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ESTIMATION OF URBAN ENVIRONMENT BASED ON LAND-USE FORECAST*

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1. Introduction

During the recent past the awareness for urban environment has grown considerably. This is mainly due to the deteriorated environmental conditions being witnessed in metropolitan areas, particularly those in developing countries. With the rapid expansion of the metropolitan population, and hence the changes in land-use and transport, urban environment degradation has emerged as one of the serious urban problems. Most environmental problems can be regarded as externalities of land-use and transport. Transport and traffic originated environmental items, such as air pollution and noise pollution, have already become the subject of many researches. Although transport environment is a critical component of the urban environment, land-use originated environmental items, such as solid waste and water pollution, are not at all negligible items. Except for studies regarding the environmental impacts of industrial plant locations, only a few research have been carried out on the land-use originated environment. There had been some research, which estimate the urban environmental items at the metropolitan level. Unfortunately, these studies could not explain the variations in the environmental items at finer spatial levels such as zone.

2. Basic Concepts

(1) Background and the scope of this study

The present study is supposed to be incorporated in an analysis system for integrated policy measures of land-use, transport and environment in a developing metropolis[1], in which land-use forecast is given by the integrated land-use and transport model (RURBAN)[2]. According to the conceptual framework of the analysis system proposed by Miyamoto and Udomsri[1], the analysis system can accommodate separate models for land-use, transport and environment. These models are connected to each other by a common simulation data set. This means that the environment forecast model can be developed independently of the main system building. This study basically assumes that the land-use and transport situations required for the environment estimation are available from the simulation data set. In the analysis system, the unit of analysis for land-use was zone. In the environmental estimation also the same unit was used for the convenience. Further, we assume the zoning is defined by a rectangular grid system for simplicity, although it is convertible to an irregular zoning system of a real city.

As many models are readily available to predict environmental impacts due to transport situations, it is advantageous to use those models to estimate transport environment and to establish an estimation method for land-use related environment, which is lacking at present. In this paper, therefore, only the land-use originated environmental impacts are dealt with.

Out of the different land-use categories, environmental impacts of industrial land-use are not considered here. It is extremely difficult to generalize the environmental impacts of industrial land-use, which constitute a wide range of activities, both of type and magnitude. Moreover, they are not spatially distributed as residential and commercial land-uses, and Environmental Impact Assessments (EIA) are available for major industrial locations, even in developing metropolises.

(2) Basic concepts of the estimation procedure

Even for similar land-use conditions, different metropolitan areas may yield different impacts on the environment owing to the differences in climate, topography, local customs, socio-economics of the population etc. This makes it difficult to find generalized relationships or equations between land-use and environmental situations for different metropolises, without making the estimation procedures unnecessarily, and uneconomically, complex. These complicated methodologies will eventually be highly data intensive. What we propose to overcome this difficulty is to find the relationships from the metropolis itself, by calibrating the model using sampled data of the metropolis, keeping the estimation procedure as simple as possible. After identifying the basic variables which affect the particular environmental impact, empirical relationships are established through sampled observations.

Land-use originated environmental items fall in to two types, according to the proportionality they have, to the activity intensity of the land-use. Magnitudes of some environmental items, such as solid waste generation, depend on the intensity of land-use activity. Impacts like Increased surface runoff due to increased paved areas, on the other hand, are independent of the intensity of land-use. In this study, land price of a zone is considered as a representative index of the intensity of a particular

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land-use, as well as the land-cover composition of the zone. Land price, a simulation output of the land-use model, is therefore used to define the land-cover composition and the emission rates of pollutants, as described in a later chapter.

3. Estimation System for Environment

(1) Denotations

Following denotations are used in this chapter.

N : number of activity units belong to a land-use activity ; P : land price of a zone

C : area of the land-cover of a land-cover type ; R : pollutant emission rate of a pollutant

W : pollutant emission of a pollutant ; E : value of an environmental indicator

superscripts :

b : base year ; f : forecast year

subscripts :

i : zone number ; k : land-use activity type ; h : land-cover type

m : pollutant type ; j : environmental indicator number

(2) Initial data for the land-use simulation model and land-cover estimation

Developing metropolises are characterized by rapid changes in land-use and unavailability of up-to-date data. Therefore a data system comprising of remote sensing information and easily available physical data has been proposed for this analysis system. However, these data will be used only for the base year in the initial calibration stage and data for subsequent years will be forecast by the land-use simulation model. The most important input variable obtained this way is the number of activity units for each land-use category (N^b_{ki}). This is estimated indirectly through band information from remote sensing and other physical data aggregated at zone level. A set of parameters are established to relate the band information and the number of activity units. Parameter estimation is carried out using data for sampled zones. Number of activity units for sampled zones are obtained by the conventional survey method. A pilot application of the method has been conducted in a part of Yokohama city and satisfactory results are obtained with about 0.8 correlation coefficients between estimated and observed population by 0.25 km^2 grid. Land-use simulation needs some other information such as transport condition etc., which are given separately.

Remote sensing information are aggregated at zone level to estimate the land-cover (C^b_{hi}) also. Estimation of land-cover composition from remote sensing data is more straightforward, for it has been the conventional approach to derive the land-cover data.

(3) Output from the land-use simulation model

Land-use simulation model generates two important sets of information for the environmental estimation; number of land-use activity units (N^f_{ki}) and land price (P_i). Both these information are necessary to estimate the emission rates of pollutants, whereas land price is needed for the land-cover estimation.

(4) Land-cover (C^f_{hi}) estimation

Land-cover forecast is made based on the relationship between the land-cover composition and the land price. Land-cover for the base year is available from remote-sensing information supported by sample survey, and land price is available from land-use simulation model. It is possible to derive relationships between land-cover and land-price from the base year information. These relationships can be expressed in terms of share curves as shown in Figure 1. The shares of all the land-cover types for a particular zone should add up to one. It is possible to estimate the land-cover composition quantitatively using the share curves, when the land-price and the total area of the zone is known.

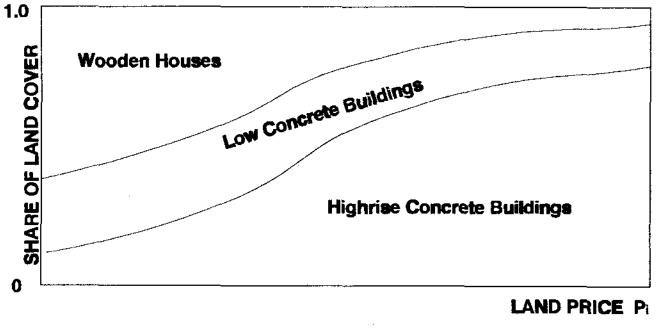

Figure 1 : Share of Land-Cover (h) of a Land-Use Activity (k). (example of residential use)

(5) Emission Estimation of Pollutants

Emission rate of a particular kind of pollutant is assumed to vary with the activity level in the city. As stated earlier, this is represented by the land price. The proposed methodology is to conduct a simple survey to cover all the land-use activities and different economic levels, i.e., land price at the location. Since the survey can be made by individual household, large number of samples are not needed. Pollutant generations such as solid waste, waste water or air pollutants can be estimated this way. The same methodology is used to estimate the energy consumption due to land-use also. With this approach, if the land price of the location is known, emission rate of a particular kind of pollutant from a given land-use activity can be found. This may be expressed as;

$$W_{mi} = \sum_k N_{ki} . R_{km} = \sum_k N_{ki} \cdot g_{km}(P_i)$$

Where;

R_{km} : rate of emission of pollutant m from land-use k

$g_{km}(P_i)$: function that expresses R_{km} in terms of land price (P_i)

(6) Primary environmental indicators

Primary environmental indicators are the environmental conditions prevail in the zones, which can be expressed independent of the influences of neighbouring zones and are often to be determined in the course of estimation of other environmental indicators. Examples for primary environmental indicators are percentage green area, percentage surface water area and energy consumption per unit area. However, energy consumption in the zone is contributed by transport energy consumption also. This is estimated considering the link traffic conditions of the road links enclosed in the zone, and is available from the transport model.

(7) Environmental Simulation Model

Environmental simulation model estimates environmental indicators for each zone using data from; emission generation (W_{mi}), land-cover composition (C_{hi}), and climatic and topographic data for each zone. Although emission generation and land-cover composition of a particular zone contributes to the environmental situation of the zone, there is a contribution from the neighbouring zones too; or this can be identified as an effect of the agglomeration of environmental impact. However, this is not the case for primary environmental indicators, which are defined on the characteristics of that particular zone only. In the environmental simulation model effect of neighbouring zones is incorporated by considering the physical flow of pollutants under the given climatic and topographic conditions. Amount of pollution at a particular location is to be defined not as the pollution generation but as pollution situation at the location, for the term to be of practical use. Pollution situation of a zone is defined by;

Pollution Situation = Generation + Inflow - Outflow - Service Capacity

Application of this general concept is different from a type of impact to another. Pollution estimation procedure for three example environmental impacts, with different application of this concept, are given below.

a) Urban heat island effect

Increase in the nighttime temperature, compared with a typical rural area nearby, is the most detectable characteristic of the urban heat island phenomena[6]. It is evident from many researches that the temperature rise is a function of building density, city size, land-cover or paving type, presence of green area, presence of water bodies, energy consumption etc.[6,7,8]. It has been found that there is a contribution from the topography and cloudiness as well and wind causes the heat island to blow away[6,9]. Oke and Hannell defined the critical wind speed, above which heat island cannot be detected, is highly correlated (0.97) to the logarithm of the population of the city, which is a measure of the city size[6].

Out of the variables above, land-cover composition (paving types, presence of green areas, water bodies and building density) and energy consumption are primary environmental indicators which are available after each simulation. The influence of other factors such as solar radiation, topography etc. remain constant for particular region and are independent of land-use change. An empirical relationship could be found between the so selected explanatory variables and the nighttime temperature rise for no-wind conditions for a particular metropolis. Such previous researches for whole cities have found good correlations6). Increase in temperature under no-wind condition (ΔT_i) can be expressed as;

$$\Delta T_i = \alpha_1 X_{i1} + \alpha_2 X_{i2} + \dots\dots + \alpha_p X_{ip} = \sum_p \alpha_n X_{in}$$

Where;

$X_{i1}, \dots X_{ip}$: values of p explanatory variables for zone i

$\alpha_1, \dots \alpha_p$: parameters that relate explanatory variables to temperature rise, to be estimated using data for sampled zones for the base year

It should be noted that the explanatory variables has to be expressed independent of zone area, for example, energy consumption per unit area, green area percentage etc., if the zones are of different sizes. Temperature rise for the base year, ΔT_i^b, can be derived from remote-sensed temperature band information corrected for street level by ground measurements. The observation should be for a no-wind case.

In the case of heat island effect, *generation* means the temperature rise under no-wind condition, due to internal conditions prevailing in the zone. The wind, however, transports the heat island in the direction of the wind, causing *inflow* and *outflow* effects. The shift of this temperature contour map was well observed for the Tokyo metropolitan area under wind conditions[9]. There is no *service capacity* in regard to heat island effect.

b) Solid wastes

Amount and composition of solid waste generated depends on the nature and intensity of the land-use activity. Even for residential land-use, it is a function of economic level, social attitudes and customs etc. This fact has been observed in solid waste studies carried out in developing metropolises also[5]. Some region dependent factors like geography, climate and status of regional economy also affect the solid waste generation.[3]. Since these region dependent factors may differ from a metropolis to another, it is wiser to derive the information for the study region through actual field data.

A good indicator of the economic level of the locator, be it residential, commercial or so forth, is the land price at his location. A simple solid waste survey conducted at individual household level, representing locations at different land prices yields satisfactory information. One advantage of this approach is that a large sample is not required.

A breakdown of the solid waste composition (recyclables, combustibles, non-combustibles etc.) is also important as the treatment processes involved differ according to the type of waste.

In the case of solid wastes, generation means the total solid waste *generation* in the zone, whereas *service capacity* is the capacity of the collection and disposal facilities provided at each zone. There is no *inflow* or *outflow* associated with solid wastes.

c) Waste water

Under waste water there are two main parameters of importance; volume and the degree of pollution concentration, usually expressed in terms of BOD. A similar procedure is adopted to acquire necessary information, as in the case of solid wastes.

Waste water studies are often conducted with the pollution studies of water bodies, as treated effluents as well as untreated waste water very often enter waterways or lakes[3]. In the environmental simulation model also the flow of waste water down the waterways is considered. Surface water quality of a zone is defined as the highest concentration of pollutants present in the stream network enclosed in the zone. Average discharges along the stream network and pollutant concentration entering the study area are given to the model separately.

Once the *generation* of waste water inside the zone is estimated both in terms of quantity as well as strength, and the *service capacity* is estimated to show the intake capacity, effluent strength and volume, strength (BOD) and amount of waste entering the stream network is known. Any untreated waste water also is assumed to be entering the stream network. Flow of waste is traced along the waterways as *outflows* and *inflows* between zones.

4. Concluding Remarks

In this paper, the procedure for environmental estimation starting from the land-use forecast is discussed. Land price, a simulation output from land-use model, is used to interpret the land-use activity intensity and land-cover composition, two of the main governing variables for the environment estimation. Environmental situation at a zone is expressed in terms of pollutant generation in the zone, inflow of pollutants into the zone, outflow from the zone and the service capacity provided at the zone. Empirical study is now following the basic system and the estimation methods described here.

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