A System for Estimating Life Cycle Environmental Load from Urban Areas
Based on Using the Detailed Land Use Data
- An Analysis of the Urban Shrinking Policy -

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ABSTRACT
This study aims to construct a system for analyzing the relationship between urban structure and environmental load. In this system, life cycle environmental load is from the construction, operation and waste disposal of infrastructure and buildings. Also, environmental load from transport activities is calculated. Spatial unit is a mesh of about 500*500 meter size. The system, which includes the time serial cohort model with infrastructure and buildings, can describe the dynamically spatial changes. As an environmental load, CO2 is evaluated. An application to a real city indicates that 1) urban shrinking leads to less CO2 emission because per capita CO2 emission in the central dense area is less than that in suburban sparse areas, 2) additional CO2 emission from waste disposal and new construction of infrastructure and buildings can be canceled out by reducing emission after urban shrinking, and 3) the effect of emission reduction with concurrent shrinking is larger than that with gradual shrinking considering the timing of rebuilding housings.

INTRODUCTION
After years of spectacular economic growth, the others in Japan are understanding the pressures of progress in motorization, and the urban sprawl. In the low-density sprawled cities, because of high dependence on the automobiles, it has become the spiral structure which the motorization develops much more. And in such a kind of city, there is a tendency that the environmental load due to automobile utilization is a lot. Besides, as the necessity of infrastructure such as roads, water supply and sewerage increased, more environmental load would occur by updating and maintenance activities.

In recent years, “compact city” concept is recognized as a sustainable urban area structure with less environmental load and high QOL (Quality Of Life), which has been of a growing interest. However, the restructuring into compact city is not equal a low-environmental load construction of the urban spatial structure. Because even if the activities for compact city with reduced environmental load, the environmental load that caused by the disposal of existing buildings and the construction of infrastructures in restructuring can not be ignored.

This paper proposes a methodology for evaluating the environmental load that occurred in the buildings of urban areas, construction of infrastructures, maintenance activities, renewal and disposal activities. It is applied to a real city to consider whether the restructuring to compact structure of urban space could have an effect on reduction of the environmental load.

METHODOLOGY
Application of LCA to the urban areas
In this paper, the city with a complex of buildings and infrastructure is regarded as an urban system. Environmental load through its life cycle from the system (System Life Cycle Environmental Load: SyLCEL) will be evaluated. In addition, the environmental load due to the activities based on the urban system is also calculated. Because of this, it is possible to evaluate changes in environmental load from social behavior by the situation of buildings and infrastructure. In this way, the author called this concept of evaluation which the boundary is extended to the activities on buildings and infrastructure as “Extended Life Cycle Environmental Load: ELCEL”.

Target at buildings, infrastructure and activities
In Table 1, the objectives evaluated in this paper include of buildings, infrastructure and setting up life time have been collected. Only residential buildings are picked up. Buildings offered to business are not considered. For infrastructure, road, railway, park and water and sewage services will be treated. Lifetime use the durable years which are ordered by “Ministerial ordinance on durable years of the depreciable assets” in Japan. Passenger transport activity is just treated.

In the cohort model, renewal of buildings and infrastructure is represented which supposing after durable years to be reconstructed at the same location. In other words, the serial change of location is not simulated. Therefore, the required exogenous variables of cohort model may be taken from the extension of the current trend...
Environmental load is represented in equation (1) to get the five kinds of environmental load (CO₂, SO₂, NOx, CH₄ and N₂O) of each mesh. Finally, the value multiplies the population amount of environmental load caused by traffic per trip length in each mesh are estimated by the data of the transport, values of trip production ratio, modal split and infrastructures to suppose a standard design, then about method may be applied. First, for each kind of buildings and infrastructures to suppose a standard design, then about method may be applied. For the results of 2000 to 2004, the result is distinguished by each life stage. CO₂ emission is mainly generated in suburbs. In addition, Figure 3 is the spatial distribution of CO₂ emission from 2000 to 2004. This distribution is similar with that of residences in Figure 1. CO₂ emission per residences from 2000 to 2004 is estimated as Figure 4. This distribution shows that CO₂ emission is mainly generated in suburbs. In addition, Figure 5 shows the comparison of CO₂ emission in DID (Densely Inhabited District) and non-DID per resident population from 2000 to 2004. The result is distinguished by each life stage. CO₂ emission per resident population in non-DID are 12% larger than in DID from 2000 to 2004. For the results stated above, the conversion policy to compact city that relocate the resident from suburb to the inner city suggests

\[ EL_i = \sum_k e^k T^k S^k a^k \]  

(1)

**Table 1** System boundary and setting for life time

<table>
<thead>
<tr>
<th>Classification</th>
<th>Urban facilities</th>
<th>Type</th>
<th>Life time[yr]</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buildings (Residence)</td>
<td>Dwelling house</td>
<td>Wooden house</td>
<td>25</td>
<td>Including consumer (house) sector</td>
</tr>
<tr>
<td></td>
<td></td>
<td>House of steel beam</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Multiple dwelling house</td>
<td>House of reinforced concrete/ House of steel framed</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Transport facilities</td>
<td>Road</td>
<td>Asphalitic pavement</td>
<td>10</td>
<td>Construction method: Cutting overlay</td>
</tr>
<tr>
<td></td>
<td>Rail</td>
<td>-</td>
<td>-</td>
<td>Environmental load from running is considered in transport activity</td>
</tr>
<tr>
<td>Disposing facilities</td>
<td>Sewer culvert</td>
<td>-</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water distributing pipe</td>
<td>-</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Park</td>
<td>Urban park</td>
<td>Park in residential area / Comprehensive park / Special park</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Transport activity</td>
<td>-</td>
<td>Passenger transport</td>
<td>-</td>
<td>Evaluated as ELCEL</td>
</tr>
</tbody>
</table>

**APPLICATION TO A REAL CITY**

**Target city**

Toyota city (the area is considered before the merger of municipalities in 2005, the population is approximately 350,000, the area about 300m²) in Japan is picked up. Distribution of the resident population in 2000 national census is shown in Figure 1.

**Estimated results of CO₂ emission**

Unit estimation period is every five years from 2000 to 2049. LC-CO₂ from buildings, infrastructures and activities in the target city is estimated. Figure 2 shows the changes in amount of the total emission and Figure 3 is the spatial distribution of CO₂ emission from 2000 to 2004. This distribution is similar with that of residences in Figure 1. CO₂ emission per residences from 2000 to 2004 is estimated as Figure 4. This distribution shows that CO₂ emission is mainly generated in suburbs. In addition, Figure 5 shows the comparison of CO₂ emission in DID (Densely Inhabited District) and non-DID per resident population from 2000 to 2004. The result is distinguished by each life stage. CO₂ emission per resident population in non-DID are 12% larger than in DID from 2000 to 2004. For the results stated above, the conversion policy to compact city that relocate the resident from suburb to the inner city suggests

\[ EL_i = \sum_k e^k T^k S^k a^k \]  

(1)
the possibility to reduce the life cycle CO₂ emission from buildings and infrastructures.

ANALYSIS OF URBAN SHRINKING POLICY

Scenario setting

CO₂ reduction effect under the urban shrinking policy is analyzed. Targeted urban spatial structure is shown in Table 2.

The removed area is about 15% of the total city area and the population ratio is about 1.5%. According to Figure 4, per capita CO₂ emission is high level. On the other hand, the concentrated area is about 0.3% and the population is about 0.5%. This area is located at 2km northwest of the Toyota central station. This area is urbanization control area, as the population has not been increased.

The alternative scenarios progressing urban shrinking are set as follows:

Scenario(1): Concurrent shrinking

In 2005-2009, infrastructures and housing are broken down and relocated concurrently for whatever durable years.

Scenario(2): Gradual shrinking

Each housing which will reach their life time at the each period after 2005 is torn down and relocated.

Effects are analyzed by comparing with change in CO₂ emission due to urban shrinking policy. They are caused by disposal in removed area and new construction in concentrated area. Concretely the following things are considered.

1) Houses, roads, sewage pipe and water pipe systems of mainlines are disposed in origin areas.

2) The amount of new houses and infrastructure is identified according to the percentage of population growth with the total residential floor space per population. The amount of infrastructure in concentrated areas is constant.

3) It is assumed that new houses are made by reinforced concrete.

4) Indicators for passenger transport in concentrated areas (trip production ratio, modal split and average trip length) are not changed.

Change of CO₂ emission due to urban shrinking

Figure 7 shows the "with/without" ratio trend of the amount of CO₂ "with" policy implementation case to "without" case. This result is summarized below.

Scenario(1): Concurrent shrinking

Because of a lot of relocation in 2005-2009, with/without ratio of CO₂ emission is relatively large. However, the reduction effect appears in the later period.
Scenario (2): Gradual shrinking

With/without ratio of CO\textsubscript{2} emission is largely unaltered due to increase in CO\textsubscript{2} emission with implemented policy. It is offset by the CO\textsubscript{2} reduction of residence using stage in 2005-2024. But the reduction effect due to relocating represents by 2025-2029 when 70% of the population has relocated. After 2030, since 90% of the population finishes relocating, significant reduction effect shows.

For these results above, it is able to change to low CO\textsubscript{2} urban structure with shrinking policy.

Then, CO\textsubscript{2} payback time with urban shrinking is shown by the difference in the cumulative CO\textsubscript{2} of with case and without case in Figure 8. In case of scenario (2), it takes as long as about 25 years to payback of CO\textsubscript{2} from shrinking policy. But it is within the life time of buildings.

In addition, as CO\textsubscript{2} emission from residence with urban shrinking policy is larger than that from passenger transport, the CO\textsubscript{2} reduction effect with scenario (1) is smaller than with scenario (2).

2) CO\textsubscript{2} emission per capita in DID is smaller than that in non-DID.
3) The shrinking policy decreases total CO\textsubscript{2} emission from the city.
4) By implementation of shrinking policy, CO\textsubscript{2} can be paybacked within the building life time.
5) CO\textsubscript{2} reduction with gradual shrinking scenario is larger than that with concurrent shrinking scenario because the CO\textsubscript{2} reduction effect from passenger transport is not so significant.

ACKNOWLEDGMENT

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REFERENCES


Table 2 Analyzed urban shrinking policies

<table>
<thead>
<tr>
<th>Location</th>
<th>Refer to Figure 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Removed area</td>
<td>Northeast urbanization control area, district of large environmental load per resident population</td>
</tr>
<tr>
<td></td>
<td>Average population from 2005 to 2009: 5,646 (1.5% of all population)</td>
</tr>
<tr>
<td></td>
<td>Number of mesh: 18 (14.7% of all mesh)</td>
</tr>
<tr>
<td>Concentrated area</td>
<td>District near urban center and less population concentrating</td>
</tr>
<tr>
<td></td>
<td>Average population from 2005 to 2009: 1,906</td>
</tr>
<tr>
<td></td>
<td>Number of mesh: 4</td>
</tr>
<tr>
<td></td>
<td>Additional population is allocated equally to each mesh</td>
</tr>
<tr>
<td>Scenario for the measure of</td>
<td>(1) Concurrent shrinking scenario: All relocate from 2005 to 2009</td>
</tr>
<tr>
<td>implementation</td>
<td>(2) Gradual shrinking scenario: From 2005 gradual shrinking in renewal time for each residence</td>
</tr>
</tbody>
</table>

Figure 6 Origin and destination mesh for urban shrinking policy

Figure 7 Change of CO\textsubscript{2} emission due to urban shrinking

Figure 8 CO\textsubscript{2} payback time with urban shrinking