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ESTIMATION OF TRANSPORT DEMAND USING SATELLITE IMAGE: CASE STUDY OF CHIANG MAI, THAILAND

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ABSTRACT: Transport demand is one of the essential datasets for urban / transport planning and policy development. However, the full size of travel demand survey requires large amount of cost, therefore the survey is merely conducted in developing countries. Their policy decision might be based on the old and limited datasets. In this study we propose a new approach to estimate transport demand using the night-time light satellite image based on the correlation of these two factors. Taking the case of Chiang Mai Metropolitan area, we found a soft relationship between the night-time light intensity and trip generation/trip attraction. Transport survey data is provided by Chiang Mai University for the year 2016. NOAA provides cloud free monthly composite of night-time light satellite image (VIIRS-DNB) by Suomi-NPP satellite of which resolution is 15 arc-second (about 500m by 500m at equator). It is spatially more precise than zones of travel demand survey and monthly frequency. Applying the relationship between transport demand and night-time light intensity, we propose a method to update the transport demand with higher spatial resolution.

Keywords: Transport demand update, Night-time light satellite image

1. INTRODUCTION

Current and future transportation demand are essential information for urban / transport planning and policy development. As input for transport demand analysis like traditional four step models [1] massive number of samples are required in travel survey to achieve enough accurate demand modeling to apply in policy and planning practice. They were often as big as 1-3% of the population [2]. This big sample size requires huge budget for the survey, therefore the frequency of the full-size survey is quite low even in the developed countries. Recently tracking devices like GPS and smart phone are found to have enough performance for accurate and low-cost travel survey [3], however the data privacy issue limits the use of those data in public policy.

In developing countries, the urbanization is rapidly progressing, that induces increase and expansion of urban activities including travel and land development [4]. That requires frequent monitoring of urban activities however the full-size survey is merely conducted due to its high cost.

Meanwhile several studies indicate night-time light satellite images can represent economic activities of a region [5-7]. Especially, the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor on the Suomi National Polar-orbiting Partnership (NPP) Satellite [8-12] provides a Day-Night Band (DNB) in which nighttime light is observed and it has higher performance in detecting the radiation range comparing the Defense Meteorological Satellite Program's Operational Line-scan System (DMSP-OLS) that enables to detect the light intensity within cities.

Travels are also induced by economic activities, so the night-time light image could be a cue to estimate the transport demand. For the VIIRS-DNB, National Oceanic and Atmospheric Administration (NOAA) provides monthly composite of cloud free images since April, 2012. This update frequency is enough high to capture the urban dynamics in developing countries. If this night-time light information can be applicable in updating the travel demand, it will be a very powerful tool in urban and transportation planning in developing countries.

In this study, we examine the applicability of VIIRS-DNB in travel demand update taking the case of Chiang Mai, Thailand. We focus on the zonal trip generation and attraction and try to explain the travel demand by night-time light intensity statistically. Based on this statistical relationship, we attempt to update the trip generation and attraction using the updated night-time light image.

2. DATA

In this study, we examine the relationship between trip generation / attraction and night-time light. Chiang Mai household travel survey data in

2016 is used as data for travel demand, and monthly composite of Suomi-NPP VIIRS DNB in January 2016 is used as night-time light data.

Chiang Mai household travel survey was conducted by Department of Civil Engineering, Chiang Mai University in February 2016 in which 6,236 households were visited and travel information of household members from 6 years old and above were collected. This is equivalent to an overall sample size of 3.4%. The survey area comprises of Chiang Mai Metropolitan and surrounding sub-district municipalities. Its total area is 1,606.35 sq.km. This area is divided into 142 zones. The population of target region is 761,986 in 2016. The population trip generation and attraction were estimated by expanding that of zonal sample statistic by zonal sample size expansion factor. The estimated trip generation per zone area for each zone is shown in Fig.1. The number is standardized by area because the area is different by zones. The estimated total number of trip generation / attraction is 3.6 million per day. The correlation between zonal trip generation and attraction per day is 0.95 and they have quite similar figure of spatial distribution.

The monthly composite of Suomi-NPP VIIRS DNB in January 2016 is obtained from NOAA website. We choose the image for January because it is dry season and effect of cloud on the observation is smaller than that in the months of rainy season. The projection is WGS84 latitude-longitude coordinate system, resolution of the image is 15 arc-second and the unit of the light intensity is given in nanoWatts/cm2/sr. The data overlaid with travel survey zone system is shown in Fig. 2.

Comparing the figures of spatial distribution of trip generation and night-time light, the volume and the intensity looks to have similar pattern. Fig. 3 shows the relationship between trip generation per area (horizontal axis) and average night-time light intensity (vertical axis) of each zone. A positive relationship between the night-time light and trip generation can be found in this figure. Based on this fact, we investigate the relationship between these two factors using simple non-linear model in the next section.

3. MODEL PARAMETER ESTIMATION

We assume that trips are generated/attracted only at meshes where the night-time light is more than zero and it is also assumed that the trip volume is larger as higher the level of night-time light radiation. With this assumption, we presume the following model for trip generation/attraction.

$$q_j / a_j = \alpha_0 l_j^{\alpha_1} \tag{1}$$

Where q_j is trip generation or attraction at mesh j, a_j is area of mesh j, l_j is night-time intensity at mesh j, and α_0, α_1 are parameters. Here trip generation data for each mesh is not obtained, but that for the zonal data is obtained. So above equation is aggregated by zonal level.

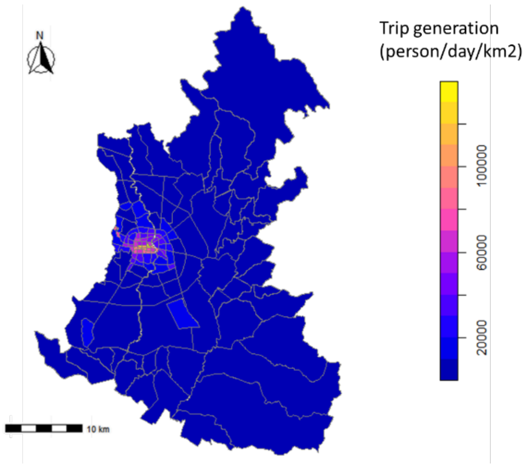

Fig.1 Spatial distribution of trip generation

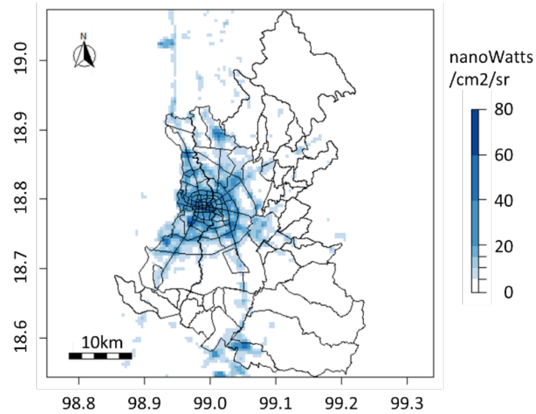

Fig.2 Night-time light intensity

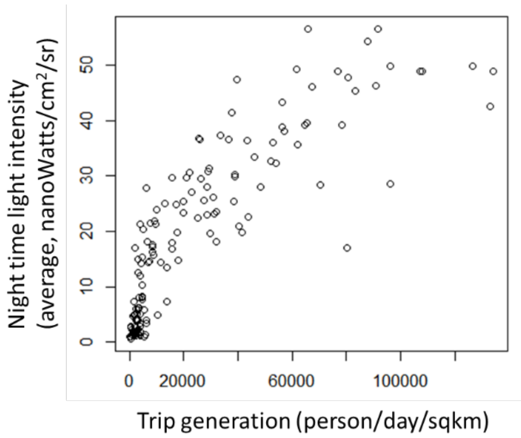

Fig.3 Relationship between trip generation and night-time light intensity

$$\frac{Q_i}{A_i} = \alpha_0 \frac{\sum_{j\in\Omega_i} l_j^{\alpha_1} a_j}{\sum_{j\in\Omega_i} a_j} = \frac{\alpha_0}{|\Omega_i|}\sum_{j\in\Omega_i} l_j^{\alpha_1} \qquad (2)$$

Where Ω_i is set of mesh whose night-time light intensity is more than zero in zone i, Q_i and A_i are trip generation/attraction and mesh area where night-time light intensity is more than zero in zone i respectively. The last term assumes area of all mesh is identical and $|\Omega_i|$ represents the number of mesh. Here Q_i is obtained from travel survey, A_i and l_j can be derived from VIIRS-DNB datasets.

The parameters are estimated by solving the following problem.

$$\min_{\alpha_0,\alpha_1}\left(Q_i / A_i - \frac{\alpha_0}{|\Omega_i|}\sum_{j\in\Omega_i} l_j^{\alpha_1}\right)^2 \qquad (3)$$

If we assume that the error term follows normal distribution, the above equation is variable part of log-likelihood function by α_0, α_1. This means the estimated parameters are maximum likelihood estimators. The statistics of estimated model is shown in Table 1. R^2 denotes the R squared of observed and estimated trip per area. Fig. 4 shows the relationship between observed and estimated trip generation. The trip attraction has quite similar figure with trip generation.

Table 1 Estimated parameters

	Trip generation		Trip attraction	
	parameter	t-value	parameter	t-value
α_0	12.73	3.45	183.5	2.94
α_1	2.28	30.29	1.58	17.42
R^2	0.70		0.74	

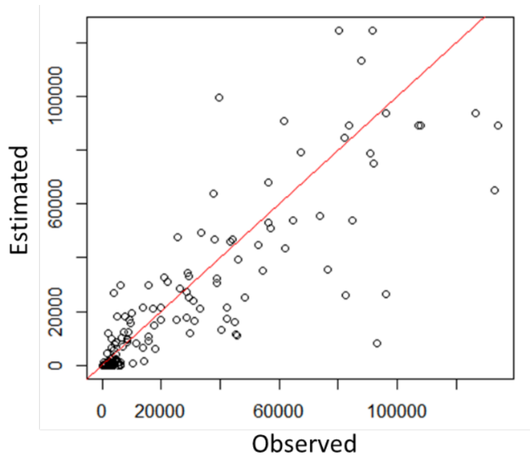

Fig.4 Plot of observed and estimated trip generation (trips/sq.km/day)

The parameter α_1 is positive and more than unity. This means as stronger the intensity of night-time light larger trips is generated/attracted. It reflects the relationship between the night-time light and trip generation as shown in Fig.3. Its t-value is enough high so this parameter is statistically significant. The representability of the model is not satisfactory. Obviously, trip generation is affected by various factors, including population, floor area of buildings, land use, and the other urban activities, and it is not necessarily determined by night-time light solely. However, this result indicate that the night-time light can represent a certain part of urban activities and also have the correlation with trip generation and attraction.

Purpose of this study is to investigate a method to update the travel demand without huge survey. The statistical significance of estimated parameter indicates the night-time light image can be a clue for the travel demand update in dynamically growing cities in developing countries.

4. ESTIMATION OF FINER RESOLUTION OF TRAVEL DEMAND

The relationship between the night-time light and travel demand would suggest the possibility of travel demand estimation in finer spatial resolution especially in suburban zones. The zone system in this transport survey, the average size of a zone is 8.4km^2 and the largest size is 158km^2. For transport policy practice, it is desirable to capture the travel demand in finer spatial scale when the demand drastically change because it affect first local traffic situation and not zone wide situation.

It would be possible to estimate the travel demand using equation (1), however Fig.4 suggests there are substantial errors in the estimation. Here we introduce following adjustment factor β_i for zone i to make the estimation fit to the zonal observation of traffic demand.

$$\beta_i = \frac{Q_i}{A_i} \Big/ \frac{\alpha_0}{|\Omega_i|}\sum_{j\in\Omega_i} l_j^{\alpha_1} \qquad (2)$$

The numerator is observed travel demand and the denominator is zonal sum of estimated demand by mesh level night-time light. Fig.5 shows the adjustment factor level of each zone on the map. This figure shows that the adjustment factor looks higher value at outer zones in the region. That would suggest the error might have relationship with the development level which may have correlation with the night-time light intensity. Fig.6 shows the relationship between zonal average of night-time light intensity (horizontal axis) and the adjustment factor (vertical axis) in logarithm scale for both axes.

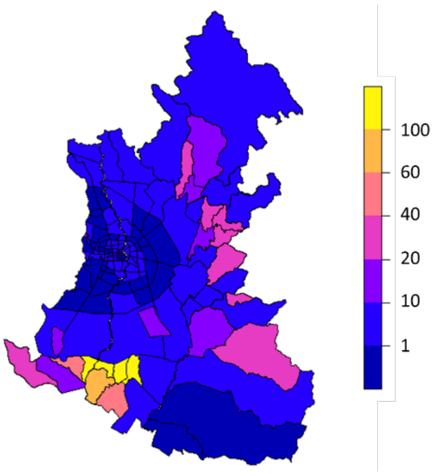

Fig.5 Adjustment factor of travel demand

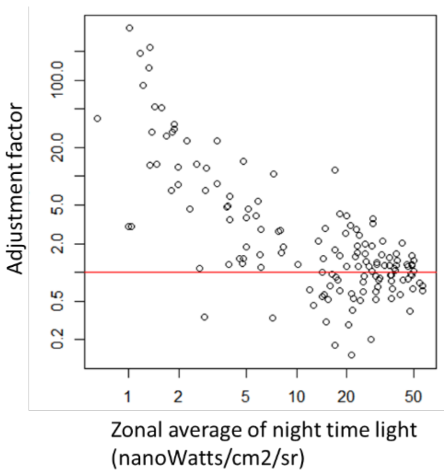

Fig.6 Night-time light and adjustment factor

From this figure, there is a tendency that the average night-time light is weaker the adjustment factor is larger. In addition, the adjustment factor tends to distribute around one when the night-time light intensity is enough high. So it would be suggested that the adjustment factor should not be fixed in lower night-time light zones. In this study we do not examine the relationship further, but for future study, at the weaker night-time light like less than 10 nanoWatts/cm^2/sr it should be modified as night-time light getting to be stronger.

The estimated mesh level trip generation maps with and without adjustment are shown in Fig.7 and 8 respectively. The estimated trip generation with adjustment (Fig.7) indicates that trips are generated at Chiang Mai city center as well as along the corridors of major radius and circular roads. That is consistent with the experience in the target city where the major economic activities are located on those places.

Without adjustment (Fig.8), trip generation in suburban area is clearly underestimated and some nodes looks over estimated compare with the adjusted estimation. This result indicates that night-time light solely does not have enough performance to estimate the travel demand and the combination with the other appropriate information is required.

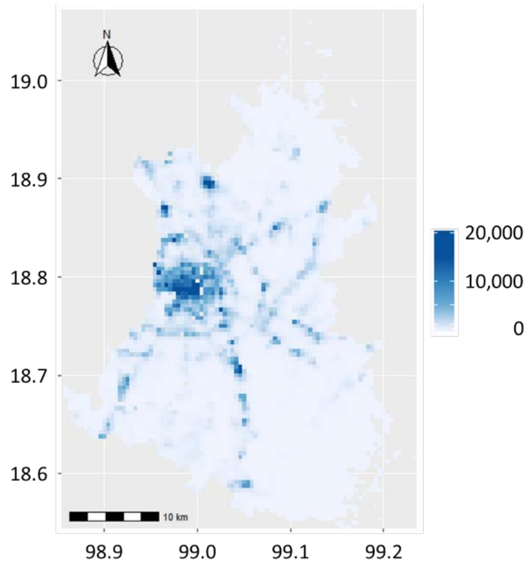

Fig.7 Estimated trip generation (adjusted)

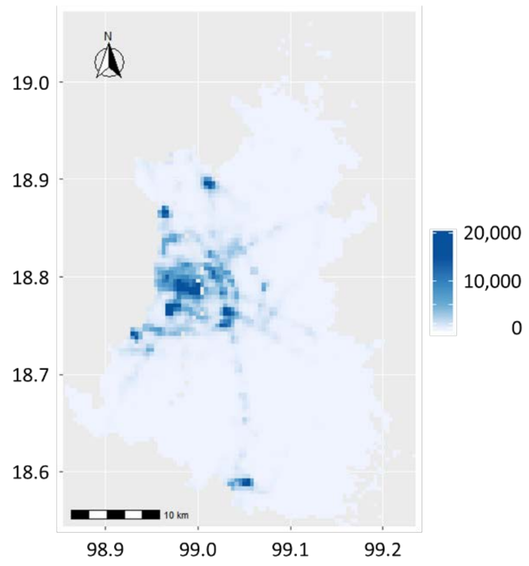

Fig.8 Estimated trip generation (non-adjusted)

5. TRAVEL DEMAND UPDATE

Taking the case of Chiang Mai Metropolitan area, we found loose relationship between trip generation /attraction and night-time light observed by VIIRS-DNB. This result indicates possibility of the travel demand update using the updated night-time light observation. In this section, we attempt to update the travel demand using the newly observed night-time light image.

Fig. 9 shows the histogram of the difference of night-time light intensity in target region between January 2016 and February 2019. The difference ranges -28 ~ +29 nanoWatts/cm^2/sr. This figure indicates that the most of the grids has almost the same intensity between the periods, but the distribution shifts towards brighter direction. The average of the change of nigh time light in the target region is 0.82 nanoWatts/cm^2/sr and the standard deviation is 2.49 nanoWatts/cm^2/sr.

The spatial distribution of night-time light change between 2016 and 2019 is shown in Fig. 10. It is noted that night-time light has gotten darker particularly at the east of target area. One site is at the north near the crossing point of Chiang Mai Outer Ring Road and Chotana Road, and the other place is Chiang Mai International Airport. Military facilities are located near these sites therefore the night-time light would occasionally change without reflecting the civil urban activities.

On the other hand, night-time light intensity has increased at two specific sites. One is at the center north of Chiang Mai city. This could reflect to the service expansion of a major provincial hospital at center north. The other is at the south part of the Outer Ring Road especially its crossing point with Chiang Mai-Lampang Highway. Alongside the south part of the Outer Ring Road, residential estates and commercial development resulting from the road being widen to 4 and 6 lanes has also been observed. This would be a factor on the night-time light change.

Applying the updated night-time light to Eq.(1), the updated traffic volume is estimated. The trip generation and attraction are estimated to increase 14% and 16%, respectively during this period. Compare with the total night-time light which is increased 18%, the travel demand increase is estimated to be moderate due to the non-linear relationship between the night-time light and travel demand. It is difficult to examine quantitatively due to lack of data, empirically the road traffic situation is getting severe with higher concentration of vehicle traffic recently. The method proposed in this paper can be provide a clue to investigate the updated spatial distribution of traffic demand.

6. DISCUSSION AND RECOMMENDATION

In this study, we attempt to examine the relationship between night-time light observed by satellite and trip generation in Chiang Mai Metropolitan Region 2016. We found that these two factors have non-linear positive relationship and estimated a model to calculate the travel demand from night-time light intensity. Based on the estimated model, we demonstrated the estimation of travel demand in finer spatial resolution compare to the ordinaly zone system. Additionally we applied this model to update the travel demand 2019. As a result, the total travel demand is estimated to increase about 15% from 2016. Looking at the spatial distribution of night-time light change, north city center and south part of outer ring road are the place where the travel demand is expected to increase significantly.

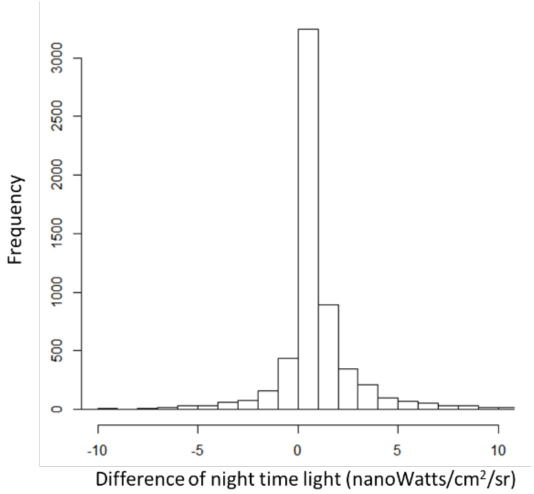

Fig.9 Difference of night-time light between January 2016 and February 2019

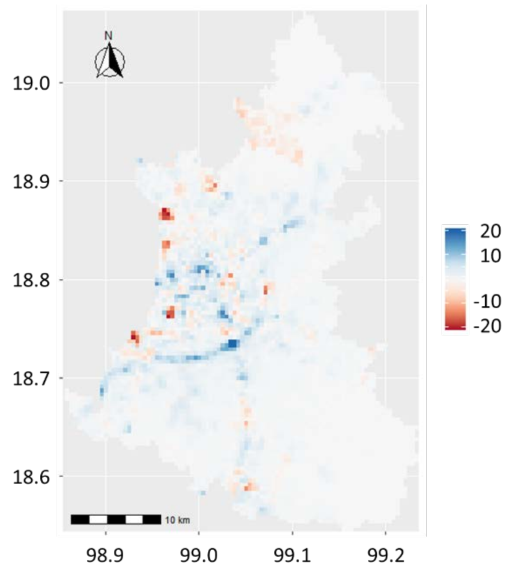

Fig.10 Spatial distribution of night-time light change between January 2016 and February 2019

The proposed appraoch would be useful especially in developing cities where the temporal transport and economic statistics and surveys are limited at the same time the urban activities are growing and spatially shifting rapidly. The satellite image employed here is published periodically which can be a clue to capture the progress of urban and transprot situation and updating the urban and transport policy and planning.

7. CONCLUSION

In this study we proposed a new method to estimate the travel demand from night time light satellite image which is periodically published and distributed through the internet. The method was examined taking the case of transport demand estimation in Chiang Mai Thailand. We found a cetrain level of representability of the transport demand observation and demonstrated the applicatiblity to a developing city.

The results in this study can be supported empirically however still need further examination to check its accuracy and reliability, and we also need further upgrading the method incorporating with the other data sources.

First, the estimation error shown in Fig. 4 is not neglegible as a projection model of travel demand. In this study we just employed adjustment factor to fit with the observed travel demand, but of course upgrade the model incorporating the other explanatory variable is desired. Sometimes population or floor area of buildings are employed as explanatory variables, however those input statistics are not surveyed frequently. It would be needed to explore the other information including open location data like Open street map and google place.

Second, further examination of the satellite image is needed. In this study we only utilize the image taken in January 2016 and February 2019. The VIIRS-DNB lose its accuracy by cloud cover because it observes visible light. Therefore the accuarcy of rainy season, for example July in Chiang Mai, is extremely low. However the images taken in the other dry month will also support the analysis. Of course another periodical satellite image products would support the analysis, but at this moment, the VIIRS-DNB is the most convenient periodical product for the urban activity analysis.

Finally, we need to investigate methods for travel survey. The data utilized in this study is relatively small sample survey and is expected to have substantial error especially in the peripheral zones in the target area. It would have induced analytical errors in this study. Travel survey methods using positioning device like smart phone and traffic counts survey are expected to improve the travel data quality.

8. ACKNOWLEDGMENTS

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