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Effective Density for the Classification of Transport Activity Centers

Dubbale Daniel A., Tsutsumi J.

***Abstract*—** This research work takes a different approach in the discussion of urban form impacts on transport planning and auto dependency. Concentrated density represented by effective density explains auto dependency better than the conventional density and it is proved to be a realistic density representative for the urban transportation analysis. Model analysis reveals that effective density is influenced by the shopping accessibility index as well as job density factor. It is also combined with the job access variable to classify four levels of Transport Activity Centers (TACs) in Okinawa, Japan. Trip attraction capacity and levels of the newly classified TACs was found agreeable with the amount of daily trips attracted to each center. The trip attraction data set was drawn from a 2007 Okinawa personal trip survey. This research suggests a planning methodology which guides logical transport supply routes and concentrated local development schemes.

***Keywords*—**Effective density, urban form, auto-dependency, transport activity centers

I. Introduction

THE Japanese southernmost prefecture, Okinawa consists a group of small islands together with the main island.

The total population was estimated to be 1,371,829 in 2007 [1]. The Island is currently challenged by the increasing rate of auto dependency. Modal share of automobile based trips has grown to 93 percent. Despite decreases in per capita income and increases in fixed and running costs of vehicles, average vehicle ownership for every household in Okinawa has reached 2.12 in 2005 [1].

The main objective of the study is to suggest planning directions which foster concentrated development and facilitate transport supply under the broad scope of managing car dependency. This study is presented in two main themes. The first theme involves analyzing the relationship between Effective Density (EFD) and Auto dependency variables. It compares EFD and conventional density in terms of their explanatory power. The second theme will show EFD's role to the classification of Transportation Activity Centers (TACs) in Okinawa. EFD represents the realistic population density, which could influence transportation activities. It is a ratio of population aged 20-74 years old and net land area excluding vast forestry, farms and open spaces. The age category in the numerator represents the concentration of active and mobile working group of the society; whereas Net Effective Area (NEA) in the denominator represents spatial territory under a constant influence of human activities.

Regression model confirms a strong relationship b/n auto-dependency and urban form factors. The study shows an area with a relatively high ED and Shopping Accessibility Index (SAI) in the island are characterized by less number of vehicle possession. Single Residence Index (SRI) is the proportion of single residences out of the total housing stock. The greater number of single residences indicates the less compactness of the district. As expected, SRI has a strong negative relationship to density, especially EFD.

In transport planning literature, number of jobs and job density variables has been used by researchers for the purpose of classification of TACs. By considering EFD's role in the formation of potential centers, EFD has been taken along with Total Jobs (TJB) to classify TACs throughout Okinawa.

After the introduction and literature review, the paper presents the status of car dependency in Okinawa, variables design, model analysis, TACs classification and the conclusion.

II. Data Acquisition

Raw statistical data related to population, vehicle ownership, jobs and housing stock was drawn from the Okinawa prefecture statistical database. Specific data sets concerning roads and public bus have been obtained from the prefectural publications on urban planning and the monorail. Data regarding shopping facilities have been collected from respective companies. The other data set related to travel has been acquired from the 2007 Okinawa personal trip survey.

III. Background Studies

The debate on urban form (in terms of shape, density and configuration) impacts on auto ownership has a long history. Scholars have discussed urban form influences on urban auto ownership and transportation activities [2]-[4].

The three principal built environment dimensions, density, diversity and design (3Ds) have a meaningful influence on how people travel. Based empirical studies, the researchers have discussed the new urbanism's theory expressed by more compact, diverse and pedestrian

Dubbale Daniel A., PhD student, University of the Ryukyus, 9030213 Senbaru-1,Nishihara, Okinawa, Japan (corresponding author, phone: +819068600663; e-mail: k088656@eve.u-ryukyu.ac.jp).

Tsutsumi J., Professor, Department of Environmental Engineering, University of the Ryukyus, 9030213 Senbaru-1,Nishihara, Okinawa, Japan.

oriented neighborhoods influence the demand for travel. In the other hand, the complexity nature of identifying the link between urban form factors and travel characteristics has been highlighted [5].

Density is one of the main urban form factors associated with car dependency. Many scholars acknowledged the negative relationship between density and car dependency. In the research work discussing lessons from Hong Kong stated that stricter policy rather than population density is responsible for the low levels of car ownership [6]. Studies also confirm that urban development pattern and design attributes can potentially govern transport modal split. Based on the study made on metropolitan Adelaide in Australia researchers recommended that micro-scale urban features should be given more attention in transport policy proposals, due to their role in shifting modal choices [7].

Most of the researchers advocate the compact city theory by citing the socio-economic, transportation and environmental benefits. Some researchers stress the importance of regulations as an effective tool than a physical planning. This research work favors compact density approaches in car dependency and urban transportation issues but follows different methodological approach by redefining density. EFD variable has also been used in the process of TACs classification. Transport activity centers (TACs) are important for transport analysis including in the planning stages of public mass transit services. Researchers have used different methodologies to classify TAC's [8]-[10].

IV. CAR DEPENDENCY IN OKINAWA

Vehicle ownership is not the only factor that affects car dependency. Factors regarding quality of alternative modes and the degree of urban form and land use suitability should be considered in order to show the presence of car dependency.

Motorization rate which is measured by number of cars per thousand populations has shown a sharp increase from 1960s. According to the projection made by researchers, Japan will attain 730 vehicles per thousand populations by year 2030 [11]. However, recent data shows that the motorization level in Okinawa has surpassed the 700 mark.

Public transport accommodates less than four percent out of the total modal share. The performance of public bus in Okinawa decreases through time. (See table I) travelers who had abandoned public modes apparently switched to private car mode. The total distance traveled by bus is decreasing in a much slower rate than decreasing rate of travelers. It shows public bus service in Okinawa is becoming energy consuming and less efficient.

V. VARIABLE DESIGN

In this research work EFD is used to further explain the relation between auto dependency and travel characteristics. Vehicle per driver population (VDP) also considers potential drivers than the general population. It is a quotient of total number of vehicles and size of population category that includes 20-74 years old.

TABLE I
PUBLIC BUS PERFORMANCE TREND IN THE PAST

Years	Annual mileage (In'000 Kms)	Passenger (In '000)	AnnualCO_2 Emission* passenger (In grams)
1998	45,831	45,013	939
1999	45,959	42,490	997
2000	45,227	40,741	1024
2001	36,761	39,265	959
2002	45,398	37,636	1113
2003	44,116	34,353	1185
2004	37,761	27,656	1260
2005	40,537	29,737	1258

Raw data Source: Okinawa prefecture road section.
** The estimation made based on the GHG protocol initiative methodology by applying distance based estimating tool. 0.9226 Kg per kilometer has been taken as CO_2 emission factor*

The proportion of single family housing has been included in the variable as a measure of compactness. Single family housing is usually accompanied by expansive green areas or courtyards and therefore it is associated with larger residential area per person. The availability of shopping facilities in every square kilometer has been taken as an influential variable to explain the relationship between land use mix, density and auto ownership. The number of department stores, convenience stores and super markets in all districts has been considered. Most trips made in an urban area are for working purposes. Regional job distribution effectively governs daily travel patterns in that specific area. Factors related to job distribution and concentration plays a significant role in urban transport analysis [3], [10]. Other variables that are intended to represent auto dependency are included in the variable list (Table II).

VI. DISCUSSION

Non linear regression analysis between Auto dependency variables (VPH, VPC, and VDP) and Density has shown an indirect relationship which is stronger in year 2005 than 2000. The summarized analysis result in table 3 also indicates further strong relationship, when the analysis is made between those auto dependency variables and EFD.

TABLE II
VARIABLE DESCRIPTION

Variable Name	Description
-Potential drivers population	Population age category (20 – 74 years)
-Net Effective Area (NEA)	Net surface area (km^2) excluding vacant, farm, open fields and forests.
-Single family Residence Proportion (SRI)	Proportion of single dwelling units out of the total housing stock.
-Density	Population per square Km
-Effective Density (EFD)	Driving-age population (20 – 74 years old) divided by NEA
-Vehicle per household (VPH)	The number of motor vehicles per household.
-Vehicle per drivers population(VDP)	The number of motor vehicles per Driving age population.
-Vehicle per Capita (VPC)	The number of motor vehicles per capita
-Shopping Accessibility Index(SAI)	Shopping facilities per NEA in km^2
- Total Jobs (TJB)	Number of jobs or employment
- Job Density (JOBDEN)	Jobs per km^2

This shows that

- Higher density development influences auto dependency. Typically, increased settlement density is characterized by less auto dependency.
- EFD is more strongly related to auto dependency than the conventional density.
- Auto dependency trend in Okinawa is continuing and the explanatory power of the density variable is increasing.
- EFD represents urban density better than the ordinary general density, therefore should be preferred to the urban transportation analysis.

VDP created a stronger relationship to EFD and density than VPC does. This is because VPC represents vehicle share per general population, while VDP represents vehicle share per drivers' population, which is more realistic representation than VPC.

The SRI is an important urban form variable that shows the housing concentration in a certain neighborhood. An increase in SRI indicates less dense neighborhood or district. Typical single residence housings are usually characterized by the non-vertical space based development. As expected, SRI has strong negative relationship with density especially with EFD. But SRI has a strong positive relationship with VPH. which confirms that single housing concentration are always associated with higher rate of auto dependency.

SAI measures the availability of services and shopping facilities in a certain defined location It shows the extent of land use variety (mix) and is negatively related to VPH and positively related to Density. This result supports the concept that land use mix and availability of services and facilities decreases the rate of auto-dependency.

VII. Model Analysis for EFD

EFD modeling was developed to measure the extent of urban form impacts in a certain location. The multinomial regression model designed to represent the role of the three basic urban form variables, which is discussed so far. This model is presented as a simple instance which can be further developed to include more variables in various urban scales.

$$EFD = 1272 - 1214\ SRI + 555\ SAI + 1.14\ JDN \quad (1)$$

Predictor	Coefficient	T-Test	P
Constant	1272.3	1.37	0.185
SRI	-1214	-0.98	0.337
SAI	554.6	4.61	0.000
JDN	1.1356	5.87	0.000

R-Sq = 94.7% R-Sq (adj) = 94.0%

The SAI and the JDN variables have positive impact on EFD while the SRI has a negative one. The model simply indicates that in order to increase EFD in a certain defined location, single residence development should be discouraged in favor of mass housing development and the accessibility to the shopping facilities should be improved.

VIII. Classification of Transportation Activity Centers

Multi-central planning approach is a popular planning method that benefits urban transport planning by distributing destinations to various urban centers. It allows traffic flow to spread throughout the region and creates potentials for the expansion and networking of mass transit services. A mono-central planning on the other hand is typically characterized by a high volume of traffic at the city center. Intense traffic flow usually causes a higher degree of congestion. Okinawa is characterized by those mono-centrality features. The Capital Naha city is the major city center which accommodates larger share of jobs and services than any other centers in the island, for instance; number of private firms around Naha city in 2005 was 18,555,where as the second biggest city which is Okinawa city had 5,315 [1].

In medium-sized islands like Okinawa, it is important to devise a simple and effective way that prioritizes centers, in order to supply a transport service. TACs classification in Okinawa aims to halt the rate of car dependency through the provision of appropriate mass transport services. It also provides basic information about centers that promotes local compact development. EFD model analysis explains how the increase in EFD in a certain location encourages collective housing development, job concentration and shopping accessibility.

TACs are not very different than the conventional urban centers, but it considers jobs concentration as an impact factor up on urban transportation than any other factors.

TABLE III
REGRESSION ANALYSIS RESULT SUMMARY

Variables		Best fitted Model	Year- 2000			Year- 2005		
Dependent	Independent		Adj.R^2	β_1 [st.Er]	Cst [st.Er]	Adj.R^2	β_1 [st.Er]	Cst [st.Er]
VPH	DEN	Expon.	-0.362	-7E-5 [000]	2.521[.116]	-0.494	-8E-5[000]	2.53[.093]
	EFD	Expon.	-0.535	-9.6E-5[000]	2.73[.122]	-0.571	-9E-5[000]	2.7 [.109]
VDP	DEN	Power	-0.647	-0.11 [.015]	2.23[.219]	-0.787	-0.12[.012]	2.63[.202]
	EFD	Power	-0.718	-0.156 [.019]	3.401[.448]	-0.803	-0.17[.016]	3.98[.441]
SRI	DEN	Expon.	-0.482	-7.6E-5[000]	0.743[.028]	-0.658	-6E-5[000]	0.72[.022]
	EFD	Expon.	-0.670	-7.1E-5[000]	0.798[.029]	-0.705	-7E-5[000]	0.73[.026]
VPC	DEN	Power	-0.407	-0.17	1.91	-0.702	-0.11	1.51
	EFD	Power	-0.671	-0.15	2.05	-0.713	-0.15	2.21
SAI	DEN	Power	0.782	0.67	0.014	0.874	0.7	0.01
	EFD	Power	0.935	1.02	6E-4	0.936	1.01	7E-4
VPH	SRI	Power	0.654	0.835[.129]	3.24[.185]	0.680	0.804[.118]	3.27[.182]
	SAI	Expon.	0.519	-0.12 [.025]	2.7[.121]	0.559	-0.12[.002]	2.69[000]

Tests are significant at $\alpha = 0.05$ significant level, 95 % Confidence level (Two tailed).

Identifying influential centers by considering total employment and employment density has been studied primarily by researchers [8]. They define TACs as a contiguous set of zones, each with employment density and the total employment greater than a threshold value. Other scholars define activity centers as areas with higher than adjacent concentrations of employment at the traffic analysis zone [10]. Caselo and Smith have classified TACs based on total employment and employment density of centers in Philadelphia metropolitan area. They weighted employment type based on trip attraction rate; for example, retail employment attracts more trips than agriculture employment, and thus fewer retail employments have a capacity to attract more trips than agriculture employments. Our focus is not only to identify influential centers but also prioritize potential centers for the purpose of transportation analysis and mass transit supply. In this study TACs are classified based on EFD and TJB variables using Rank Mean Value (RMV). This method prioritizes centers according to the weight of their EFD and TJB value.

A. Rank Mean Value (RMV) Method

Rank Mean value is a simple method that involves the ranking of each case value of two or more variables and calculating their mean. TAC classification has done based on the calculated mean. The resulted mean arranged in the ascending Order and grouped in to four levels of TACs (see Table IV).Different grouping criteria and assumptions can be used according to the region. In this case, assumption is taken to determine the levels by setting up group boundaries primarily based on the mean distribution.

TABLE IV
TAC CLASSIFICATION

Centers	Rank			Level
	ED	TJ	$\bar{x}$	
Naha	1	1	1	I (CBD)
Ginowan	4	5	4.5	I
Urasoe	2	3	2.5	I
Nago	15	6	10.5	II
Itoman	10	7	8.5	II
Okinawa	9	2	5.5	I
Tomigusuku	3	8	5.5	I
Uruma	20	4	12	II
Nanjyo	16	9	12.5	II
Motobu	23	18	20.5	IV
Kin	19	21	20	III
Kadena	7	19	13	III
Chatan	8	14	11	II
Nishihara	11	12	11.5	II
Yaese	12	13	12.5	III
Yonabaru	5	16	10.5	II
Haebaru	6	11	8.5	II
Kunigami	22	23	22.5	IV
Ogimi	25	18	21.5	IV
Higashi	24	26	25	IV
Nakijin	26	22	24	IV
Onna	19	20	19.5	III
Ginoza	21	24	23	IV
Yomitan	13	10	11.5	II
Kitanagusku	17	17	17	III
Nakagusku	14	15	14.5	III

$$RMV_{in}(\bar{x}) = \frac{EFD_{in} + TJB_{in}}{2} \quad (2)$$

Where RMV_{in} = Rank Mean Value of the i^{th} center of total n centers

EFD_{in} = *the i^{th} Center Rank in Effective Density of n centers*

TBJ_{in} = *the i^{th} Center Rank in Total Jobs of n centers*

And If

$\bar{x} < 8$ = I
$8 < \bar{x} < 12$ =II
$12 < \bar{x} < 20$ =III
$20 < \bar{x}$ =IV (Suburbs)

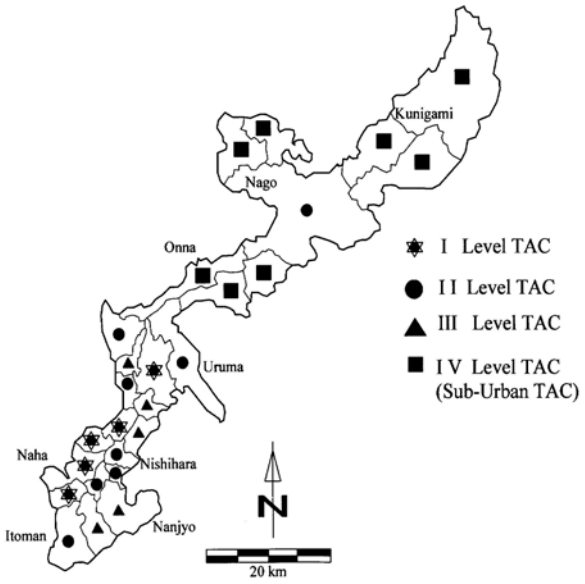

Fig. 1 Geographical Location of TACs

Fig. 1 shows the locations of TACs. Most first level TACs are found along the southern west coast of the island, where as the southern east coast mainly occupied by third level TACs. The northern part is apparently identified as suburban TACs.

B. TACs and trip attraction rate

Bogart and Ferry defines TACs in Cleveland, Ohio and they verified their classification method by selecting the ten busiest intersections in the region and note that all are within or near the classified activity centers [9]. This method indicates the intensity of traffic flow within and around the centers. In this study, the number of trip attracted to each TACs were used to check whether it match the level of TACs. In order to test the method of TACs classification, daily work trip attraction towards each center has been analyzed based on Okinawa personal trip survey 2007 data. Fig. 2 shows the amount of daily work trip attraction to those specific centers. The number of trips attracted to centers decreasing from level 1 TACs to suburb TACs

IX. Conclusion

A review of literature suggests that transit is most competitive in higher density areas. It also brings development and helps to realize local density [5],[13]. Such kind of development often referred as Transit Oriented Development (TOD) [14]. Based on these conceptual and practical bases the key planning objective in Okinawa would be linking TACs through transit and strive to increase EFD for the low level TACs Okinawa is plagued by the absence of efficient public transport that deprived mobility throughout the island. The main economic sector of the island which is tourism is being largely affected by the problem. Researchers and

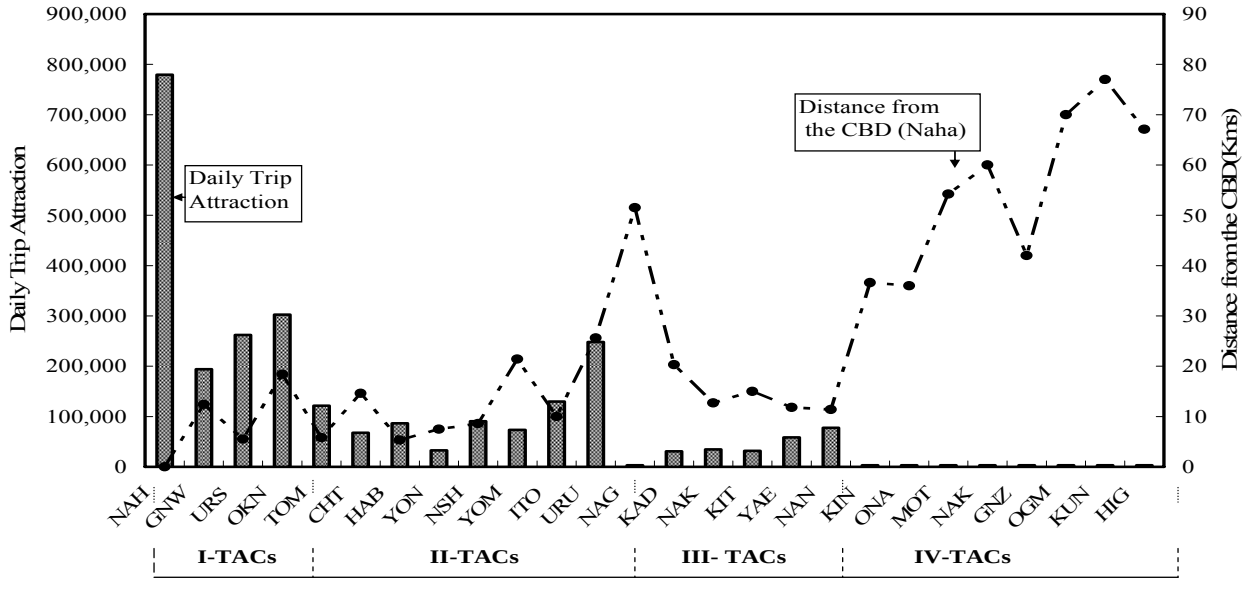

Fig. 2 TACs Daily Trip Attraction Rate and their Distance from the CBD

policy makers mostly advocate transit supply and extension of existing monorail service as viable solution. In year 2007, Okinawa prefecture office has planned for the extension of the monorail. The monorail extension

proposal is a major step forward towards the development of transit service in Okinawa. But basic guides to the route selection remain a challenge. This piece of research work has shown the potential of TACs classification by analyzing socio-economic and spatial data to produce a simpler and sound methodology that able to classify TACs for medium-sized island regions.

Comprehensive transportation planning guides are very useful to coordinate different levels of transportation analysis and projects. In order to avert the threat of excessive auto dependency, planning guides have to be carefully formulated. Concentrated development strategies coupled with identification of TACs definitely help car dependency and transportation problems both by supplying the existing demand and potentially providing competent and affordable alternatives.

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