# 都市内移動とエネルギー消費に対する都市環境の影響要因 : 福岡市を対象として

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# 都市内移動とエネルギー消費に対する都市環境の影響要因
# —福岡市を対象として—

# The Effect Factors of Built Environment on Travel Behavior and Travel Energy Consumption
# —A Case Study of Fukuoka City—

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The goal of this study is to provide additional insights to the linkages between built environment, travel behavior(travel purpose and travel mode choice) and travel energy consumption for reducing transportation related fuel consumption and emissions. This paper applies Linear Regression Model(LRM) analysis to examine the influence of built environment attributes; "5Ds"(Density, Diversity, Design, Destination accessibility and Distance to transit) and socio-demography on non-motorized travel, motorized travel and energy consumption for five different travel purposes(work, study, business, private and return home) at both trip origin and trip destination. The analysis result shows that people travel a long distance for work and private purpose whereas for business purpose they travel a shorter distance. The result identifies that increase of travel energy consumption is mainly due to work trip. Reduction of energy consumption is found possible even though work origin is far from CBD; by promoting higher density(D1) and better transit accessibility(D5) at work origin. Also, found that higher land use mix(D3) at work destination has no direct effect on energy consumption but has direct effects on the increase of non-motorized travel which ultimately effect indirectly on travel energy consumption reduction .

***Keywords:*** *Built Environment, Travel Behavior, Travel Energy Consumption, 5Ds, Fukuoka*
都市環境、移動、移動エネルギー、5Ds、福岡

## 1. Introduction

### 1.1. Background

Planning initiatives in many regions and communities throughout the world have been directed at changing land use in order to reduce travel energy consumption, decrease greenhouse gas emissions and achieve other economic, social and environmental benefits. A substantial body of research has suggested that a swift towards more compact and walkable development patterns could reduce transportation related fuel consumption and emissions[1)-4)]. This is because land use planning is widely considered as a fundamental and long-term strategy to reduce the dependence on automobiles as it determines the basic spatial settings for various activities[5), 6)].

Many studies found that the built environment variables are associated with the levels of usage for transit and non-motorized modes[7)-12)]. It is often concluded that how urban form is planned and organized determines travel energy consumption to large extent. However, a transition towards energy efficient cities requires an effective upgrade of individual travel behavior as it plays a huge role in reducing travel energy consumption on a city level.

According to Fox[13)], travel behavior is a strategy by which individuals fulfill their needs and wishes by performing activities at various locations. As a matter of course, most households select residential locations at least partly based on their travel abilities, needs and preferences[14)]. It has been acknowledged that technical improvements in vehicle efficiency alone have a lower impact on saving energy but ones combined with urban planning discipline has a significant role in reducing energy consumption in a city by creating such environment where people tends to walk, drive less or use public transport mode. The goal of this paper is to identify the significant factors of built environment that need to consider for reducing travel energy consumption in a city.

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### 1.2. Literature Review

A review of studies on transportation and land use interactions indicates that the aspect of urban form that most influences travel behavior is the travel purpose. A number of papers concentrate on the travel behavior involved in particular types of travel purpose, for example, local shopping trip[15], journey-to-work trips[16], maintenance trips[17] and non-work travel[18]. As the travel activity plays an important role in influencing travel energy consumption on a city level, it cannot be neglected and it is better to consider all the travel purposes. This research has analyzed all types of travel purposes(work, study, business, private and return home) at both trip origin and destination for a better understanding of the relationship between built environment and travel behavior. Though many researchers examine the connection between the built environment and travel behavior, there has been relatively less attention on the influence of built environment on travel energy consumption.

In addition, some papers discuss the use of a particular mode of transport whereas other papers used a travel survey to capture details of all travel modes used within a particular time period. However, the majority of papers deal with the use of either the car or public transport as the primary mode of transport[19]. A few papers focus on walking or cycling activities alone[20]. Chatman[18] studied the confounding influence of modal (auto, transit, walk/bike) preferences in the relationship between the built environment and non-work travel. In order to achieve an overview of energy consumption in a city, it is important to include all types of travel modes in a research. This research has included all travel mode types(Non-motorized: walk and bicycle; Motorized: rail, bus, taxi, car, bike and others).

### 1.3. Objective

- To analyze empirically the flow of trip for different travel purposes at both trip origin and destination.
- To identify the effect of built environment and socio-demography on purpose wise non-motorized travel and motorized travel at the trip origin and destination simultaneously.
- To explore the effect factors of built environment and socio-demography on travel energy consumption while traveling for different purposes.

### 1.4. Methodology

This study mainly uses three types of data based on Fukuoka City: Urban data, Person Trip Survey(PTS) data and Energy intensity data(Fig. 2). PTS is a person-based travel survey conducted every ten years by Ministry of Land, Infrastructure and Transport (MLIT). Daily travel is collected using one-day trip diaries for all household members in selected households. As the PTS data 2007 is the latest survey data of Fukuoka, we collected urban form data and energy intensity data also from 2007 to get the research result more reliable and accurate.

Urban data of Fukuoka city was decomposed into 108 zones as in Fig. 1. Zones were referred to the PTS zone which is based on the zoning of Road traffic census held in 2005. In this research, Island City which is an artificial island built in Hakata Bay to boost the city's port functions has excluded because we had a travel data of it but the master data doesn't contain socio-demography(i. e. respondent from Island City is null). From PTS master data, socio-demography and trip data were extracted and

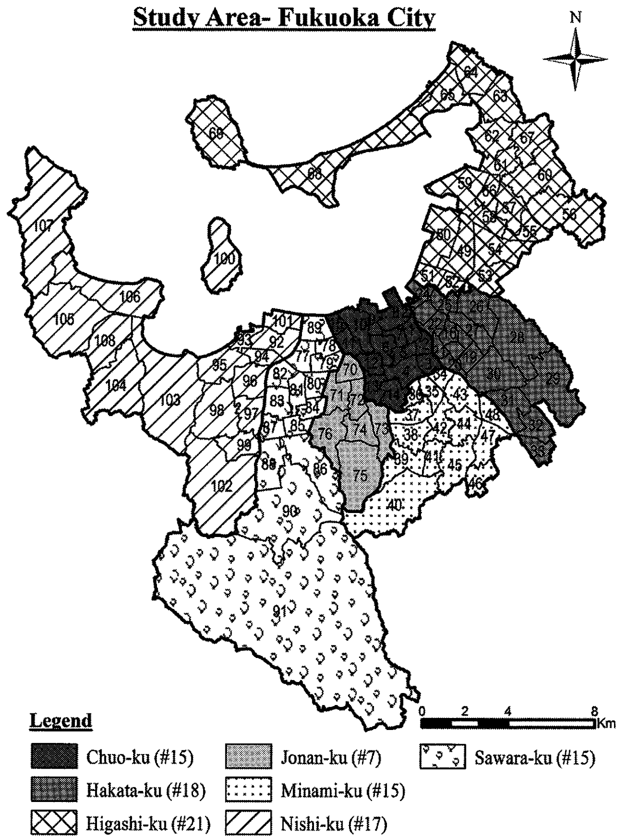

Fig. 1 Study Area ※ #: Zone count

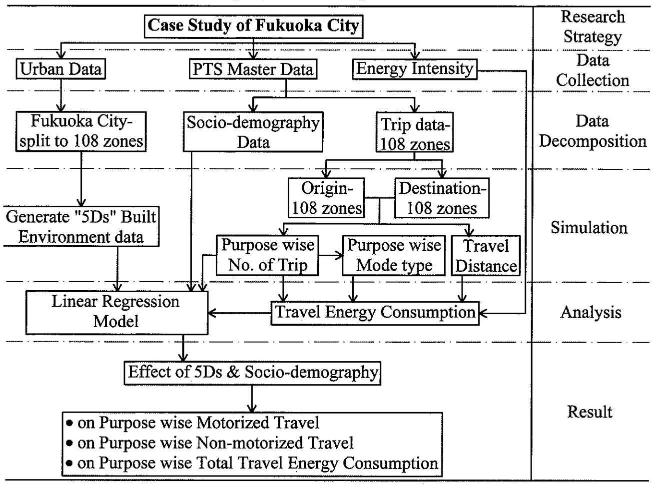

Fig. 2 Research Methodology

decomposed into 108 zones. Trip data was further divided into the trip origin and trip destination. Energy intensity data was used to calculate total energy consumption for various travel purposes. Empirical Analysis and Linear Regression Model(LRM) were applied as an analysis method. The empirical analysis was performed by using GIS and LRM analysis was carried out on SPSS. It enables the identification and characterization of relationships among multiple variables. The analysis examined the effect of built environment attributes(5Ds) and socio-demography on purpose wise motorized travel, non-motorized travel and total travel energy consumption at trip origin and destination seperately.

This research covers 135,302 respondents and 5,559,737 total trips. This research only focused the travel that was generated within the Fukuoka City.

## 2. Variables Analyzed

### 2.1. Dependent Variables

Dependent variables included travel behavior related variables(travel purpose and mode choice) and travel energy consumption at both trip origin and trip destination. Travel purpose included the measure for work, study, business, private and return home. The mode choice has analyzed in term of non-motorized and motorized.

### 2.2. Independent Variables

Socio-demography variables(age, gender and occupation) and built environment attributes were independent variables for this research. Occupation was divided into 6 types(Agriculture, production, sales/ service, administrative, student and housewife/ others) based on PTS master data. While many different measures can be used to characterize the built environment but for this research, we used the measure- "5Ds" which is frequently used and accepted in most of the research[21)-23)]. 5Ds included density, diversity, design, destination accessibility and distance to transit. In this research, density(D1) was measured in terms of population density and household density. Diversity(D2) was measured by using land use mix index(Entropy)[3),6),12)] as shown in Eq(1). Design(D3) was taken as 3-way and 4-way road intersection, Destination accessibility(D5) was considered as the distance to Central business district(CBD). For this research, CBD is considered as the existing location of Fukuoka City Hall becasue this area has the higher transit accessibility, higher jobs and shopping opportunities. Distance to transit(D5) was measured as bus accessibility and rail accessibility. A number of road intersections were calculated using Spatial Statistics tool in GIS. The road of 1.2m also included in the intersections simulation

Land use mix index= $\{-\sum_k (P_i * (Ln\, P_i)\}/(Ln\, P_i)$ ....Eq(1)

$p_i$= proportions of each of land use types(in this research; residential, commercial, industrial, utility facility and public open space)
$k$= number of land use types(in this research; 5)

$$EC = \sum_{j=1}^{n} \sum_{i=1}^{m} T_{ij} * D_i * EI_j \qquad \text{...............Eq(2)}$$

Where,
EC= Total Energy consumption(MJ/person/day)
$n$ = Total number of travel mode
j = Travel mode type{Rail, Bus, Car, Taxi and Bike}
$m$ = Total number of travel purpose
$i$ = Travel purpose{work,School,Business,Private,Return Home}
$Tij$= Travel for purpose 'i' by mode 'j'
$Di$= Travel Distance for travel purpose 'i' (km)
$EIj$= Energy Intensity factor for travel mode 'j' (MJperson/ km)
{(Rail-0.20, Bus-0.72, Car-2.41 & Taxi-5.43)[24)] and Bike[25)]-1.2}

Table. 1 Descriptive status of each variable

| Variable | | | Mean | SD | Min | Max |
|---|---|---|---|---|---|---|
| Socio-Demography | | Age | 42.37 | 3.61 | 5 | 103 |
| | | Male | 586.09 | 356.70 | 0 | 1340 |
| | | Female | 666.70 | 414.62 | 5 | 1581 |
| | | Agriculture | 0.62 | 1.84 | 0 | 13 |
| | | Production | 5.18 | 3.81 | 0 | 27 |
| | | Sales & service | 16.10 | 8.26 | 0 | 60 |
| | | Administrative | 31.54 | 6.17 | 12 | 50 |
| | | Student | 17.92 | 6.32 | 0 | 34 |
| | | Housewife/others | 28.58 | 7.19 | 0 | 59 |
| Built Environment | D1 | Population density | 2965.10 | 1642.92 | 2.20 | 8827.70 |
| | | Household density | 69.59 | 51.31 | 0.57 | 204.53 |
| | D2 | Land use mix | 0.50 | 0.13 | 0.08 | 0.71 |
| | D3 | 3-way road | 363.11 | 263.65 | 24.00 | 1746.00 |
| | | 4-way road | 87.54 | 45.83 | 4.00 | 218.00 |
| | D4 | Distance to CBD | 7.75 | 5.44 | 0.54 | 33.28 |
| | D5 | Bus Accessibility | 5.48 | 3.35 | 0.00 | 22.38 |
| | | Rail Accessibility | 0.30 | 0.32 | 0.00 | 0.98 |
| At origin | Non-Motorized travel | Work | 1109.82 | 795.48 | 0.00 | 4400.00 |
| | | Study | 1373.21 | 869.74 | 0.00 | 3378.00 |
| | | Business | 317.48 | 609.10 | 0.00 | 5438.00 |
| | | Private | 2479.19 | 2057.78 | 24.00 | 17294.00 |
| | | Return home | 4103.43 | 2429.75 | 105 | 12822 |
| | Motorized travel | Work | 3217.65 | 1884.04 | 45 | 7095 |
| | | Study | 487.11 | 327.93 | 0 | 1708 |
| | | Business | 3998.38 | 2926.26 | 159 | 20475 |
| | | Private | 3008.19 | 1570.75 | 80 | 9562 |
| | | Return home | 5645.37 | 7391.80 | 108 | 72387 |
| at destination | Non-Motorized travel | Work | 1108.54 | 1093.68 | 0 | 7577 |
| | | Study | 1373.21 | 1047.88 | 0 | 4923 |
| | | Business | 317.48 | 665.79 | 0 | 5880 |
| | | Private | 2476.93 | 2603.93 | 24 | 23635 |
| | | Return home | 4106.80 | 2387.70 | 28 | 9525 |
| | Motorized travel | Work | 3212.35 | 4662.07 | 44 | 40387 |
| | | Study | 486.90 | 690.25 | 0 | 4989 |
| | | Business | 3997.46 | 3147.80 | 272 | 22754 |
| | | Private | 2996.13 | 3933.90 | 43 | 39900 |
| | | Return home | 5663.43 | 3341.16 | 27 | 11866 |
| Energy Consumption (EC) | at origin | Work | 29649.53 | 21257.43 | 111.79 | 82974.38 |
| | | Study | 3174.37 | 3719.64 | 0.00 | 31735.05 |
| | | Business | 52415.86 | 32993.37 | 2794.05 | 157342.82 |
| | | Private | 25771.02 | 24414.20 | 691.26 | 237688.28 |
| | | Return home | 51675.40 | 50142.55 | 1605.83 | 428398.69 |
| | at destination | Work | 29562.79 | 28598.05 | 875.35 | 202974.38 |
| | | Study | 3173.83 | 5373.65 | 0.00 | 38882.39 |
| | | Business | 52401.93 | 34083.87 | 4042.95 | 174626.11 |
| | | Private | 25536.54 | 30259.08 | 331.39 | 228409.93 |
| | | Return home | 52024.09 | 42680.81 | 12.17 | 307855.31 |

※ SD- Standard Deviation

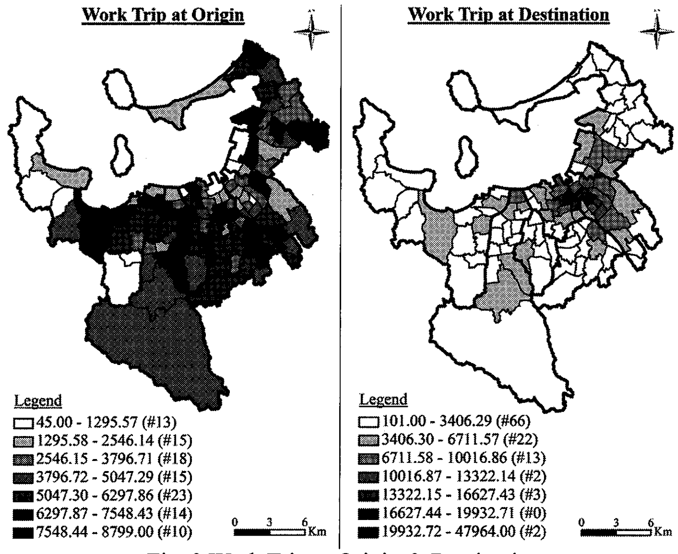


Fig. 3 Work Trip at Origin & Destination

Table 2. Linear Regression Model Analysis for Work Trip

| Work trip | Origin | | | | | | Destination | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Non-motorized | | Motorized | | EC | | Non-motorized | | Motorized | | EC | |
| | SC | Sig. | SC | Sig. | SC | Sig. | SC | Sig. | SC | Sig. | SC | Sig. |
| Pop. density | 0.096 | 0.435 | 0.107 | 0.138 | -0.053 | 0.525 | -0.047 | 0.685 | -0.057 | 0.668 | -0.054 | 0.724 |
| HH density | 0.468 | 0.000 | -0.132 | 0.061 | -0.256 | 0.002 | 0.200 | 0.076 | -0.031 | 0.812 | -0.127 | 0.390 |
| Land use | 0.151 | 0.178 | 0.076 | 0.244 | 0.195 | 0.012 | 0.084 | 0.423 | -0.006 | 0.960 | 0.126 | 0.362 |
| 3-way | 0.006 | 0.966 | 0.042 | 0.591 | 0.451 | 0.000 | 0.212 | 0.096 | 0.110 | 0.457 | 0.183 | 0.278 |
| 4-way | 0.327 | 0.006 | 0.237 | 0.001 | 0.160 | 0.044 | 0.104 | 0.339 | 0.164 | 0.195 | 0.192 | 0.183 |
| CBD access | -0.186 | 0.150 | -0.091 | 0.224 | -0.011 | 0.895 | -0.084 | 0.485 | -0.154 | 0.269 | -0.296 | 0.064 |
| Bus access | -0.025 | 0.788 | -0.023 | 0.667 | -0.028 | 0.653 | 0.579 | 0.000 | 0.583 | 0.000 | 0.340 | 0.004 |
| Rail access | -0.018 | 0.824 | -0.004 | 0.938 | -0.039 | 0.477 | 0.112 | 0.141 | 0.104 | 0.239 | 0.092 | 0.360 |
| Age | 0.111 | 0.278 | -0.100 | 0.097 | -0.121 | 0.084 | 0.110 | 0.249 | 0.156 | 0.161 | 0.106 | 0.401 |
| Male | -0.231 | 0.540 | 0.801 | 0.000 | 0.361 | 0.160 | 0.201 | 0.567 | 0.176 | 0.667 | -0.128 | 0.783 |
| Female | 0.488 | 0.168 | -0.129 | 0.528 | 0.068 | 0.775 | -0.256 | 0.436 | -0.372 | 0.331 | -0.156 | 0.719 |
| Agriculture | -0.006 | 0.978 | -0.164 | 0.168 | -0.147 | 0.285 | -0.020 | 0.916 | 0.111 | 0.614 | -0.002 | 0.994 |
| production | -0.170 | 0.675 | -0.326 | 0.169 | -0.068 | 0.804 | -0.061 | 0.871 | 0.267 | 0.545 | 0.112 | 0.823 |
| Sales | -0.422 | 0.644 | -0.587 | 0.273 | 0.021 | 0.973 | -0.220 | 0.796 | 0.583 | 0.557 | -0.081 | 0.943 |
| Admin | -0.350 | 0.608 | -0.406 | 0.307 | 0.016 | 0.972 | -0.272 | 0.669 | 0.297 | 0.688 | -0.106 | 0.900 |
| Student | -0.405 | 0.570 | -0.487 | 0.243 | -0.049 | 0.920 | -0.429 | 0.519 | 0.237 | 0.759 | -0.192 | 0.828 |
| Others | -0.587 | 0.468 | -0.389 | 0.409 | 0.096 | 0.861 | -0.450 | 0.550 | 0.193 | 0.825 | -0.473 | 0.635 |
| P-value | | 0.000 | | 0.000 | | 0.000 | | 0.000 | | 0.000 | | 0.000 |
| $R^2$ | | 0.671 | | 0.888 | | 0.849 | | 0.714 | | 0.612 | | 0.498 |
| Freedom F(17,90) | | 10.783 | | 42.076 | | 29.783 | | 13.2 | | 8.368 | | 5.244 |

※ SC- Standardized Coefficient

considering to travel by walk and bicycle. For the station area of influence, an area of a circle with a radius of 0.55km(avg. walking distance) has taken whose center is a subway or rail station[23]. Total travel energy consumption was calculated using a number of trips by each mode type for different purposes, travel distance and mode wise energy intensity. Formulated equation was shown in Eq(2). For travel distance and distance to CBD, we used the shortest distance which is calculated by using OD Cost Matrix. The data for the descriptive status of each variable are shown in Table 1.

### 3. Analysis Results

The Empirical Analysis and Linear Regression Model (LRM) analysis are applied for all the travel purposes separately. The analysis result of LRM has been described here only which are identified highly significant. With the LRM analysis method, the explained P-value and the variance ($R^2$) at the different term is measured as a summary of model fit. The term which has P-value less than 0.05 and higher $R^2$ value is identified as statistically significant or better model fit. An independent variable that has significant (Sig.) value less than 0.05 is identified as a uniquely significant factor because changes in the independent variable's value are related to changes in the dependent variable. Likewise, in the LRM, the negative sign of standardized coefficient(SC) indicates that the independent variable is negatively associated with the dependent variable. This is vice versa for the positive sign.

#### 3.1. Work Trip

#### 3.1.1. Empirical Analysis for work trip

The empirical analysis showed that the trips for work purpose are generated from various zones but the destinations are almost the same zone- zone 1 of Chuo-ku and zone 16 of Hakata-ku(Fig. 3). This is due to the fact that these zones are associated with the highly mixed land use area, higher bus accessibility and rail accessibility. Whereas the origin zones of work trip are found having higher proportion of residential areas with lower proportion of commercial, industrial and open space; indicating that origin zones for work trip are characterized as less mixed land use.

#### 3.1.2. Linear Regression Model analysis for work trip

The regression result for work trip(Table 2) showed better model fit for motorized travel at origin with 89% of the variance($R^2$=0.888, P-value<0.000). It meant that built environment and socio-demography variables of origin for work trip are found more influencing factor for motorized travel. D3(4-way road intersection) is identified as a significant factor for work-related motorized travel. This suggests that road intersection has an important role for the increase of work-related motorized travel at origin which is also supported by the positive sign of SC. There has been a range of studies shows that better road connectivity resulted in walking and cycling. So the result from this research is different. This is due to the fact that the workplaces in Fukuoka City are further away from the residential location so there is no significant relation to the road design at the origin. The negative sign of SC showed that the built environment variables; D1(household density), D4(distance to CBD) and D5(bus and rail accessibility) are inversely associated with work-related motorized trip at origin; indicating that people living closer to CBD tend to drive more. Poor accessibility to transit has a key role for increasing work-related motorized travel at origin due to a longer travel distance tend to drive or park-and-ride that results in increase of work-related motorized travel.

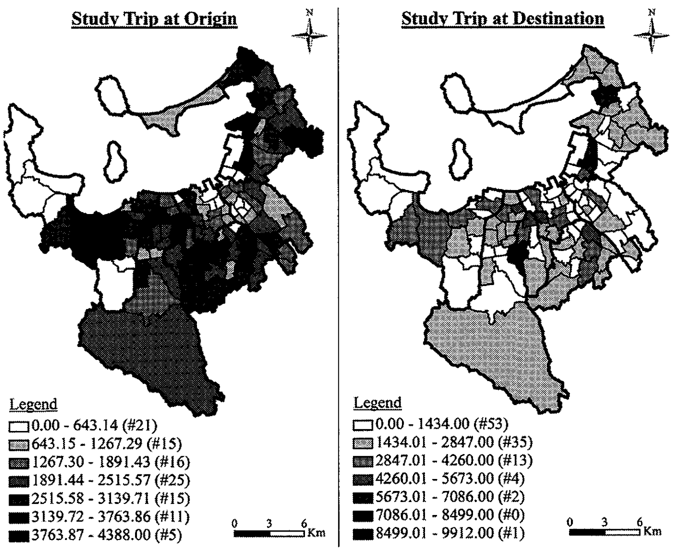


Fig. 4 Study Trip at Origin & Destination

Table 3. Linear Regression Model Analysis for Study Trip

| Study trip | Origin | | | | | | Destination | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Non-motorized | | Motorized | | EC | | Non-motorized | | Motorized | | EC | |
| | SC | Sig. | SC | Sig. | SC | Sig. | SC | Sig. | SC | Sig. | SC | Sig. |
| Pop. density | 0.009 | 0.900 | -0.154 | 0.144 | -0.347 | 0.028 | -0.162 | 0.250 | -0.329 | 0.068 | -1.904 | 0.060 |
| HH density | -0.084 | 0.236 | -0.116 | 0.257 | 0.004 | 0.977 | -0.081 | 0.553 | 0.167 | 0.336 | 1.154 | 0.252 |
| Land use | -0.026 | 0.699 | 0.067 | 0.485 | 0.069 | 0.628 | 0.137 | 0.284 | 0.216 | 0.185 | 0.334 | 0.739 |
| 3-way | -0.093 | 0.247 | 0.038 | 0.740 | 0.076 | 0.660 | 0.151 | 0.332 | 0.368 | 0.064 | 1.522 | 0.132 |
| 4-way | 0.183 | 0.009 | 0.318 | 0.002 | 0.258 | 0.083 | 0.130 | 0.327 | -0.029 | 0.862 | 0.150 | 0.881 |
| CBD access | -0.197 | 0.011 | -0.097 | 0.375 | 0.039 | 0.811 | -0.164 | 0.264 | -0.035 | 0.849 | 0.358 | 0.721 |
| Bus access | 0.068 | 0.213 | -0.052 | 0.507 | -0.116 | 0.324 | -0.015 | 0.890 | -0.018 | 0.895 | -0.078 | 0.938 |
| Rail access | -0.091 | 0.060 | 0.110 | 0.115 | 0.108 | 0.297 | 0.274 | 0.004 | 0.479 | 0.000 | 3.744 | 0.000 |
| Age | 0.015 | 0.799 | -0.103 | 0.238 | -0.119 | 0.361 | -0.064 | 0.581 | 0.056 | 0.706 | 0.512 | 0.610 |
| Male | 0.780 | 0.001 | 0.633 | 0.051 | 0.798 | 0.098 | 0.391 | 0.364 | 0.215 | 0.694 | 0.118 | 0.906 |
| Female | -0.048 | 0.817 | -0.020 | 0.948 | -0.273 | 0.541 | 0.150 | 0.709 | -0.004 | 0.995 | 0.383 | 0.703 |
| Agriculture | -0.241 | 0.046 | -0.154 | 0.374 | 0.051 | 0.844 | -0.273 | 0.239 | -0.062 | 0.834 | -0.724 | 0.471 |
| production | -0.469 | 0.052 | -0.199 | 0.564 | 0.208 | 0.687 | -0.547 | 0.239 | 0.042 | 0.943 | -0.016 | 0.987 |
| Sales | -0.857 | 0.115 | -0.259 | 0.740 | 0.656 | 0.572 | -1.139 | 0.276 | -0.005 | 0.997 | -0.239 | 0.811 |
| Admin. | -0.763 | 0.060 | -0.219 | 0.706 | 0.522 | 0.546 | -0.814 | 0.296 | 0.049 | 0.960 | -0.206 | 0.837 |
| Student | -0.442 | 0.296 | -0.138 | 0.820 | 0.421 | 0.642 | -0.741 | 0.363 | 0.041 | 0.969 | -0.211 | 0.833 |
| Others | -0.734 | 0.126 | -0.148 | 0.829 | 0.690 | 0.501 | -0.870 | 0.346 | -0.030 | 0.979 | -0.239 | 0.812 |
| P-value | | 0.000 | | 0.000 | | 0.000 | | 0.000 | | 0.005 | | 0.014 |
| $R^2$ | | 0.885 | | 0.761 | | 0.47 | | 0.572 | | 0.309 | | 0.282 |
| Freedom $F(17,90)$ | | 40.745 | | 16.885 | | 4.686 | | 7.073 | | 2.366 | | 2.084 |

※ SC- Standardized Coefficient

Similarly, in terms of work-related energy consumption (Table 2), the model is found significant at origin with 85% of the variance($R^2$=0.849, P-value<0.000). This suggests that reduction in work-related motorized travel and energy consumption is associated with factors at trip origin where D1(household density), D2(land use mix) and D3(road intersection) are identified as the major effecting factors for reducing work-related travel energy consumption at origin. The negative sign to household density showed that people living in a low household dense area tend to consume more travel energy; it is likely due to unavailability of work opportunities near residential areas. The positive sign of SC to land use mix and road intersection indicates that even the trip origin has a higher mix of land use and a better road connectivity, there has no significant influence on the work-related travel energy consumption. This suggests that whether or not there is a balance of land use types at work trip origin is irrelevant to people's choice of workplace and travel mode and thereby irrelevant to the travel energy consumption.

The work-related non-motorized travel showed a better model fit at trip destination with 71% of the variance(Table 2). D5(bus accessibility) is uniquely significant. It suggests that to encourage non-motorized travel, planning implications need to focus on transit accessibility at work destination.

### 3.1.3. Analysis of socio-demography variables for work trip

The negative sign of SC showed that age has negative relation with work-related motorized travel and energy consumption, indicating that older people tend to travel a short distance(Table 2). Male population is significantly associated with motorized travel, suggesting that females tend to travel less than males. This is due to the fact that female often works near home to balance their job and family responsibilities. This is also consistent with our result where female showed negative relation to motorized travel. As for occupation, sales and administrative affairs are found positively associated with travel energy consumption which explains that those with highly educated individuals and office workers tend to use motorize mode.

## 3.2 Study Trip

### 3.2.1. Empirical Analysis for study trip

The trips for study purpose are found generated from most of the residential zones(Fig. 4). The analysis showed that these zones are also worked as destination for study trip which meant that people are traveling a shorter distance for study. It also indicates that the educational institutions mainly primary schools are decentralized throughout in Fukuoka City.

### 3.2.2. Linear Regression Model analysis for study trip

From the regression result(Table 3), it is found that study trip is vital for non-motorized travel with 89% of the variance($R^2$=0.885) at origin. D3(4-way road intersection) and D4(Distance to CBD) are found significant factors for study-related non-motorized travel which meant that road connectivity, as well as CBD accessibility are key indicators of non-motorize mode use for study trip. In fact, rise in road intersection results rise in a smaller block size. Smaller block size indicates better road connectivity and that is friendly for non-motorized travel. In terms of CBD accessibility, the positive sign of SC showed that closer to the CBD area, people tend to use non-motorized mode. This is likely to the fact that surrounding areas of CBD have comparatively more educational facilities. The positive sign of SC showed that D1(population density), D3(4-way road intersection) and D5(bus accessibility) have a positive relation with

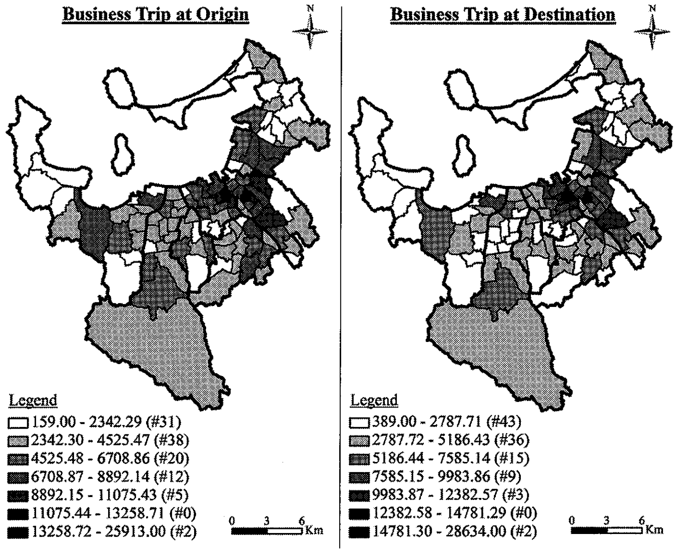


Fig. 5 Business Trip at Origin & Destination

Table 4. Linear Regression Model Analysis for Business Trip

| Business trip | Origin | | | | | | Destination | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Non-motorized | | Motorized | | EC | | Non-motorized | | Motorized | | EC | |
| | SC | Sig. | SC | Sig. | SC | Sig. | SC | Sig. | SC | Sig. | SC | Sig. |
| Pop. density | -0.060 | 0.625 | -0.138 | 0.355 | -0.280 | 0.093 | -0.050 | 0.685 | -0.112 | 0.449 | -0.255 | 0.160 |
| HH density | 0.057 | 0.636 | 0.069 | 0.633 | 0.136 | 0.396 | 0.053 | 0.654 | 0.029 | 0.839 | 0.089 | 0.611 |
| Land use | -0.095 | 0.399 | 0.039 | 0.775 | 0.004 | 0.980 | -0.090 | 0.419 | 0.038 | 0.777 | 0.032 | 0.845 |
| 3-way | 0.115 | 0.399 | 0.187 | 0.256 | 0.413 | 0.025 | 0.130 | 0.335 | 0.134 | 0.413 | 0.213 | 0.284 |
| 4-way | 0.108 | 0.353 | 0.255 | 0.072 | 0.277 | 0.078 | 0.117 | 0.311 | 0.180 | 0.198 | 0.163 | 0.336 |
| Dis | -0.041 | 0.752 | -0.385 | 0.015 | -0.334 | 0.055 | -0.013 | 0.918 | -0.291 | 0.061 | -0.158 | 0.400 |
| Bus access | 0.735 | 0.000 | 0.418 | 0.000 | 0.216 | 0.084 | 0.730 | 0.000 | 0.433 | 0.000 | 0.272 | 0.047 |
| Rail access | 0.084 | 0.301 | 0.060 | 0.541 | 0.036 | 0.738 | 0.091 | 0.259 | 0.130 | 0.185 | 0.124 | 0.296 |
| Age | 0.170 | 0.099 | 0.182 | 0.144 | 0.049 | 0.722 | 0.161 | 0.115 | 0.105 | 0.396 | 0.027 | 0.855 |
| Male | 0.212 | 0.576 | 0.483 | 0.291 | 0.668 | 0.189 | 0.194 | 0.604 | 0.305 | 0.502 | 0.428 | 0.438 |
| Female | -0.285 | 0.419 | -0.378 | 0.376 | -0.355 | 0.453 | -0.310 | 0.375 | -0.264 | 0.534 | -0.147 | 0.775 |
| Agriculture | 0.254 | 0.212 | -0.091 | 0.711 | -0.265 | 0.331 | 0.258 | 0.202 | -0.000 | 0.999 | -0.259 | 0.383 |
| production | 0.469 | 0.250 | -0.226 | 0.645 | -0.457 | 0.402 | 0.473 | 0.241 | -0.023 | 0.963 | -0.355 | 0.550 |
| Sales | 1.096 | 0.233 | -0.648 | 0.559 | -1.241 | 0.313 | 1.154 | 0.205 | -0.302 | 0.784 | -1.319 | 0.325 |
| Admin | 0.679 | 0.320 | -0.656 | 0.427 | -0.998 | 0.276 | 0.737 | 0.277 | -0.319 | 0.697 | -1.002 | 0.315 |
| Student | 0.603 | 0.400 | -0.739 | 0.393 | -1.186 | 0.217 | 0.630 | 0.374 | -0.506 | 0.555 | -1.248 | 0.233 |
| Others | 0.717 | 0.376 | -0.872 | 0.373 | -1.231 | 0.257 | 0.783 | 0.329 | -0.506 | 0.602 | -1.339 | 0.258 |
| P-value | | 0.000 | | 0.000 | | 0.000 | | 0.000 | | 0.000 | | 0.008 |
| $R^2$ | | 0.67 | | 0.517 | | 0.407 | | 0.676 | | 0.525 | | 0.297 |
| Freedom: F(17,90) | | 10.745 | | 5.673 | | 3.64 | | 11.06 | | 5.843 | | 2.24 |

※ SC- Standardized Coefficient

study-related non-motorized travel. This indicates that the residential area with higher density, better road connectivity and easy access to bus services are likely to have shorter travel distance which can be traveled by walk, bicycle and park- and-ride.

Similarly, the result(Table 3) showed that study-related motorized travel at origin has 76% of the variance($R^2$=0.761) whereas energy consumption has only 47% ($R^2$=0.47). This meant people tend to use school bus/ shuttle for a shorter distance.

**3.2.3. Analysis of socio-demography variables for study trip**

The result showed that as the age of student rise, increase in non-motorized travel whereas a decrease in motorized travel and energy consumption at trip origin(Table 3). This might due to the fact that small aged children are usually dropped by their parents or that students are sent to school by school bus/shuttle. However, the result is opposite in the case of destination whereas the age of student rise, non-motorized travel decrease and motorized travel, as well as energy consumption increased. It indicates that primary education is available at a walkable distance from home location but for higher education, one needs to travel a longer distance.

**3.3 Business Trip**

**3.3.1. Empirical Analysis for business trip**

The empirical result for business trip at both origin and destination showed that almost same travel pattern at both trip ends which meant people are traveling a short distance for business purpose(Fig .5). Zone 1 of Chuo-ku and 16 of Hakata-ku are identified as highly traveled zones for business purpose. It is due to the fact that these zones are associated with the highest rank of land use mix, bus and rail accessibility.

**3.3.2. Linear Regression Model analysis for business trip**

The regression result for business trip showed better model fit for non-motorized travel at both trip origin and trip destination with 67% of the variance(Table 4). That meant people are not traveling a longer distance for business purpose with motorize mode so the effect of built environment and socio-demography are found very low on business-related travel energy consumption. D5(bus accessibility) was found uniquely significant which meant that access to bus stops acts as the proxy indicator of increase or decrease in business-related non-motorized travel.

Similarly, for business-related motorized travel also, D5(bus accessibility) is found uniquely significant(Table 4). Here it is important to note that D5 is an important effect factor of built environment for business-related motorized and non-motorized travel. In terms of energy consumption, the model is significant only at origin with 41% of the variance. D5(bus accessibility) is found uniquely significant at trip ends. The negative sign of SC showed that D1(population density) and D4(distance to CBD) are inversely related to business-related energy consumption. This result suggests that higher population density even though further away from CBD has potential to reduce business-related travel energy consumption if better transit accessibility is available.

**3.3.3. Analysis of socio-demography variables for business trip**

The regression analysis result revealed that there is no significant relation with socio-demography variables in all the terms (non-motorized travel, motorized travel and energy consumption) for business trip(Table 4). The positive sign of SC explained that male population is positively associated

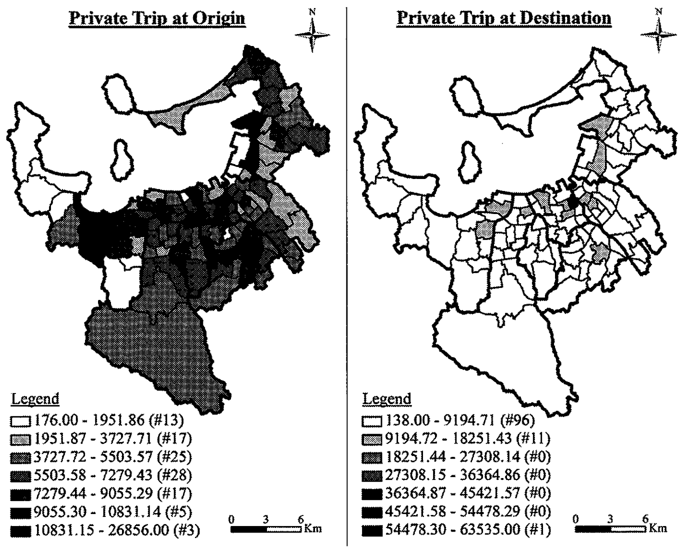


Fig. 6 Private Trip at Origin & Destination

Table 5. Linear Regression Model Analysis for Private Trip

| Private trip | Origin | | | | | | Destination | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Non-motorized | | Motorized | | EC | | Non-motorized | | Motorized | | EC | |
| | SC | Sig. | SC | Sig. | SC | Sig. | SC | Sig. | SC | Sig. | SC | Sig. |
| Pop. density | -0.075 | 0.546 | -0.131 | 0.241 | -0.312 | 0.067 | -0.079 | 0.563 | -0.099 | 0.517 | -0.281 | 0.116 |
| HH density | 0.125 | 0.306 | -0.182 | 0.095 | -0.063 | 0.701 | 0.021 | 0.872 | -0.143 | 0.334 | -0.045 | 0.794 |
| Land use | -0.093 | 0.412 | 0.048 | 0.638 | 0.053 | 0.726 | -0.089 | 0.469 | -0.087 | 0.528 | -0.028 | 0.862 |
| 3-way | -0.041 | 0.766 | 0.198 | 0.108 | 0.015 | 0.934 | 0.001 | 0.992 | 0.100 | 0.551 | 0.081 | 0.679 |
| 4-way | 0.155 | 0.189 | 0.246 | 0.021 | 0.223 | 0.161 | 0.033 | 0.799 | 0.085 | 0.554 | 0.087 | 0.602 |
| CBD access | 0.072 | 0.580 | -0.233 | 0.047 | 0.115 | 0.511 | 0.152 | 0.285 | 0.065 | 0.680 | 0.156 | 0.397 |
| Bus access | 0.670 | 0.000 | 0.469 | 0.000 | 0.103 | 0.418 | 0.764 | 0.000 | 0.810 | 0.000 | 0.541 | 0.000 |
| Rail access | 0.095 | 0.249 | 0.044 | 0.549 | 0.090 | 0.420 | 0.045 | 0.618 | 0.009 | 0.932 | 0.108 | 0.355 |
| Age | 0.052 | 0.618 | 0.032 | 0.730 | -0.085 | 0.546 | 0.030 | 0.789 | -0.010 | 0.937 | -0.114 | 0.439 |
| Male | 0.416 | 0.278 | 0.434 | 0.205 | 0.225 | 0.663 | 0.668 | 0.111 | 0.360 | 0.440 | 0.316 | 0.561 |
| Female | 0.044 | 0.902 | 0.110 | 0.729 | 0.313 | 0.516 | -0.246 | 0.526 | -0.179 | 0.680 | 0.042 | 0.934 |
| Agriculture | 0.181 | 0.380 | 0.105 | 0.568 | 0.038 | 0.892 | 0.24`9 | 0.267 | 0.180 | 0.472 | 0.109 | 0.709 |
| production | 0.300 | 0.466 | 0.332 | 0.366 | 0.294 | 0.596 | 0.483 | 0.281 | 0.432 | 0.389 | 0.369 | 0.527 |
| Sales | 0.729 | 0.432 | 1.072 | 0.197 | 0.847 | 0.499 | 1.108 | 0.274 | 1.033 | 0.361 | 0.913 | 0.488 |
| Admin | 0.553 | 0.423 | 0.702 | 0.256 | 0.603 | 0.518 | 0.838 | 0.266 | 0.768 | 0.362 | 0.645 | 0.511 |
| Student | 0.331 | 0.648 | 0.716 | 0.269 | 0.495 | 0.612 | 0.583 | 0.459 | 0.532 | 0.546 | 0.421 | 0.682 |
| Others | 0.615 | 0.452 | 0.997 | 0.174 | 0.855 | 0.439 | 0.932 | 0.296 | 0.891 | 0.372 | 0.860 | 0.459 |
| P-value | | 0.000 | | 0.000 | | 0.000 | | 0.000 | | 0.000 | | 0.003 |
| $R^2$ | | 0.662 | | 0.731 | | 0.385 | | 0.6 | | 0.498 | | 0.319 |
| Freedom F(17,90) | | 10.359 | | 14.37 | | 3.314 | | 7.933 | | 5.261 | | 2.484 |

※ SC- Standardized Coefficient

with non-motorized travel, motorized travel and energy consumption indicating that male population tends to travel more for business purpose than females.

### 3.4 Private Trip

#### 3.4.1. Empirical Analysis for private trip

The trips for private purpose are found generated almost from every zone where zone 1 of Chuo-ku is identified as the main destination(Fig. 6). It showed that people are traveling a longer distance for private trip where the trip destinations are found CBD surrounding area. This is likely due to the fact that closer to the CBD is relative to the availability of shopping and entertainment facilities.

#### 3.4.2. Linear Regression Model analysis for private trip

The result of the regression demonstrated that private trip model(Table 5) is a better fit for motorized travel at origin with 73% of the variance($R^2$=0.731, P-value<0.000). It suggests that reduction in motorized travel is associated with the effecting factors of private trip at origin where D3(4-way road intersection), D4(distance to CBD) and D5(bus accessibility) are found uniquely significant which meant that these variables of built environment are influencing factors for private trip-related motorized travel. D4(Distance to CBD) is found negatively associated with motorized travel at origin which meant that people living closer to the CBD tend to travel more by motorized mode for private purpose.

Energy consumption for private trip is found significant only at origin; however, there is not found any unique significance in relation with independent variables(Table 5). The negative sign of SC to D1(population density and household density) showed inverse relation with private trip-related motorized travel and energy consumption at trip origin, indicating that less dense area is associated with longer private trip distance, increase of motorized travel and energy consumption.

In the case of private trip-related non-motorized travel, somewhat surprisingly, the result showed that as D1(population density) and D2(land use mix) increase, non-motorized travel decreased(Table 5). This can be explained by the fact that D1 and D2 at both trip ends have no significant influence on the private trip-related non-motorized travel. This is consistent with our intuition, whether or not there is a balance of land use types near the home location is irrelevant to people's choice of travel for private purpose.

#### 3.4.3. Analysis of socio-demography variables for private trip

Similar to business trip, in the model for private trip also there is no significant relation with socio-demography variables(Table 5). The negative sign showed that age has the inverse relation with private trip-related energy consumption at both trip origin and destination. It indicates that old aged people tend to travel less and at a shorter distance.

### 3.5. Return Home Trip

#### 3.5.1. Empirical Analysis for return home trip

It is remarkably found that zone 1 of Chuo-ku and 16 of Hakata-ku are highly indicated as an origin for return home whereas almost all zones are found as the destination(Fig. 7). All the zones which were origin for work trip and private trip are found as the destination for return home.

#### 3.5.2. Linear Regression Model analysis for return home trip

Return home trip showed a better fit model for motorized travel at destination location(Table 6). It is obvious that trip generated with motorized travel is more likely to end up or return home also by motorized mode. This is satisfied with the regression result from work trip(89% of the variance on motorized travel) and private trip(73% of the variance on

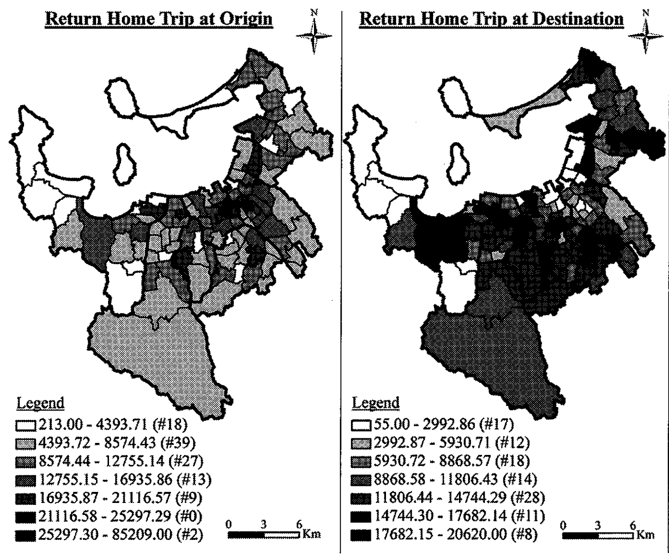

Fig. 7 Return Home Trip at Origin & Destination

Table 6. Linear Regression Model Analysis for Return Home Trip

| Return Home Trip | Origin | | | | | | Destination | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Non-motorized | | Motorized | | EC | | Non-motorized | | Motorized | | EC | |
| | SC | Sig. | SC | Sig. | SC | Sig. | SC | Sig. | SC | Sig. | SC | Sig. |
| Pop. density | -0.106 | 0.359 | -0.109 | 0.442 | -0.222 | 0.178 | 0.025 | 0.763 | 0.019 | 0.777 | -0.215 | 0.055 |
| HH density | 0.068 | 0.546 | -0.076 | 0.580 | -0.054 | 0.735 | 0.206 | 0.012 | -0.149 | 0.025 | -0.124 | 0.250 |
| Land use | 0.114 | 0.281 | -0.036 | 0.779 | 0.023 | 0.875 | 0.046 | 0.541 | 0.069 | 0.265 | 0.117 | 0.246 |
| 3-way | 0.150 | 0.240 | 0.136 | 0.385 | 0.168 | 0.353 | -0.103 | 0.263 | 0.098 | 0.191 | 0.260 | 0.035 |
| 4-way | 0.025 | 0.819 | 0.135 | 0.311 | 0.158 | 0.305 | 0.217 | 0.007 | 0.253 | 0.000 | 0.213 | 0.043 |
| CBD access | -0.020 | 0.870 | -0.048 | 0.744 | -0.075 | 0.658 | -0.130 | 0.137 | -0.141 | 0.048 | 0.048 | 0.678 |
| Bus access | 0.444 | 0.000 | 0.711 | 0.000 | 0.528 | 0.000 | 0.022 | 0.732 | -0.011 | 0.835 | -0.049 | 0.553 |
| Rail access | 0.145 | 0.060 | 0.101 | 0.277 | 0.161 | 0.138 | -0.031 | 0.579 | -0.032 | 0.472 | 0.013 | 0.855 |
| Age | 0.007 | 0.944 | 0.079 | 0.501 | 0.024 | 0.857 | 0.041 | 0.556 | -0.083 | 0.143 | -0.117 | 0.206 |
| Male | 0.668 | 0.062 | 0.254 | 0.557 | 0.156 | 0.755 | 0.320 | 0.212 | 0.528 | 0.012 | 0.363 | 0.286 |
| Female | -0.010 | 0.977 | -0.274 | 0.497 | -0.116 | 0.804 | 0.446 | 0.064 | 0.142 | 0.463 | 0.179 | 0.572 |
| Agriculture | -0.067 | 0.723 | 0.158 | 0.498 | 0.086 | 0.749 | -0.125 | 0.363 | -0.098 | 0.377 | -0.014 | 0.938 |
| production | -0.176 | 0.643 | 0.392 | 0.400 | 0.336 | 0.532 | -0.347 | 0.208 | -0.144 | 0.517 | 0.198 | 0.587 |
| Sales | -0.377 | 0.661 | 0.878 | 0.404 | 0.600 | 0.621 | -0.708 | 0.255 | -0.089 | 0.858 | 0.663 | 0.421 |
| Admin. | -0.307 | 0.631 | 0.588 | 0.452 | 0.384 | 0.671 | -0.574 | 0.215 | -0.063 | 0.865 | 0.495 | 0.420 |
| Student | -0.469 | 0.484 | 0.429 | 0.600 | 0.229 | 0.809 | -0.531 | 0.273 | -0.074 | 0.849 | 0.422 | 0.511 |
| Others | -0.355 | 0.639 | 0.578 | 0.532 | 0.300 | 0.779 | -0.642 | 0.242 | 0.072 | 0.871 | 0.703 | 0.334 |
| P-value | | 0.000 | | 0.000 | | 0.000 | | 0.000 | | 0.000 | | 0.003 |
| $R^2$ | | 0.71 | | 0.567 | | 0.419 | | 0.849 | | 0.901 | | 0.734 |
| Freedom F(17,90) | | 12.944 | | 6.936 | | 3.825 | | 29.741 | | 48.229 | | 14.572 |

※ SC- Standardized Coefficient

motorized travel).

D1(household density), D3(4-way road intersection) and D4(distance to CBD) are found uniquely significant for return home trip-related motorized travel at destination whereas D5(bus accessibility) is found uniquely significant for both motorized travel and energy consumption at origin. This meant that people living in a residential area with better bus accessibility and services are attracted to the destination which has higher household density and a better road connectivity that encourage them to walk, cycling and park-and-ride. This suggests that return home trips are made at longer distance and it also indicates that to encourage public transit and reduce energy consumption, D5 plays a significant role.

### 3.5.3. Analysis of socio-demography variables for return home trip

The male population was found uniquely significant for motorized trip at destination/residential location, indicating that males have a higher propensity to effect on motorized travel(Table 6). The negative sign of SC to the subject of age at home location showed inverse relation to motorized travel and energy consumption indicating that older people tend to travel less. It might be due to their retired life, they don't have to go to work, or driving may simply more difficult than taking public transport.

## 4. Conclusion

This research provides additional insights into the linkage among built environment, five different purpose-related non-motorized travel, motorized travel and travel energy consumption by applying Empirical analysis and Linear Regression Model(LRM) analysis methods. This research results adequately responded to the objectives that were set out in Section 1.3.

The empirical analysis used in this research is based on the trip generation to perform activities at diverse locations. It concludes that the work trip and study strip predominantly generate from higher residential areas. Travel destinations for work, business and private purposes are identified closer to central business district (CBD) that are associated with a highly mixed land use, higher bus and rail accessibility. Regarding travel distance, the results suggest that travel for work, private and return home purposes, people travel a longer distance while a shorter distance travel for study and business purpose.

The analysis results presented in section 3 support the second and third objectives of this paper. This research confirms that reduction in motorized travel and energy consumption is possible with higher population and household density (D1) at work trip origin but simultaneously need to improve Transit accessibility (D5). It meant that even work destinations are further away from the CBD, it consumes low travel energy due to likelihood of taking transit modes rather than private cars. Furthermore, the finding suggests that higher land use mix (D2) does not have a direct effect on reducing work-related travel energy consumption, however; it has a direct effect on the increase in non-motorized travel at work destination which indirectly supports to decrease work-related travel energy consumption at destination.

Similarly, this research confirms that increase in non-motorized travel is associated with study trips. The empirical result showed that most of the study trips are originate and traveled to the same zone which indicates that people prefer shorter travel distance for study purpose. The regression result showed that higher road intersections (D3) significantly effect in non-motorized trip as it provides better road connectivity and that is friendly for non-motorized travel. However, study trip shows effect on the increase in motorized travel, it does not show significant influence on travel energy consumption which suggests that people tend to use school bus/ shuttle for a shorter distance. Also, the current policy in Fukuoka City that requires pupils to choose schools in their living areas is found effective to reduce study-related travel energy consumption. The result suggests that the effective policies and strategic planning concerning school locations in Fukuoka City would be significant planning implication concerned with the city which is under a rapid urbanization and motorization process.

The empirical result showed that the origin and destination for business trip are mostly to the CBD surrounding areas and it is also found that for business purpose, people use high energy intensity transport mode (private car and taxi). This is one of the reasons for higher energy consumption in CBD areas. Non-motorized travel is found comparatively more significant for business trip. So, business-related energy consumption can be reduced by increasing non-motorized travel where bus accessibility(D5) is identified significant factor.

Private trip showed comparatively low significant on travel energy consumption, suggesting that a research on energy consumption on the basis of private trip is statistically insignificant but it is significant for accounting number of trips of motorized travel and non-motorized travel due to influencing factors of built environment and socio-demography. This empirical result shows that the most of the private trips are generated in the areas where higher bus accessibility(D5) and traveled to CBD surrounding areas, indicating bus system covers most of the Fukuoka area that attracts people to take a bus for private trip.

The empirical analysis of return home showed that most of the origin zones are the zones of destination for work trip and private trip. The result concludes that a reduction in motorized travel and energy consumption is associated with higher density(D1) at trip destination but need to improve transit accessibility(D5) at both trip ends. This result is satisfied with the result of work and private trip model analysis.The result highlights that residential location is an influencing factor for travel mode choice and energy consumption.

**Acknowledgement**

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