# IMPACT ANALYSIS OF POPULATION DENSITY ON OUTDOOR WALKING TIME

*Masayoshi Tanishita*

*Chuo University, Tokyo, 112-8551, Japan*

*Email: tanishi@civil.chuo-u.ac.jp*

*and*

*Takumi Asada*

*Chuo University, Tokyo, 112-8551, Japan*

*Email: t-asada@civil.chuo-u.ac.jp*

## ABSTRACT

It is well known that there is a negative relationship between population density and household car ownership and usage because of easy access to public transit and higher car ownership and usage cost. However, it still unclear whether higher population density increases walking or not. Transit stations in close proximity may also decrease walking time. This paper analyses the relationship between individual outdoor walking time and population density controlling demographic and household characteristics using nationwide person trip survey data. There is a quadratic relationship between population density and outdoor walking time. The value which maximizes outdoor waling time is around 6,000 persons/km$^2$.

*Keywords: Outdoor walking time, Population density,*

## INTRODUCTION

It is well known that there is a negative relationship between population density and household car ownership and usage, because of easy access to public transit and higher car ownership and usage costs. However, it remains unclear whether or not higher population density increases walking.

Of course, there is a large and growing body of evidence on the relationship between the built environment and physical activity (PA). Saelens et al. (2003) showed that residents of high-walkability neighbourhoods reported higher residential density, land use mix, street connectivity, aesthetics, and safety.

Frank et al. (2006) evaluated the association between a single index of "walkability" that incorporates land-use mix, street connectivity, net residential density, and retail floor area ratios, along with health-related outcomes in King County, Washington. They found a 5% increase in walkability to be associated with a 32.1% per-capita increase in time spent in physically active travel, a 0.23-point reduction in body mass index (BMI), 6.5% fewer vehicle miles travelled, 5.6% fewer grams of oxides of nitrogen (NOx) emitted, and 5.5% fewer grams of volatile organic compounds (VOC) emitted. These results connect development patterns with factors that cause or exacerbate several prevalent chronic diseases.

Humpel et al. (2002), Bauman and Bull (2007) and Rahman et al. (2011) reviewed related papers and reveal reasonably consistent associations among access to PA facilities, convenient and proximate access to destinations, high residential density, land use, and urban walkability scores. There were also reasonably consistent associations among perceived safety, exercise equipment, pavement ("sidewalks"), and PA participation.

Saelens and Handy (2008) also reviewed 13 papers and show that previous reviews and newer studies document the consistent and positive relationships between walking for transportation and each of population density, distance to non-residential destinations, and land-use mix. Findings with regard to route/network connectivity, parks and open space, and personal safety are more equivocal, while those regarding recreational walking are less clear.

Rodriguez et al. (2009) showed that after adjustment for individual-level characteristics and neighbourhood connectivity, higher density, greater land area devoted to retail uses, and self-reported proximity of destinations and ease of walking to places were each related to walking.

Based on a survey with over 700 participants from 36 environmentally diverse, Forsyth et al. (2009) showed that not all but some populations such as less healthy and unemployed or retired were more affected by neighbourhood environmental characteristics.

Manaugh and El-Geneidy (2011) showed that walkability score affected walk trips and households with more mobility choices were more sensitive to their surroundings than those with less choice.

Contrary to prior research, Oakes et al. (2007) conclude that the effects of density and block size on total walking time and PA were modest to nonexistent, if not contrapositive to hypotheses.

In Japan, Lee et al. (2007) delineate the association between residents' perception of their neighbourhood environments (NEs) and walking time in objectively different regions. The study results suggest that an NE may influence daily walking time; however, this analysis is a simple comparison of two areas. Kondo et al. (2009) analysed the association between daily

PA and the NEs of two areas in a city; the sample sizes therein are small, and there was no control for household car ownership.

Transit stations in close proximity may also decrease walking time. This study analyses the relationship between individual outdoor walking time and population density, while controlling for demographic and household characteristics and transport infrastructure (road density and railway station density), using nationwide person-trip survey data.

## DATA

To identify the impact of population density on outdoor walking time, we analyse the 2005 nationwide person-trip survey data from Japan. From this data, we can obtain more than approximately 60,000 individuals' times spent in outdoor walking, bicycling, and in using a car and public transport in a day, along with demographic and households characteristics, from among 53 cities. We also collected data pertaining to population density, road length, number of transit stations, and the shapes of urbanized areas in each of those 53 cities.

With regard to the shapes of urbanized areas, we classified them into three types (i.e., circle/linear/others); Table 1 outlines this typology.

Table 1 - Classifications of 53 Japanese cities based, on shapes of urbanized areas

| Type | City |
|---|---|
| Circle | Gifu, Hitoyoshi, Iwata, Kainan, Kanazawa, Kochi, Kofu, Koriyama, Kyoto, Matsudo, Matsue, Matsuyama, Morioka, Nankoku, Ohmihachiman, Osaka, Otake, Oyabe, Sakai, Sapporo, Tokorozawa, Tokushima, Utsunomiya, Yamanashi |
| Linear | Hiroshima, Ina, Kagoshima, Kameyama, Kawasaki, Kobe, Kumamoto, Nagato, Ome, Otaru, Saitama, Shizuoka, Yokohama, Yuzawa |
| Others | Chitose, Fukuoka, Hirosaki, Inagi, Joetsu, Kitakyusyu, Nara, Sendai, Shiogama, Soja, Takasaki, Tokyo 23wards, Toride, Urasoe, Yamanashi |

Needless to say, the purpose of a person-trip survey is not to tabulate outdoor walking time; therefore, these data bear limitations. For example, when we use a car, we walk to or from the space where a car is parked; however, this walking time is ignored and/or omitted by respondents. In addition, respondents may fail to report walking activity whenever they consider it troublesome to do so; as a result, many respondents answer “zero” to questions about outdoor walking time. Figure 1 shows the distribution of outdoor walking times; it is necessary to take this distribution into consideration in the process of analysis.

Table 2 shows the descriptive statistics of explanatory variables. Regarding road length and stations, we take the ratio of these two variables and hereafter we call it Transport Infrastructure Index (TII). With regard to dummy variables, we show the number of records within the samples.

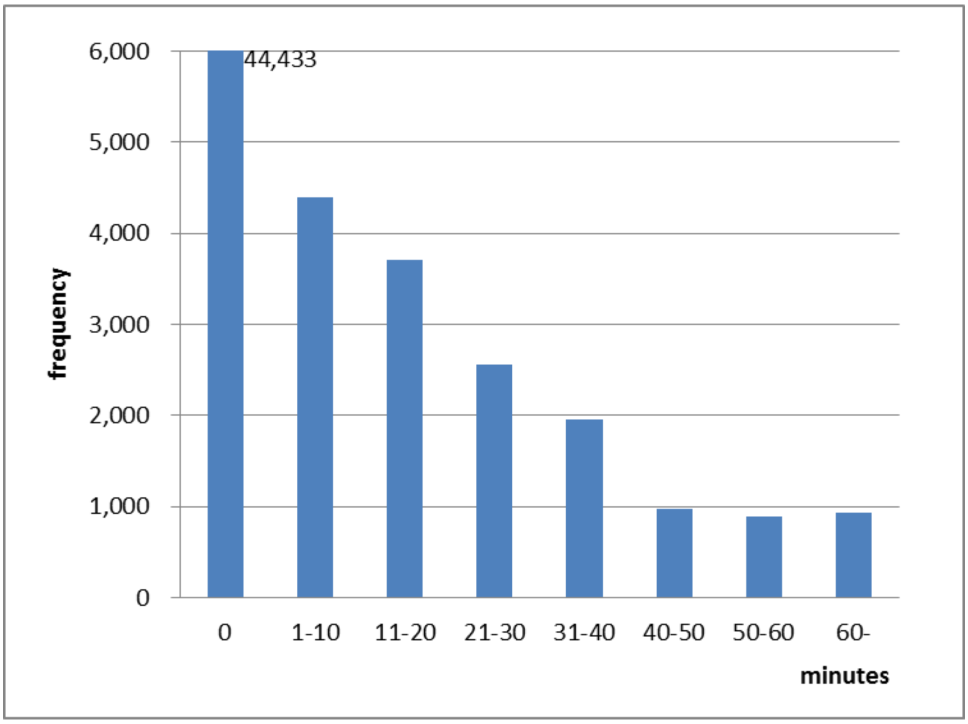


Figure 1 - Distribution of outdoor walking time

Table 2 - Descriptive statistics of explanatory variables

| Explanatory variable | | Mean : Standard deviation (Frequency) |
|---|---|---|
| Urban structure | | |
| log( Population density) | | 2.97 : 0.56 |
| log( Road density/Station density ) | | −1.27 : 4.11 |
| Shapes of urbanized areas( dummy) | ･Circle | (26) |
| | ･Linear | (16) |
| | ･Others | (15) |
| Personal attribute | | |
| Age | | 52.04 : 17.53 |
| Household size | | 3.39 : 1.45 |
| Gender( dummy) | ･Male | (28,353) |
| | ･Female | (31,836) |
| Type of employment( dummy) | ･Employed person | (31,135) |
| | ･Housewife | (8,786) |
| | ･Part-time job | (6,473) |
| | ･Unemployed･Others | (1,094) |
| Car onwership and use( dummy) | ･For personal use | (28,751) |
| | ･For family | (11,012) |
| | ･Non-possession | (20,426) |

# METHODOLOGY

While controlling for age, household size, gender, job, car ownership, transport infrastructure, and urbanized area shape, we analysed the relationship between population density and each of outdoor walking time and total travel time. Because there are many instances of zero and nonnegative answers for explained variables, we apply Tobit and zero-inflated count models (i.e., Poisson/negative binominal).

**Tobit Model**

$$y_i = \begin{cases} y_i^* & \text{if } y_i^* > 0 \\ 0 & \text{if } y_i^* \leq 0 \end{cases},$$

where $y_i^*$ is a latent variable:

$$y_i^* = \beta x_i + u_i, u_i \sim N(0, \sigma^2).$$

The Tobit model supposes that there is a latent (i.e., unobservable) variable $y_i^*$. This variable linearly depends on $x_i$ via a parameter (vector) $\beta$ that determines the relationship between the independent variables $x_i$ and the latent variable $y_i^*$. In addition, there is a normally distributed error term $u_i$ used to capture random influences on this relationship. The observable variable $y_i$ is defined as being equal to the latent variable whenever the latent variable is greater than 0, and 0 otherwise.

**Zero-Inflated Count Models**

Zero-inflated count models are two-component mixture models that combine a point mass at zero with a proper count distribution. Thus, there are two sources of zeros: the point mass, or the count component. Usually the count model is a Poisson or negative binomial regression (with log link). The geometric distribution is a special case of the negative binomial, with a size parameter equal to 1. To model the unobserved state (i.e., zero vs. count), a binary model is used, in the simplest case containing only an intercept but potentially containing regressors. For this zero-inflation model, a binomial model with different links can be used, which are typically logit or probit.

We also analyze total travel time using this model, and thereafter interpret the results.

## RESULTS

### Model Comparison

With regard to the functional form of each explanatory variable, the coefficients of determination of each model are shown in Table 3.

The coefficients of determination are not high enough; the negative binominal model shows the highest coefficient of determination.

### Parameters

We provide below the estimation results of walking and total travel time (Tables 4 and 5, respectively).

Table 3 - Comparison of coefficients of determination in each model

| Model | Dependent variable | Coefficient of determination |
|---|---|---|
| Multiple regression | Walking Time | 0.14 |
| | log(Walking Time+1) | 0.20 |
| zero-inflated(negbin) | Walking Time | 0.31 |
| zero-inflated(Poisson) | Walking Time | 0.21 |
| Tobit | Walking Time | 0.18 |
| | log(Walking Time+1) | 0.23 |

Table 4 - Estimation results of outdoor walking time

| Outdoor Walking Time | Time (negbin with logit link) | | | Zero-inflation (binomial with logit link) | | |
|---|---|---|---|---|---|---|
| | Estimate | z value | | Estimate | z value | |
| (Intercept) | 0.79 | 3.30 | *** | 3.46 | 9.57 | *** |
| log( PD) | 0.75 | 5.99 | *** | *-0.23* | *-1.16* | |
| (log( PD))^2 | -0.099 | -4.91 | *** | -0.11 | -3.52 | *** |
| TII | -1.22.E-04 | -3.25 | ** | 3.54.E-04 | 4.76 | *** |
| City Shape dummy: linear | 0.095 | 5.91 | *** | -0.36 | -13.67 | *** |
| City Shape dummy: others | 0.070 | 4.71 | *** | -0.19 | -8.14 | *** |
| HH size | -0.034 | -6.92 | *** | 0.12 | 16.15 | *** |
| Gender dummy:Male | 0.14 | 9.28 | *** | 0.059 | 2.46 | * |
| Job dummy: housewife | 0.064 | 3.12 | ** | 0.38 | 11.66 | *** |
| Job dummy: part time | *-0.02* | *-1.04* | | 0.21 | 6.08 | *** |
| Job dummy: students | 0.15 | 4.01 | *** | -0.36 | -4.92 | *** |
| Job dummy: out of work | 0.16 | 8.02 | *** | 0.50 | 16.17 | *** |
| log( Age) | 0.26 | 6.99 | *** | -0.14 | -2.67 | ** |
| Car ownership dummy: family shared | 0.96 | 4.99 | *** | -2.82 | -9.24 | *** |
| Car ownership dummy: no car | 0.88 | 5.29 | *** | -3.47 | -13.22 | *** |
| log( Age):family shared car | -0.22 | -4.30 | *** | 0.49 | 6.12 | *** |
| log( Age):no car | -0.18 | -4.20 | *** | 0.63 | 9.34 | *** |
| ln( theta) | 0.59 | 46.07 | *** | | | |
| | | | | | | |
| PD* ( persons/km2) | 6,244 | | | - | | |
| AIC | 192,444 | | | | | |
| AIC(0): linear model | 497,002 | | | | | |

Note: Italic represents statistically no significance at 5% level.

Table 5 - Estimation results of total travel time

| Total travel time | Time (negbin with logit link) | | | Zero-inflation (binomial with logit link) | | |
|---|---|---|---|---|---|---|
| | Estimate | z value | | Estimate | z value | |
| ( Intercept) | 2.95 | 25.84 | *** | -4.77 | -12.49 | *** |
| log( PD) | 0.52 | 7.92 | *** | 0.55 | 2.68 | ** |
| (log( PD))^2 | -0.046 | -4.20 | *** | -0.15 | -4.20 | *** |
| TII | -8.97.E-05 | -3.41 | *** | 3.03.E-04 | 3.45 | *** |
| City Shape dummy: linear | 0.092 | 9.65 | *** | *-0.02* | *-0.69* | |
| City Shape dummy: others | 0.082 | 9.95 | *** | 0.061 | 2.39 | * |
| HH size | -0.013 | -4.85 | *** | 0.048 | 6.32 | *** |
| Gender dummy:Male | 0.23 | 26.62 | *** | *-0.01* | *-0.34* | |
| Job dummy: housewife | -0.26 | -21.14 | *** | 0.58 | 16.83 | *** |
| Job dummy: part time | -0.19 | -16.27 | *** | -0.50 | -10.27 | *** |
| Job dummy: students | 0.31 | 11.52 | *** | 0.34 | 3.43 | *** |
| Job dummy: out of work | -0.19 | -16.06 | *** | 1.08 | 36.55 | *** |
| log( Age) | *0.01* | *0.71* | | 0.54 | 9.15 | *** |
| Car ownership dummy: family shared | 0.24 | 2.28 | * | 1.13 | 2.97 | ** |
| Car ownership dummy: no car | 0.62 | 6.63 | *** | -0.87 | -2.83 | ** |
| log( Age):family shared car | *-0.05* | *-1.88* | . | -0.20 | -2.00 | * |
| log( Age):no car | -0.18 | -7.53 | *** | 0.47 | 6.15 | *** |
| ln( theta) | 0.60 | 92.55 | *** | | | |
| | | | | | | |
| PD* ( persons/km2) | 423,278 | | | 78 | | |
| AIC | 525,686 | | | | | |
| AIC(0): linear model | 642,873 | | | | | |

Note: Italic represents statistically no significance at 5% level.

There is a quadratic relationship between population density and outdoor walking time. The population density value at which outdoor walking time is maximized is around 6,000 persons/km$^2$. This means that a very high population density can decrease outdoor walking time. In addition, housewives and students tend to spend more time in outdoor walking than those in the paid workforce. The population density value that maximizes total travel time is about three times larger than that of outdoor walking time.

A number of interesting results were found:

- The variable of the square of population density showed statistical significance and a negative value. The population density value bearing the maximum outdoor walking time was estimated at 6,000 (persons/km$^2$). The cities of Sakai and Nagoya most closely approach this value. Whenever population density is low, since a car must be used, outdoor walking time is low; also, since the convenience of public transit is high in densely populated areas, it can be said that there is a tendency for outdoor walking time to become relatively shorter there.
- However, total travel time tends to grow as population density increases.
- The parameter of Transport Infrastructure Index shows a negative value; this suggests that the higher railway/subway station density is, compared to road density, the longer outdoor walking time and total travel time will become.
- The outdoor walking time of round-shaped cities is shorter than those with straight-line shapes; this finding is also true of total travel time.

- As the number of household members increases, outdoor walking time tends to become shorter. If there are many household numbers, the portion shared [ask/are accompanying or/for requirements/someone] will increase, thus shortening outdoor walking time. The same tendency is seen with regard to total travel time.
- The outdoor walking time of males exceeds that of females. This result aligns with that of a national survey on nutrition, and it is also true of total travel time.
- As for people who own their own cars, their outdoor walking times and total travel times are relatively shorter.
- On the employment form, the outdoor walking times of housewives and unemployed persons were found to be longer than those of workers. On the other hand, the total travel times of housewives and unemployed persons were shorter. Student also tended to have longer total travel times than workers.
- As age increased, outdoor walking time tended to become longer, but there was no significant difference seen in total travel time.

# CONCLUSIONS

This paper analysed the relationship between individual outdoor walking time and population density, while controlling for demographic and household characteristics; it did so by using nationwide person-trip survey data from Japan. The variable of the square of population density showed statistical significance and a negative value. When population density is low, since a car must be used, outdoor walking time is lower, and since the convenience of public transit is high in densely populated areas, there is a tendency for outdoor walking time to become shorter there. The population density at which outdoor walking time is maximized was found to be approximately 6,000 persons/km$^2$. Of the 53 cities examined, those of Sakai and Nagoya most closely approached this value.

Transport Infrastructure Index (the ratio of road and station density) also affected outdoor walking time. To enhance outdoor walking time, moderate access to shops, transit stations, and other public facilities is important. However, Transit stations in close proximity may not increase walking times. Needless to say, station density is correlated with population density. We need further analysis to confirm this validity.

Walking is good for managing obesity and health. Finkelstein et al. (2009) estimated that the medical cost of obesity could have risen to $147 billion per year by 2008 in the USA. MacDonald et al. (2010) showed that an increase in PA leaded to a decrease in BMI. In Charlotte, North Carolina, an approximate 1.2% reduction in BMI and an 81% reduction in the odds ratio of being obese were observed upon the opening of light rail transit (LRT). Stokes et al. (2008) estimate that the opening of this LRT will save approximately USD1,260 million in medical expenses by 2015. We hope to expand our work from the view point of health.

Variables regarding the district-level built environment should be included in future analyses; for example, disaggregating the Transport Infrastructure variables and introduction of variables indicating land-use mix and safety etc. In addition, not only outdoor walking times, but also transit and indoor walking times should be considered. Of course, not only time but also activity level and/or air quality may be good factors to consider in future research. Finally, optimal population density should be discussed from the viewpoints not only of walking and transport, but also of various activities.

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