity-travel engagements and how their socio-demographic and built environment factors have shaped their travel behaviour over time, not only for one particular decision (e.g. travel mode to school) but also to investigate the impacts of such decisions on the rest of their travel-activity engagements on the given day.

Using a series of conventional large-scale household travel surveys conducted in the Osaka metropolitan area of Japan in 1980, 1990 and 2000, with a structural equation modelling framework, this study examines the mechanisms underlying children's activity and travel engagements and how the mechanisms have changed over time. The next section offers a

brief review of the changes in the Osaka metropolitan area over time along with the travel data that are used in this study. Section 3 presents the behavioural mechanisms adopted in this study. The results of statistical analyses are discussed in Section 4, whilst the final section presents our conclusions.

2. THE OSAKA METROPOLITAN AREA AND TRENDS ON CHILDREN'S TRAVEL PATTERNS

For this longitudinal analysis, the Osaka metropolitan area person trip datasets for the years 1980, 1990, and 2000 were used. The data was obtained from conventional large-scale household travel surveys that were conducted in the Osaka metropolitan area of Japan in 1970, 1980, 1990 and 2000, with sampling rates of 2.4% to 3.0%. This dataset contains the socio-demographic characteristics of the observed samples, including children, as well as their household characteristics. Information on children under the age of 15 years is entered by a responsible adult. It also records the duration, purpose and number of activities and trip engagements of the observed samples on the observed day and the chosen mode, as well as home and work locations (zone) of the observed individual[1]. To support our study, these datasets have been supplemented with land use and network data from Fukui (2003) and Susilo and Kitamura (2008).

The study area: the Osaka Metropolitan Area

The Osaka metropolitan area itself is the second largest in Japan, after the Tokyo metropolitan area, with three core cities of Osaka, Kyoto, and Kobe. Osaka is the largest among the three and is the centre of commerce in this metropolitan area; Kyoto was the ancient capitol of Japan established in 794; and Kobe is the maritime centre of the area. The region covers a total area of 11,700 square kilometres within a radius of about 50 to 60 km from the centre of Osaka. With a population totalling about 18.6 million as of 2000, it is one of the largest metropolitan areas in the world. The area has very dense, mixed-use land developments, and has well-developed rail networks. However, within the study area, there are also low density areas that are primarily for agriculture. For a detailed look at the development of urban Japan see Kitamura et al. (2003) and Sorenson (2002). The *weighted* sample profiles of the person trip dataset can be seen in Table 1. Table 2 shows the activity-travel characteristics for children only, who are the focus of this study. Due to the unavailability of accessibility indices in 1970 data and also the comparability of the collected data over the observed period, for the subsequent analyses, the 1970 data is excluded. Scrutinising the data collection method and observed values of the variables, the previous studies on this dataset (e.g. Fukui, 2003) have confirmed that the data between 1980 and 2000 are comparable.

<TABLE 1 here>

Changes in socio-economic and mobility in the study area

[1] Unfortunately, due to privacy issues, the household link information between respondents has been removed from the dataset which makes the inclusion of the parents' information impossible. Regaining and incorporating this information to the analysis would remain as a direction future study.

At the metropolitan level, the residential population in the study area has steadily increased through 2000, although the rate of growth has visibly declined. Fukui (2003) showed how the residential population in the Osaka metropolitan area has decentralized; the number of younger residents has been increasing in the mixed residential area, while the average age of the populations are aging in neighbourhoods closer to the nuclei of the metropolis. The average number of vehicles per household in the Osaka metropolitan area increased from 0.41 in 1970 to 0.66 in 1980, 0.88 in 1990, and 0.97 in 2000. The area, which is densely populated and well-served by public transit, has had a lower rate of vehicle ownership than the nationwide average, which was 1.13 vehicles per household in 2000. The more built up parts of the metropolitan area, including commercial centres and mixed commercial areas, have very low rates of motorization. Car use has remained practically unchanged among commercial and mixed-commercial (more jobs than residents) areas, and the share has increased only slightly in urban mixed-residential (more residents than jobs) areas even when household life-cycle stage is considered (Sun et al., 2009). On the other hand, more recently developed areas on the periphery in general show higher levels and faster growth rates of vehicle use. With the increase in the fraction of private car trips there has been a decline in the share of public transit in those areas, and private car trips are starting to dominate recently urbanizing areas (Kitamura et al., 2003; Kitamura and Susilo, 2005). However, this pattern has not yet influenced children's travel *to* school, but is emerging in after school travel with more children in those less built up areas leaving school by car than in more densely populated areas (Waygood and Kitamura, 2009).

Trends on children's activity-travel pattern in the study area

The *weighted* children's and general population's travel characteristics in the 1980, 1990 and 2000 datasets are summarized in Table 2. The children in this study are defined as individuals who are less than 20 years old. This age definition is taken because in Japan 20 years is the age of adulthood[2]. The data was pre-coded in 5 year age groupings, so it was not possible to further refine this aspect. Information for children under the age of five is not gathered. As can be seen in the table, the number of daily trips, especially non-compulsory purpose trips, for both children and the general population has increased in the last two decades. The number of children's daily trips has increased by about 3.3% between 1980 and 2000, which is similar to the increase rate for the average population's daily trips (3.1%). Within the same period, children's non-compulsory trips have increased 38%, while the average population increase rate was approximately 29%. Overall, children make more trips, but spend less time travelling than the average population, which is not surprising given the school location in this area of Japan tends to be within 0.5 km walking distance (10-15 minute walk) from their home location (Waygood and Susilo, 2011). The children in the Osaka metropolitan areas also chain fewer trips on their daily trip patterns than the average population[3]. Nevertheless, the table also shows that both children and the general population tend to increase the efficiency of their trip patterns by doing more visits per trip.

<TABLE 2 here>

In terms of travel mode share, as shown by Figure 1, adults have a much more significant private car share than children. As children are not legally allowed to use private cars until

[2] The legal age to drive a moped in Japan is 16, and the age to drive a car is 18.
[3] A trip chain is defined in this study as a series of trips that starts, and ends, at the home base in which one or more destinations are visited.

the age of 18 in Japan this should be the case if children have high levels of independent travel. Whilst the adults have moved more to private motor car use between 1980 to 2000, children have seen greater growth in mass transit (more than doubled) while retaining a roughly 70% mode share for non-motorized travel as late as 2000.

<FIGURE 1 here>

It is clear from the discussions above that people's travel behaviours, including children, have been continuously changing overtime. However, as shown in Table 2 and Figure 1, the changing patterns of children are unique compared to those of adults. Whilst the over time changes of adults' travel behaviours have been examined recently (e.g. Bamberg, 2006; Susilo and Kitamura, 2008), to the authors' knowledge, only a few studies have examined the temporal changes of children's travel behaviour (e.g. McDonald, 2006, Hillman et al, 1990) and most of the previous studies only focused on a particular child's trip purpose and ignored how the over time changes of this particular trip purpose influenced their daily activity-trip engagements.

Given that an individual's potential to engage in events and processes are constrained and depend on a set of circumstances linked to the individual as well as to her/his environment (Hägerstrand, 1970; Jones, 1979; Susilo and Dijst, 2009), it is important to understand how a change in a particular trip purpose would enable or constrain children to engage in other trips and activities within a given day. These constraints define the set of spatio-temporal opportunities children have for travelling to activity places and to participate in activities (Susilo and Dijst, 2010). For example, the probability of whether the children would be able to engage in a certain activity depends on whether s/he would have time to travel to the location and spend a reasonable amount of time on the activity. Shorter travel times (resulting from shorter distances and/or higher speeds) could mean that more time is allocated to activities. A change in one parameter (e.g. number of compulsory trips) may start a chain reaction that changes other travel parameters (e.g. number of non-work visits, available travel time, travel mode etc.) which may be unique for different groups of children at different levels of development. In the next section, we will examine how these relationships influence each other and how these have changed over the 20 years of observation within one integrated framework using a structural equation modelling.

3. THE MODEL STRUCTURE

A model system of children's activity engagement and travel is developed in this study taking into consideration pertinent elements that influence their activity-travel engagements. The relationships are synthesised and hypothesised based on the literature discussed above. The model includes as endogenous variables: their constraints from school commitments, the number of discretionary activities, the number of trip chains, and the proportion of private car trips, compared to the other modes, on the given day. The model system embodies the causal structure postulated for these variables. The proposed model structure can be seen in Figure 2 below. An arrow indicates the direction of a hypothesised causal relationship.

It is assumed that the amount of children's walking and cycling trips depend on: (1) their socio demographic characteristics, (2) their compulsory commitments (number of school

trips[4] and duration), (3) the opportunities that are available based on their built environment conditions and (4) their ability to chain their trips and spend time in non-work/school activities[5, 6]. Instead of using the proportion of children walking and cycling trips on a given day, in this model the proportion of private car trips is used as the dependent variable. The reason for using this dependent variable is because focusing on walking and cycling trips in the Japanese case may undermine a significant proportion of children who used public transport (which involves walking and cycling as well). Therefore, whilst the proportion of car trips is used as the dependent variable, the analysis will focus on what variables discourage children's travel by private car and how this relates to their daily non-compulsory activity engagements and trip chains.

As expected, synthesising and hypothesising a model framework of children's trip and activity making behaviour produced a complex structure (see Figure 2) and complexity between endogenous and exogenous variables. To analyse this model framework, a structural equation model is used. Structural equation modelling (SEM) is a powerful technique for the analysis of multiple simultaneous causal relationships among endogenous variables, and between endogenous and exogenous variables. In fact, numerous studies using SEM methods have been conducted on travel demand and travel behaviour (see Golob, 2003, and Choo and Mokhtarian, 2005, for some examples of this method in travel demand analyses), but they have mainly focused on analyses of adults' travel behaviour. Fyhri and Hjorthol (2009) have used SEM to analyse children's independent travel in Norway. However they used a cross-sectional design and did not include activity participation in the analysis. This is essential in understanding the reasons underlying children's trip making behaviour.

<FIGURE 2 here>

Assuming:

R = the vector of variables representing the children residential areas, including accessibility indices, and
W = the vector of children's socio demographic attributes.

and let

C_{atc} = children's school activity constraints,
C_{nwt} = number of children's non-work trips,
C_{nwd} = duration of children's non-work activities,
C_{ntc} = number of trip chains, and
C_{nmt} = number of children's private car trips

[4] School trips is used here to refer to any trip to the school location. This would include trips to the school for after-school activities such as clubs.
[5] We acknowledge that children's travel mode is also influenced by children's and parents' attitudes towards walking and cycling. However, unfortunately, this information is not available within these datasets. Using a separate data set from the same area of Japan, Waygood (2009a) did not find any correlation between children's attitudes to modes and their use.
[6] Given that children's activity-travel engagements in the US are influenced by the parents' activity-travel engagements (Bianchi, 2000; Copperman and Bhat, 2007), parents' activity-travel engagements should be included in the model framework in Figure 2. Unfortunately, as mentioned earlier, due to privacy issues, the household link information between respondents has been removed from the dataset which makes the inclusion of the parents' information impossible. This would remain as a direction future study.

Then the model system may be formulated in general form as follows:

$$\begin{cases} C_{atc} = f_{C_{atc}}(school\ duration, number\ of\ school\ trips) \\ C_{nwt} = f_{C_{nwt}}(C_{atc}, R, W) \\ C_{nwd} = f_{C_{nwd}}(C_{atc}, C_{nwt}, R, W) \\ C_{ntc} = f_{C_{ntc}}(C_{atc}, C_{nwt}, C_{nwd}, R, W) \\ C_{pct} = f_{C_{pct}}(C_{atc}, C_{nwt}, C_{nwd}, C_{nwt}, R, W) \end{cases} \quad (1)$$

It is assumed in this model system that children's school activity engagements, like the number of school trips and school duration, C_{atc}, act as an explanatory variable that influences the number of children's non-compulsory trips, C_{nwt}, which together with children's school constraints will influence the duration of non-compulsory activities that children would be able to do on the given day, C_{nwd}. All of these variables will influence the children's trip chain patterns, C_{ntc}, and also their propensity to use a private car as their travel mode, C_{pct}.

The vector R contains two types of measures that represent residence and work area characteristics: residence area type and accessibility indices. The residence area type that is used is based on the urban area classification scheme developed by Fukui (2003) and defined as follow:

- A *highly commercial area* is an area with the highest densities of commercial development. These areas have a higher daytime population compared to the night-time population.
- *Mixed commercial areas* have a high density of commercial development, though not as high as a commercial area and have residential development as well, often of a high density. There is a less distinct change in the day and night populations.
- *Mixed residential areas* do not have sufficient work for the population and most residents must commute to another area. These areas are distinguished by a higher night-time population than day-time.
- *Autonomous areas* have a roughly equal amount of residential and commercial development which allows residents to live and work within the area. There is not significant change in the day- and night-time populations. The population density is lower than for the mixed residential areas. These areas are separate from the main urban development and typically represent towns in agricultural areas.
- *Undeveloped (rural) areas* have low densities of both commercial and residential development. These often represent smaller farming communities.

The accessibility indices that were used in this study are similar with those used by Kitamura and Susilo (2005) which are defined as:

$$I_i^{mp} = \sum_j \frac{A_j^p}{t_{ij}^m} \quad (2)$$

where

I_i^{mp} = the accessibility index at zone i for activity type p by mode m,

A_j^p = the attraction measure of zone j for activity type p,

t_{ij}^m = the mean travel time between zones i and j by mode m,

and m = private car, or rail; and p = work (employment used as the attraction measure), social (population as the attraction measure), or shopping (retail establishments as the attraction measure)[7, 8].

4. SEM ANALYSIS RESULTS

The estimation results of the models can be seen in Tables 3, 4 and 5 for the 1980, 1990 and 2000 models, respectively, and the discussion of the results are provided in the following section. '*Children aged 15-19*' and '*Resides at undeveloped (rural) areas*' were used as reference variables for age and residential location dummy variables. An explanatory variable would be considered to significantly influence the dependent variable at $\alpha = 5\%$ if the absolute t-stats value equal or are larger than 1.96. The magnitude and the type of the influence (e.g. positively/negatively influence the dependent variable) are shown by the value of the estimated coefficient.

Changes in impact of the school engagements on child trip making behaviour

As shown by the estimation results in Tables 3, 4 and 5, children aged between 10-14 made more school trips and spent more time in school than their younger (5-9 years old) and older (15-19 years old) counterparts. For example, in 2000 (see Table 5), on average, 10-14 year old children spent 44 and 73 minutes longer (44+29 minutes) in school than the older (15-19 years old) and younger (5-9 years old) children respectively. They also made 0.14 more school trips than the older children. Since school engagements, which are represented by school trips and durations, are compulsory for the children, these school engagements will presumably become constraints for the children in choosing slower travel modes (e.g. walking and cycling) as their time would be more restricted. However, at the same time, these constraints will act as a catalyst which encouraged children to chain their trips within their school trips, which is highly supported by the Japanese built environment condition with a high level of mixed land-use. Whilst the trends are similar with the 1990 (Table 4) and 1980 datasets (Table 3), the differences between the age groups are smaller in the later years. Presumably this is because the length of elementary/grammar school days recently has increased more than high school as expectations increase and non-traditional class subjects were added to the curriculums in 1989 (The Library of Congress, 1994).

As expected, the estimation results show that compulsory activity engagement is one of the most significant variables that influenced the number of non-school visits, the number of trip chains and their travel mode choice. In the 1980s and 1990s, a higher number of school trips and longer school duration reduced the number of children's non-school trips (e.g. shopping, leisure and social trips), reduced the duration of these non-school activities, but increased the amount of trip chaining that children did. Interestingly, whilst the longer school duration also encouraged more travel by private car, a higher number of school trips actually encouraged travel modes other than private car.

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[7] Whilst recent research (Páez et al., 2010) shows that the meaning of accessibility is different for different age cohorts, which may be the case between younger and older children, to avoid any confusion of the accessibility interpretation between age groups, in this study we only use one accessibility definition as described in Equation 2. The use of unique accessibility definitions for each age cohort remains as a recommendation for future research.

[8] The distance-decay exponential represents our perceived accessibility (cognitive distance) which decreases in an exponential relationship with the travel distance.

Moreover, whilst the behavioural interaction in 2000 is similar with 1980's and 1990's, a higher number of school trips among children in 2000 coincided with an increase in the number of non-school trips. This may show that, in the last two decades, children in the Osaka metropolitan area have become more resilient and increased the efficiency of their trip pattern by chaining extra trips on their school trips whenever possible.

<TABLE 3,4,5 here>

Changes in non-school activity engagements

Whilst there were not any significant gender differences in non-school trip making in 1980, in 1990 and 2000 boys significantly made fewer non-school trips than girls. Moreover, whilst boys significantly spent a longer duration in non-school activities than girls in 1980 and 1990, the difference becomes smaller and less significant in later years (the difference only becomes significant at $\alpha = 10\%$ in 2000; boys spent 1.9, 1.2 and 0.8 minutes longer on non-school activities than girls in 1980, 1990, and 2000, respectively). This shows that over the past 20 years boys have become less mobile and they tend to spend their non-school activity in fewer locations than girls. The difference between the genders on time spent in out-of-home non-school activities is getting smaller over time.

Interestingly, the estimation results also show that younger children (5-9 years old) are becoming more travel active relative to their older counterparts. Over the last twenty years they have increased the number of their non-school trips, but still spend much less time on non-school activities than older children. These younger children (5-9 years old) spent 7.5, 9.5, 15.5 minutes less for non-school activities than 15-19 years old youth in 1980,1990 and 2000, respectively, but at the same time, they made 0.09, 0.12, 0.13 trips more than the 15-19 years old youth.

A higher number of adults within a household reduced the number of children's non-school trips and the influence was stronger in the more recent years' observations. Presumably it is because a larger number of adult household members would enable the adults to share their intra-household trip responsibilities between themselves and the children are becoming less likely to accompany their parents in doing errands anymore as there is alternative care giving possibilities from other adult household members at home.

There is a strong indication that children who reside in mixed areas tend to do more non-school trips whilst the ones who live in highly commercial areas tend to spend more time in non-school activities. This relationship is significantly shown by the 1980 and 1990 respondents. However, the relationships are not clear in the 2000 datasets.

The estimation results also show that more frequent non-school activity trips would increase the amount of trip chaining but also potentially increase the amount of private car trips taken by children.

Children's trip chaining behaviour

The estimation results show that boys made more trip chains than girls and the gap between the genders is becoming larger over time. Whilst younger children (5-9 years old) made more trip chains than older children in 1980 and 1990, the 10-14 years old children have increased

their trip chaining over time and by the year 2000 they made the same number of trip chains per day as 5-9 years old children.

Interestingly, private car availability did not significantly (at α=5%) increase the amount of children trip chaining in any observed year. The results here are consistent with similar analysis in the Osaka metropolitan area which focused on commuters (Susilo and Kitamura, 2008), which runs entirely counter to the common belief that private car travellers are more mobile and chain trip more often to combine more visits into a trip chain (e.g., Strathman and Dueker, 1995). This is presumably due to the travel environment created by the well developed transit networks and dense land use in the study area. In Japanese urban areas such as the Osaka metropolitan area, public transport terminals provide superb access to a large number of opportunities which apparently encourages public transport users, including children, to engage in more activities and pursue complex commutes with non-work/school activities. The common belief that public transport is less suitable for trip chaining than the private car travellers evidently does not apply in metropolitan areas of Japan; the belief appears to be a rule of thumb for car-oriented urban areas. The observation here supports the notion that activity engagement and travel patterns are conditioned by transportation networks and land use developments.

Proportion of travel using private car

Against the conventional wisdom and past research (e.g. Hillman et al., 1990) that suggests that girls are protected more than boys, the estimation results show that in the last two decades, boys are travelling by car more frequently. It is not clear from this research why this might be. However, it is important to note that girls in this development pattern are not as car dependent as their western counterparts appear to be (e.g. Babey et al, 2009; Fyhri and Hjorthol, 2009; Page et al, 2009). From an age perspective, 10-14 year old children are the ones who consistently travel least by private car whilst 5-9 years old children are the ones who consistently use private car more in the last twenty years. Car availability and more trip chains increased the amount of car trips. However, it may be that those trips are also for the parent, rather than the child. Waygood (2011) found that the majority of accompanied trips for 10 and 11 year olds in this area was for shopping or to restaurants, suggesting that they are errands run by the parent or family trips, rather than serve passenger trips often seen in the western research (e.g. McDonald, 2006, Stefan and Hunt, 2006). Built environment aspects such as better accessibility by rail to population and employment centres reduced the amount of private car trips by children and children who lived in mixed commercial and mixed residential areas are the ones who consistently travelled less by car.

More dense built environments (apart from highly commercial area residents in the 1990 dataset), accessibility by rail (to employment, stores, and other people), and a higher number of school trips have consistently reduced the amount of private car trips, however, a longer school duration, more non-school trips and a higher number of trip chains have consistently increased the proportion of children's private car trips over the three observed periods.

5. CONCLUSIONS

Using a series of conventional large-scale household travel surveys conducted in the Osaka metropolitan area of Japan in 1980, 1990 and 2000, this study explored the changes over time of children's activity-travel patterns in a holistic approach. The results show that children's

travel behaviour is a dynamic process which keeps changing. Whilst there are some trips and activity parameters which are changing over time, there are some relationships which remain constant over long term periods. For example, a higher number of school trips and longer school duration among 1980 and 1990 children reduced the number and the duration of their non-school trips (e.g. shopping, leisure and friend visit trips) and increased the amount of trip chaining. However, this is not the case for children from the year 2000 data. The models' coefficients from 1980 to 2000 show that, whilst other relationships are similar, gradually a higher number of school trips among children in 2000 were associated with an increase in the number of non-school trips. This shows that, in the last two decades, children in the Osaka metropolitan area have increased the efficiency of their trip pattern by chaining extra trips on their school trips.

The results also show that over the past 20 years boys in comparison to girls have become less engaged in activities and they tended to spend their non-school activity in fewer locations. The difference on time spent between the genders on out-of-home non-school activities is getting smaller overtime. Interestingly, the estimation results also show that younger children (5-9 years old) are becoming more travel active relative to their older counterparts. Over the last twenty years they have increased the number of their non-school trips but spent much less time on non-school activities than older children. Moreover, unlike their western counterparts, girls were not found to be chauffeured in cars more often in Japan. Rather, it was boys who were taken by car more often. Without further analysis into trip purpose it is hard to explain why this might be.

Nevertheless, the results also show that the increase of travel participation and the increase of trip chaining efficiency of the children are likely due to the superb access of Osaka metropolitan area's public transport that has allowed public transport users, including children, to engage in more activities and pursue complex commutes with non-work/school activities. Policy that aims to relieve adults from chauffeuring burdens, increase children's daily physical activity, or improve their independent travel should strongly take into consideration the evidence presented here that showed over several decades and high car ownership growth rates that a built environment with mixed use and strong public transport can achieve such goals.

Overall the results show that, overtime, more urban built environments, better accessibility by rail (to employment, stores, and other people), and a higher number of school trips have consistently reduced the amount of private car trips among children, however, a longer school duration, more non-school trips and a higher number of trip chains have consistently increased the proportion of children's travel by private car over three observed decades. Given that children's travel behaviour is a dynamic process which keeps evolving, understanding of the reasons underlying the mechanisms of children's activity-travel patterns are essential in order to provide a better projection of children's future travel patterns and also in predicting how children's travel would change in response to various transport policy measures.

It should be repeated that this study did not include income levels and education levels of parents which the authors believe may play a role in influencing parents' and children's attitudes to walking and cycling and improve the models' explanatory powers. Due to the limitation of the datasets used, it was also not possible to examine the impacts of parental attitudes and fears related to traffic or strangers and do separate analysis for children who can drive (older than 18 years old). This will remain as a possible future research direction.

ACKNOWLEDGEMENT

This research has been supported by EASTS International Research Group at "Sustainable neighbourhood and quality of live in developing countries" (IRG-10). The earlier version of this work has been submitted for presentation at the 2011 EASTS Conference, Jeju, Korea. The authors would like to thanks the anonymous reviewers for their constructive comments to the earlier version of this paper.

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LIST OF FIGURES

Figure 1. Travel mode share in the Osaka metropolitan area in 1980, 1990 and 2000
Figure 2 The structure of the model

LIST OF TABLES

Table 1. Database profiles of the Osaka metropolitan area person trip data
Table 2. Travel characteristics of children in the Osaka metropolitan area
Table 3. Estimation results for year 1980 dataset
Table 4. Estimation results for year 1990 dataset
Table 5. Estimation results for year 2000 dataset

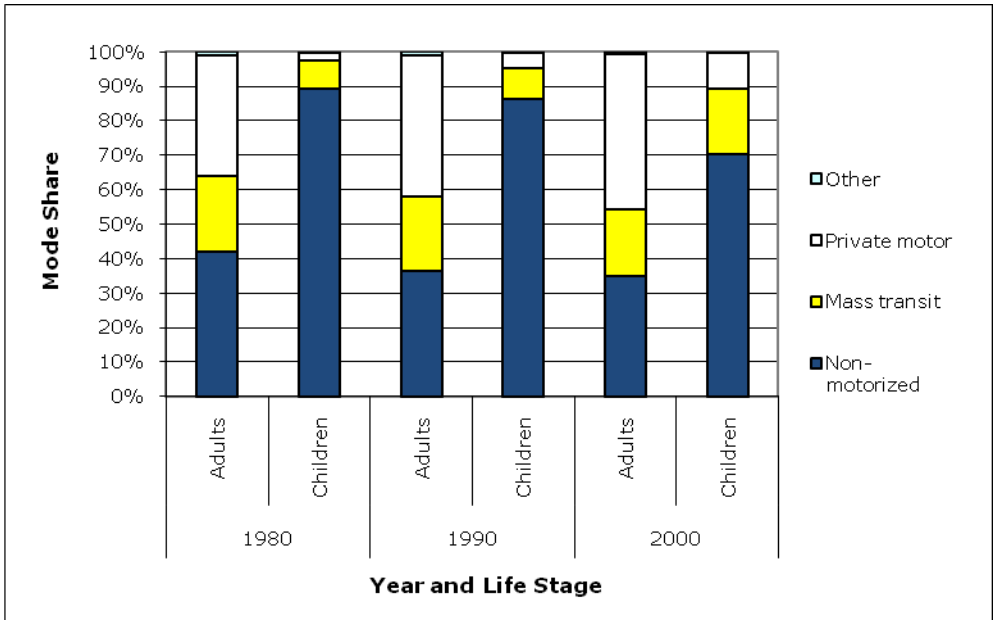

Figure 1. Travel mode share in the Osaka metropolitan area in 1980, 1990 and 2000

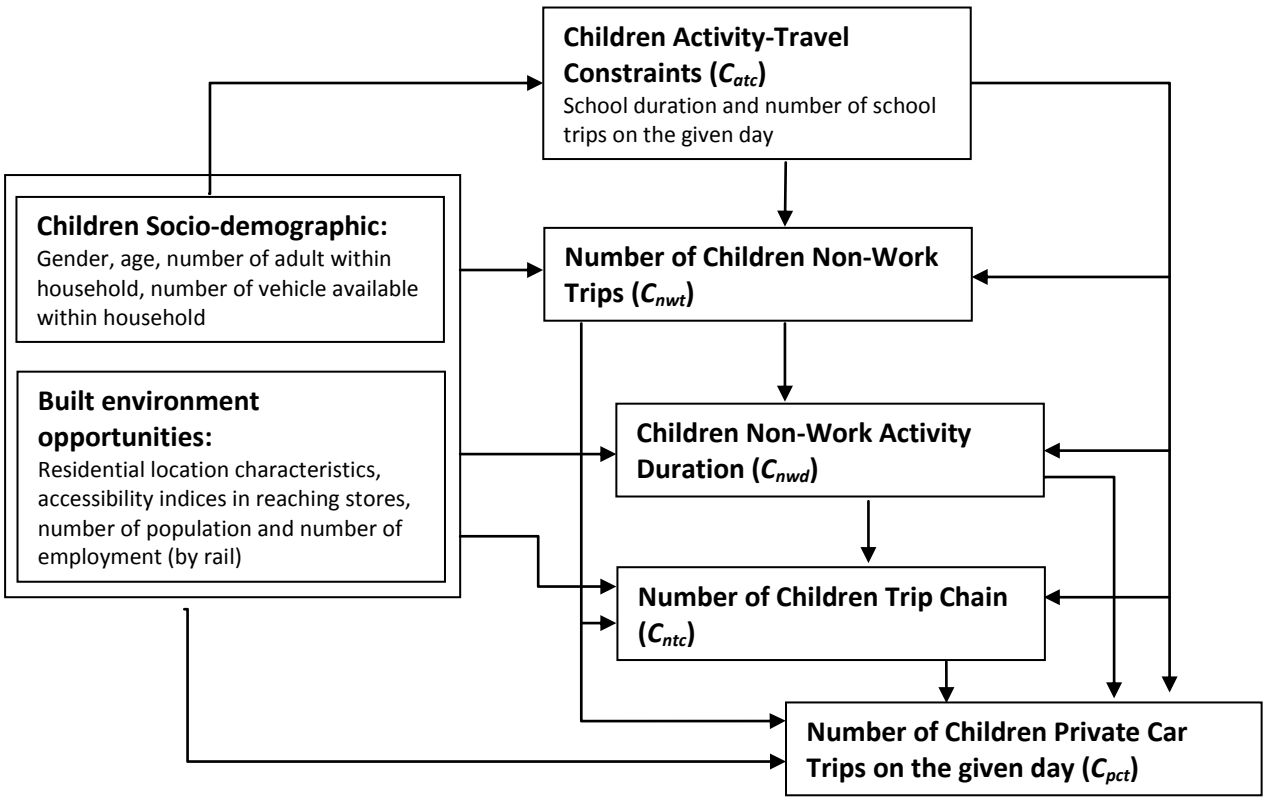

Figure 2 The structure of the model

Table 1. Database profiles of the Osaka metropolitan area person trip data

Variables	1970	1980	1990	2000
Number of samples	56,019	326,241	323,424	312,632
Male [D]	73.1%	46.4%	46.1%	46.0%
Less than 25 years old [D]	45.9%	34.3%	32.1%	25.9%
25 - 34 years old [D]	10.9%	17.8%	12.9%	15.9%
35 - 44 years old [D]	14.2%	17.1%	16.5%	12.3%
45 - 54 years old [D]	10.3%	13.6%	15.8%	14.7%
55 - 64 years old [D]	8.7%	8.6%	12.3%	14.3%
65 years old or over [D]	10.0%	8.5%	10.6%	16.9%
Number of household members	4.31	3.56	3.42	3.34
Family with dependent child [D]	67.9%	59.9%	52.2%	45.1%
Number of cars per adult household members	0.28	0.33	0.37	0.40
Driver's license ownership [D]	29.6%	26.3%	39.8%	50.5%
Resides in commercial area [D]	3.6%	2.8%	3.1%	2.9%
Resides in mixed commercial area [D]	24.3%	24.8%	25.2%	30.0%
Resides in mixed residential [D]	37.1%	63.6%	61.8%	60.3%
Resides in autonomous city [D]	33.6%	7.6%	9.7%	6.1%
Resides in undeveloped area [D]	1.5%	1.2%	0.3%	0.7%
Worker [D]	46.0%	43.0%	46.1%	45.7%
Non-worker [D]	20.8%	29.1%	29.0%	34.2%
Student [D]	33.2%	27.9%	24.8%	20.1%
Average number of trip/day	1.78	2.09	2.05	2.15

Note: [D] indicates a 0-1 dummy variable.

Table 2. Travel characteristics of children in the Osaka metropolitan area

	Children			All Samples		
	1980	1990	2000	1980	1990	2000
Total number of trips/day	2.39	2.34	2.47	2.09	2.05	2.15
Number of compulsory trips/day	0.97	0.97	0.94	0.70	0.72	0.64
Number of entertainment and other visits/day	0.25	0.24	0.34	0.45	0.45	0.58
Time expenditure for all activities (min)	425.0	438.4	441.9	346.2	337.3	319.1
Total travel time (min)	43.1	47.9	46.9	46.5	50.6	46.1
Time expenditure for compulsory activities (min)	399.4	415.0	408.5	281.1	292.9	264.1
Time expenditure for non-compulsory activities (min)	22.1	23.4	33.4	44.2	44.4	55.0
Number of visits/day	1.21	1.20	1.29	1.10	1.13	1.21
Number of trip chains/day	1.17	1.14	1.18	0.99	0.92	0.94
Average number of visits/trip chain	1.03	1.05	1.09	1.11	1.22	1.29

Note: "Compulsory trips" refer to those trips made to engage in compulsory activities such as work and school, and they are not necessarily made from the home base. "Non-compulsory trips" are those made to engage in out-of-home non-compulsory activities (e.g. shopping and entertainment).

Table 3. Estimation results for year 1980 dataset

	Number of compulsory (school) trips		Duration of compulsory (school) activity		Number of non school/work visits		Duration of non school/work visits		Number of trip chain		Proportion of private car trips on the given day	
	Coeff.	t-stats	Coeff.	t-stats	Coeff.	t-stats	Coeff.	t-stats	Coeff.	t-stats	Coeff.	t-stats
Intercept	0.84	771.92	415.12	695.72	0.53	43.67	45.40	47.36	0.28	44.69	0.19	55.58
Male					-0.0003	-0.08	1.893	7.43	0.005	3.23	0.012	13.47
Age between 5 - 9 years old	0.125	82.03	-69.81	-83.67	0.089	24.89	-7.564	-26.88	0.074	41.06	0.002	2.02
Age between 10 - 14 years old	0.149	96.19	34.62	40.67	0.114	31.70	0.366	1.29	0.024	13.13	-0.019	-19.16
Number of vehicle per household					-0.013	-9.42	-0.196	-1.86	0.0002	0.26	0.017	46.46
Number of adult within household					-0.007	-4.58	-0.282	-2.41	-0.002	-2.71	-0.004	-10.46
Resides in highly commercial areas					0.026	2.01	4.267	4.11	-0.009	-1.29	-0.013	-3.49
Resides in mixed commercial areas					0.040	9.17	1.160	3.42	0.012	5.69	-0.010	-8.79
Resides in autonomous cities					0.010	1.96	-0.611	-1.58	0.016	6.56	0.001	0.39
Resides in mixed residential areas					0.021	6.10	0.070	0.26	0.004	2.42	-0.010	-10.21
Accessibility to employment by rail					0.00001	3.86	-0.003	-14.14	-0.00003	-18.63	-0.000003	-3.70
Accessibility to population by rail					-0.00002	-11.81	-0.0002	-1.11	-0.000014	-15.75	-0.00001	-28.70
Accessibility to stores by rail					0.002	16.66	0.093	11.38	0.0024	46.61	0.001	23.64
Number of compulsory (school) trips					-0.159	-22.19	-14.280	-25.27	0.397	109.71	-0.190	-90.20
Duration of compulsory (school/part time works) (in minutes)					-0.0006	-43.64	-0.065	-62.56	0.0007	102.15	0.00005	11.57
Number of non school/work trips							77.334	300.82	0.641	278.67	0.009	5.19
Duration of non school/work trips (in minutes)									0.0012	59.16	0.000002	0.16
Number of trip chain											0.007	3.89

N = 91,713 children; where the fitness indicators of the model show:

	Number Parameter	CMIN, *df*	RMSEA	P
Default model	102	1244838, *87*	0.390	.0000
Saturated model	189			
Independence model	18	1461945, *171*	0.302	.0000

Table 4. Estimation results for year 1990 dataset

	Number of compulsory (school) trips		Duration of compulsory (school) activity		Number of non school/work visits		Duration of non school/work visits		Number of trip chain		Proportion of private car trips on the given day	
	Coeff.	t-stats	Coeff.	t-stats	Coeff.	t-stats	Coeff.	t-stats	Coeff.	t-stats	Coeff.	t-stats
Intercept	0.84	674.68	419.45	654.99	0.37	29.68	32.64	31.69	0.19	30.86	0.31	64.13
Male					-0.006	-1.78	1.204	4.27	0.008	4.72	0.012	9.63
Age between 5 - 9 years old	0.121	60.92	-52.12	-51.01	0.124	31.50	-9.417	-28.91	0.079	40.56	0.017	11.41
Age between 10 - 14 years old	0.142	74.81	33.60	34.46	0.101	26.99	-1.909	-6.13	0.044	23.70	-0.025	-17.45
Number of vehicle per household					-0.006	-3.87	-0.458	-3.35	0.0014	1.75	0.027	42.34
Number of adult within household					-0.008	-5.05	-0.267	-2.05	0.003	4.04	-0.007	-11.31
Resides in highly commercial areas					0.044	3.58	3.978	3.95	-0.005	-0.84	0.003	0.71
Resides in mixed commercial areas					0.069	15.56	2.213	6.05	0.027	12.44	-0.005	-2.96
Resides in autonomous cities					0.066	13.52	1.375	3.40	0.036	15.03	-0.001	-0.37
Resides in mixed residential areas					0.069	19.25	2.004	6.75	0.023	13.23	-0.007	-5.08
Accessibility to employment by rail					-0.00009	-37.45	-0.008	-42.61	-0.00002	-13.34	-0.00002	-16.70
Accessibility to population by rail					-0.00007	-40.60	-0.003	-18.16	0.000009	10.15	-0.00003	-45.11
Accessibility to stores by rail					0.010	85.92	0.614	59.33	0.0008	13.17	0.002	40.65
Number of compulsory (school) trips					-0.076	-11.26	-14.419	-26.02	0.384	115.49	-0.292	-106.07
Duration of compulsory (school/part time works) (in minutes)					-0.0005	-37.28	-0.040	-36.54	0.0008	119.18	0.0001	11.82
Number of non school/work trips							87.817	302.87	0.628	247.93	0.047	18.07
Duration of non school/work trips (in minutes)									0.0006	30.56	-0.0001	-4.94
Number of trip chain											0.005	2.02

N = 78,442 children; where the fitness indicators of the model show:

	Number Parameter	CMIN, *df*	RMSEA	P
Default model	102	1176620, *87*	0.409	.0000
Saturated model	189			
Independence model	18	1365119, *171*	0.314	.0000

Table 5. Estimation results for year 2000 dataset

	Number of compulsory (school) trips		Duration of compulsory (school) activity		Number of non school/work visits		Duration of non school/work visits		Number of trip chain		Proportion of private car trips on the given day	
	Coeff.	t-stats	Coeff.	t-stats	Coeff.	t-stats	Coeff.	t-stats	Coeff.	t-stats	Coeff.	t-stats
Intercept	0.84	564.83	403.96	504.69	0.61	37.96	39.12	29.31	0.12	15.30	0.14	24.20
Male					-0.019	-3.86	0.750	1.83	0.018	7.43	0.004	2.27
Age between 5 - 9 years old	0.125	56.17	-28.57	-23.81	0.125	22.94	-15.530	-34.39	0.084	31.13	0.059	29.71
Age between 10 - 14 years old	0.138	62.91	43.89	37.03	0.099	18.08	-5.226	-11.58	0.084	31.14	-0.024	-12.08
Number of vehicle per household					0.004	1.65	-0.207	-1.04	0.0003	0.24	0.031	36.56
Number of adult within household					-0.024	-10.72	0.050	0.27	0.006	5.22	-0.009	-11.53
Resides in highly commercial areas					0.021	1.11	-1.722	-1.11	0.034	3.66	-0.049	-7.38
Resides in mixed commercial areas					0.011	1.77	-2.135	-4.33	0.031	10.56	-0.055	-25.70
Resides in autonomous cities					0.044	5.12	-0.795	-1.13	0.024	5.73	-0.006	-1.87
Resides in mixed residential areas					0.016	3.09	-1.158	-2.68	0.027	10.41	-0.034	-18.05
Accessibility to employment by rail					0.000002	1.20	0.0006	4.68	-0.000003	-4.22	-0.000002	-2.93
Accessibility to population by rail					0.000003	2.54	0.0004	4.03	0.000003	4.53	-0.000004	-9.16
Accessibility to stores by rail					0.0002	1.79	-0.038	-4.80	0.00006	1.33	-0.0002	-4.56
Number of compulsory (school) trips					0.099	10.04	-3.526	-4.36	0.561	116.60	-0.184	-47.51
Duration of compulsory (school/part time works) (in minutes)					-0.001	-50.65	-0.060	-39.16	0.0005	57.61	0.0002	28.98
Number of non school/work trips							84.219	247.83	0.525	181.68	0.068	26.13
Duration of non school/work trips (in minutes)									0.0008	32.35	0.0001	8.07
Number of trip chain											0.022	7.32

N = 58,809 children; where the fitness indicators of the model show:

	Number Parameter	CMIN, *df*	RMSEA	P
Default model	102	480411, *87*	0.306	.0000
Saturated model	189			
Independence model	36	605994, *153*	0.259	.0000