A STRATEGIC CROSS-ASSESSMENT MODEL FOR VISION-LED AND CONSENSUS-LED DECISION MAKING TOWARDS SUSTAINABLE URBAN TRANSPORT

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INTRODUCTION

One of the central issues in decision making for urban transport is to identify and choose the most sustainable solutions among a wide spectrum of alternatives, involving a large number of stakeholders with multiple, often conflicting objectives. Their objectives range from provision of cost effectiveness transport service, through provision of fair and equitable accessibility to opportunities, to realisation of safe and environmentally friendly mobility style. These can hardly be achieved by a single policy instrument, and therefore require integrated strategies including a) infrastructure provision and management, b) attitudinal measures influencing people's travel behaviours and lifestyles, c) land use measures shaping transit-supportive urban structures, and d)pricing.

For a better integration of strategies, a wide scope of stakeholders with different values should be encouraged to participate fully in strategy formulation. It would thus be possible to develop a common understanding of objectives and a shared vision of the sustainable urban transport. Furthermore, it is necessary for us to find an appropriate combination of vision-led approaches and consensus-led approaches, which could reconcile conflicting objectives among stakeholders by clarifying the pros and cons of respective strategies.

As shown in "A Decision Makers' Guidebook" for developing sustainable urban land use and transport strategies, the most common approach to decision making is a mix of plan-led and consensus-led one(May; 2005). However, plan-led approaches which seek for the optimal solution or the best alternative might work well only if stakeholders/people could share the common value system. But if the value systems are different among the stakeholders, it has been proved that there are no veritable panacea to find the best solution in democracy (Arrow; 1950).

Therefore, with a special focus on vision-led and consensus-led decision making, this paper proposes an innovative framework of a cross-assessment model [1] which enables the multi-dimensional and multi-lateral evaluation of alternative strategies. This model is expected to help decision makers to disentangle possible directions towards the sustainable urban transport to meet the requirements of both a low-carbon society and an ageing society with declining population. It is designed to make cross assessment of the alternative strategies whose outcomes are compared each other with regard to the impact on welfare, economy and the environment. This model is applied to the analysis of transport strategies and urban compaction over a 30 years period for the entire urban areas in Japan.

In detail, the urban compactness is defined by the grid population data, in which the grid size is 1km×1km. We set two urban scenarios for the year 2030; 'trend' and 'compact'. Three outcome indices are selected based on the value element; financial balance of public transport operation, users' benefits, and CO2 emissions from transport sector. We also set three public transport policy alternatives, profit maximisation of public transport sector, maximisation of social net benefits, and minimisation of CO2 emissions. The impacts of them on each outcome index are estimated. As a result, this study provides a perspective of the impact of urban structures and transport strategies under a society with an ageing and declining population in Japan as well as the difference of the impact among regions which is not fully discussed in past studies.

Note that this paper focuses on urban passenger transport and does not touch upon inter-city and freight transport issues. In addition, transport and traffic conditions in our modelling are simplified to be analytically tractable and practically operational in the entire urban areas..

ANALYTICAL REQUIREMENTS FOR SUSTAINABLE URBAN TRANSPORT

Most of the analytical tools for plan-led approaches are likely to work well if objectives are specified or problems identified, and the measures which satisfy the objectives or solve the problems are easily determined. In such cases, they often focus on a limited scope of problems or are based on an ad-hoc value system, regardless of the diversification of values among the people. A successful combination of vision-led and consensus-led approaches requires an innovative analytical tool which is cable of cross-assessing the outcomes of alternative strategies from multiple perspectives and values.

In this section, we review previous studies on the relationships among urban structure, transport energy consumption, and public transport policy, which are essential topics for the discussion of sustainable urban transport strategies under a society with an ageing and declining population.

Urban structure and transport energy

Many past studied were devoted to clarify the relationships between urban structures and transport energy consumptions in order to extract information. Newman and Kenworthy (1989) summarise the data of urban transport over the world, and give the famous figure of the negative correlation between population density and fuel consumption per capita. It is cited by many studies as evidence of the effectiveness of the compact city for the transport energy saving. On the other hand, some studies point that the densification of urban population worsens the congestion and does not necessarily contribute to the energy saving (Bouwman; 2000). Ministry of Land, Infrastructure, Transport and Tourism (2002) simulates the effect of urban density on the energy consumption in travel and indicates that the high density will save the energy on road but increase inside building due to the use of elevators.

The impact of urban compaction on the transport energy saving would be different by the urban structure including the location of activities and infrastructure. Therefore the macro relationship between population density and vehicle energy consumption is not enough to lead the consensus or vision for the sustainable transport strategy. We need more detail information of activity location and transport movement, as well as the situation of public transport service provision inside the urban area.

Level of service of public transport

The relationship between urban structures and transport energy consumptions are mostly studied based on the private car travels, but the level of service (LOS) of public transport is also a considerable factor. Urban compactness will increase the travel demand density which allows the higher LOS and modal share of public transport. Modal shift from private to public transport is expected as a mitigation measure for global warming problems, but it depends on the travel density and efficiency of the public transport. Except in large cities, the private car is dominant transport mode in most developed cities. It reflects that the lower travel density the lower profitability and LOS of public transport. If administration forces to increase the public transport service at the region of low travel demand density, it would possibly increase the CO2 emissions due to the higher energy intensity of public transport at low occupancy ratio (Kii et.al; 2005, Kii and Hanaoka, 2003).

Ishida et.al (1999) quantifies the public transport domain (Vuchic; 1992, Bouladon; 1967) considering the demand and profitability of the transport sector. It evaluates the capable domain of the public transport service over the urban area and traffic density at urban centre, but the urban structure is too simplified to analyse the effect of urban compaction.

Requirements for the analysis of sustainable urban transport strategies

Past studies take various approaches to measure the impact of urban compaction and transport policies on the CO2 emissions reduction, however, these studies do not take into account the change of LOS of public transport caused by urban compaction. In addition it is also important to find the regional conditions where the transport policy will be effective for emissions reduction, but it requires comparable analysis among cities in the target region. There are land-use and transport models describing detail choice behaviour of transport modes, routes, and locations. These models need huge amount of data, therefore, they are usually applied to one or a few selected cities.

In this study, we attempt to build an urban transport model in which the LOS of public transport is identified endogenously with simplified users' behaviour in transport, and it is applied to 269 urban areas in Japan. By the cross-assessment of the urban compaction and public transport policies, the outcomes of each transport strategy and their spatial distribution are demonstrated. The results are used to identify the conditions under which urban compaction is effective for CO2 emissions reduction.

STRATEGIC CROSS-ASSESSMENT MODEL

Definition of stakeholders and a conceptual framework of the analysis

In this study, public transport operator, government, and transport user are defined as stakeholders. Their behaviours are assumed as follows.

Public transport operator

The operators decide the LOS of public transport (bus and train) to maximise their profits under the given spatial distribution of demand, fare, and subsidy. The latter two factors are determined by the government.

Transport user

Users choose the travel modes (private car, bus, train, and walk/bicycle) to minimise the generalised cost for their trip under the given fare level and LOS of public transport.

Government

Government devises transport strategies and subsidies to public transport operators to make the strategies effective. It also leads the spatial pattern of residence and work place.

We also set triple bottom lines of sustainability as economy, society and environment, and the following three strategic targets in transport policy are assumed. The abbreviation in the parenthesis indicates the target hereafter.

1. Profit maximisation of public transport operator (PM)
2. Net benefit maximisation (NBM)
3. CO2 emissions minimisation in transport sector (CO2)

The first target, PM, is equal to the minimisation of subsidy by government. In the second, net benefits is defined as sum of users' benefits and operators' profits. Based on these targets, we set three outcome indices; operators' profits, users' benefits, and CO2 emissions.

Figure 1 shows the conceptualised mechanism of mobility style formation through the behaviour of user and operator under the transport strategy and urban structure controlled by the government. In the strategic targets above described, the profit maximisation mainly attaches importance to the operator's profitability, and net benefit maximisation attaches importance to users mainly. CO2 minimisation in the transport sector is currently commitment by the government only and it does not make any benefit for user and operator directly. Though, every target affects all outcome indices, in other word, pursuing one value element will affect the achievement of the other elements as well. We define the cross-assessment as an impact analysis of policy targets on the outcome indices, and the cross-assessment model is an attempt to apply this evaluation in the real transport strategy.

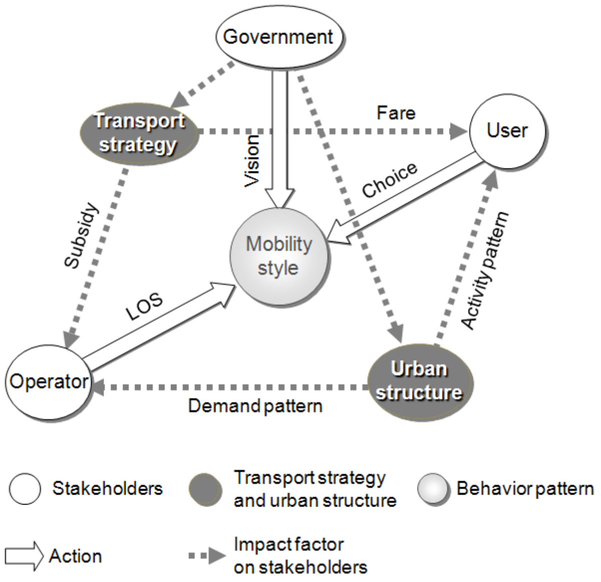

Figure 1. Inter-relationship of actions of stakeholders

Formulation of the cross-assessment model

For the strategic analysis of public transport policies, we need an analytical model which represents the transport LOS and activity location as spatial information. In this study, the urban space is represented by a grid based system, and the behaviour of transport operator and users are formulated. In addition, three indices, the financial balance of transport operation, generalised user's cost for travel, and CO2 emissions from transport sector, can be estimated. In the formulation, we put the following assumptions:

1. Urban structure of residential and workplace location, transport infrastructure, and fare level of public transport are given exogenously.

2. Travel speed of public and private transport varies spatially among grids, but does not change depending on traffic volume.

3. A single operator provides both train and bus services in each city.

4. Revenue of transport service is proportionate to passenger-km but operation cost depends on vehicle-km.

5. CO2 emission factor per vehicle-km is fixed for each transport mode.

Profit of public transport

The profit of a public transport operator Π at grid m mode k is expressed as follows.

$$\Pi_{mk} = q_{mk} l_{mk} \chi_k - C_{mk}(n_{mk}) \qquad (1)$$

Here, q_{mk} is number of passengers at grid m, l_m is route length (km), χ_k is fare rate (yen/km), C_{mk} is operation cost, n_{mk} is number of vehicles in operation. The operation cost is assumed to be proportionate with operated vehicle-km L_{mk}, and it can be described as follows.

$$C_{mk}(n_{mk}) = a_{0k} + a_{1k} L_{mk}(n_{mk}) \qquad (2)$$

$$L_{mk}(n_{mk}) = H_k v_{mk} n_{mk} \qquad (3)$$

The equation (3) represents the vehicle kilometrage as a product of operation hour H and vehicle speed v_{mk}. In this formulation, operator's profit is controlled by the number of vehicles in operation or service frequency under the given grid condition of route length, number of passengers, and fare rate. Thus, the total financial balance in a city is given as $\sum_{m,k} \Pi_{mk}(n_{mk})$.

User's benefit

We focus on user's benefit arising from the travel time and cost reduction. The generalised user's cost C for travel between origin i and destination j by mode k can be defined as follows.

$$C_{ijk} = c_{ijk}^{p} + w \cdot \left(t_{ijk}^{w}(\mathbf{n}_{ijk}) + \sum_{m} t_{mk} \cdot \delta_{ijmk} \right) \qquad (4)$$

Here, $c_{ijk}{}^{p}$ is fare for the travel between i and j , which is equal to $\chi_k \cdot l_{ij}$, where l_{ij} is travel length. w is value of time, t_{mk} and $t_{ijk}{}^{w}$ is travel time and waiting time at grid m on the route of ij. δ_{ijmk} is binary value; take one if m is on the route, and take zero if it is not. The travel route is fixed for a OD (origin and destination) trip. Additionally, the waiting time is defined as $t_{ijk}^{w} = \max_{m} \{ l_{mk} / (v_{mk} n_{mk}) | m \in M_{ij} \}$, where $M_{ij} = \{ m | \delta_{ijmk} = 1 \}$. $\mathbf{n}_{ijk}$ is defined as $\{ n_{mk} \mid m \in M_{ij} \}$, which is the vector of number of vehicles in operation for the grid on the route between ij.

We assume logit model whose representative term is given by equation (4), and the expected minimum travel cost on i-j can be written as follows.

$$C_{ij} = \frac{1}{\theta} \ln \left(\sum_{k} \exp\left(\theta \cdot C_{ijk}(\mathbf{n}_{ijk}) \right) \right) \qquad (5)$$

Here, θ is a parameter. If we assume that the travel demand on i-j is fixed as Q_{ij} and the generalised cost with and without policy measures are denoted by $C_{ij}{}^{w}$, $C_{ij}{}^{o}$ respectively, then, the total user's benefit in the city is $\sum_{i,j} Q_{ij} \left(C_{ij}^{o} - C_{ij}^{w} \right)$.

CO2 emissions

CO2 emissions of transport mode k at grid m is formulated as follows:

$$CO2_{mk} = \alpha_k L_{mk}(n_{mk}) \tag{6}$$

Here, α_k is emission factor of mode k, and L_{mk} is travel length with the grid m. That of public transport and private car are expressed as follows (suffix t denotes public transport and c denotes private car).

$$L_{mt}(n_{mt}) = H_t v_{mt} n_{mt} \tag{7}$$

$$L_{mc} = q_{mc} l_{mc} \tag{8}$$

l_{mc} is one way drive length to pass through the grid m. Number of passengers q using transport mode k at grid m , which appears in equation (1) and (8), is defined as follows by the logit model.

$$q_{mk} = \sum_{i,j} (Q_{ij} P_{ijk}) \delta_{ijmk} \tag{9}$$

$$P_{ijk} = \frac{\exp\left(\theta \cdot C_{ijk}(\mathbf{n}_{ijk}) + \theta_k\right)}{\sum_{k'} \exp\left(\theta \cdot C_{ijk'}(\mathbf{n}_{ijk'}) + \theta_{k'}\right)} \tag{10}$$

Here, θ_k is a dummy parameter for mode k. As is shown in the next section, the travel demand is estimated for elderly and non-elderly people separately. Therefore, the q_{mk} in equation (1) is a sum of travel demand of the elderly and that of the non-elderly estimated by equation (9).

Strategic targets

Figure 2 shows linkage among the formulated behaviour and the outcome indices. In this model, the number of OD trips only depends on the population distribution, but the modal share depends on the generalised travel cost of all modes as formulated in equation (10). The generalised cost is determined by the number of the in-operation vehicles of public transport using equation (4). The number of vehicles is calculated endogenously, with consideration of the modal share change, to achieve the strategic targets formulated below. When the generalised cost is determined, user's benefit is calculated using equation (5). In addition, CO2 emissions are also determined using modal share information and equation (6) and (9). The Model parameters are described in Appendix.

The three strategic targets, profit maximisation, net benefit maximisation, and CO2 emissions minimisation, can be formulated as optimisation problems over the vector of public transport vehicles $\mathbf{n}$ as follows.

$$\max_{\mathbf{n}} \sum_{m,k} \Pi_{m,k}(\mathbf{n}) \tag{11}$$

$$\max_{\mathbf{n}} \left\{ \sum_{m,k} \Pi_{m,k}(\mathbf{n}) - \sum_{i,j} Q_{ij} C_{ij}(\mathbf{n}) \right\} \tag{12}$$

$$\min_{\mathbf{n}} \sum_{m,k} CO2_{mk}(\mathbf{n}) \tag{13}$$

Here, the profit maximisation strategy would eventually lead to the abolition of unprofitable public transport routes. For the other two strategies, public transport service can be subsidised in order to achieve respective targets. In the latter case, the financial results of public transport operators will be negative, with the deficits being covered by government subsidies in this paper.

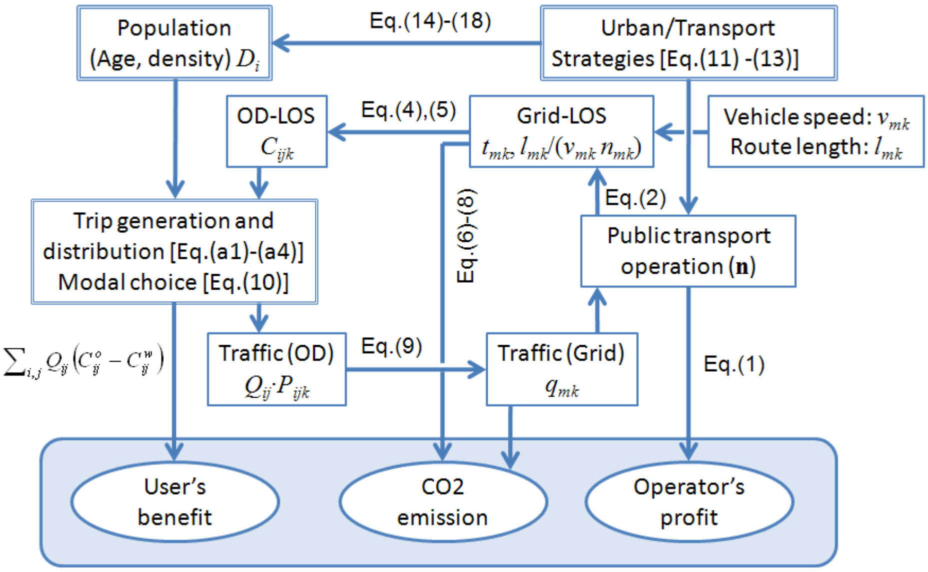

Figure 2. Stakeholder's behaviour and outcome indices

Population scenarios

We set two spatial patterns of population distribution, *'trend'* and *'compact'*, for each 269 cities in the year 2030. They are represented as grid based population datasets. Future population of municipalities are estimated by National Institute of Population and Social Security Research Japan, and the grid population is computed here so as to consistent with this data.

We denote the population of grid i in 2000 as D_i^{00}, city population as D^{00}, and that in 2030 as D^{30}. The grid population in 2000 is given by Statistical Bureau, Ministry of Internal Affairs and Communication, Japan. The grid population for 'trend' scenario in 2030, denoted by D_i^{30}, is calculated as follows.

$$D_i^{30} = D_i^{00} \cdot D^{30} / D^{00} \tag{14}$$

This equation assumes that the population distribution is just scale-down/up with the ratio of urban population of 2030 over 2000.

For ‘compact’ scenario, the grid population is set by using equation (14) if a city’s population increases. In case of decrease, it is set as follows.

$$D_i^{30} = \begin{cases} D_i^{00} & \text{where } i \in I_M \\ 0 & \text{where } i \in \bar{I}_M \end{cases} \tag{15}$$

Here, I_M is grid set of which the sum of the population is equal to D^{30}, where $D_j^{00}<D_i^{00}$ for $\forall i \in I_M$, and $\forall j \notin I_M$. $\bar{I}_M$ is complement of I_M.

When the population of the elderly is denoted by D_a^{30}, its population at grid i (denoted by D_{ai}^{30}) and that of the non-elderly (D_{ni}^{30}) are calculated using following equation.

$$D_{ai}^{30} = \left(\beta \cdot D_{ni}^{00} + D_{ai}^{00}\right) \cdot D_i^{30} / D_i^{00} \tag{16}$$

$$D_{ni}^{30} = D_{ni}^{00}(1-\beta) \cdot D_i^{30} / D_i^{00} \tag{17}$$

$$\beta = \frac{D_a^{30} - \sum D_{ai}^{00} \cdot D_i^{30} / D_i^{00}}{\sum D_{ni}^{00} \cdot D_i^{30} / D_i^{00}} \tag{18}$$

β is an adjustment factor to make the grid population consistent with city population. Figure 3 shows some examples of population distribution produced by this procedure. .

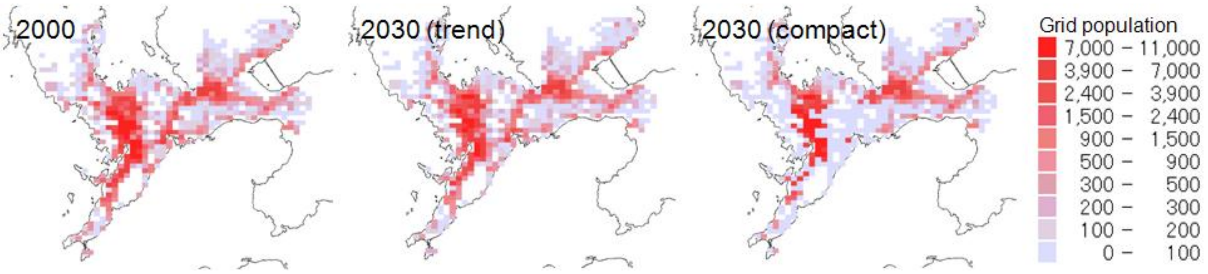

Figure 3. Spatial distribution scenario of population in 2030

CROSS-ASSESSMENT OF THE TRANSPORT STRATEGIES AND THE IMPACT OF URBAN STRUCTURE

National average of the impact

In this section, three outcome indices, financial balance of public transport operation, users’ benefits, and CO2 emissions, are compared under the three public transport strategies and two urban structural scenarios.

Figure 4 shows the CO2 emissions reduction in the year 2030 compared to the year 2000 for the cases of six scenarios and BAU (business as usual) in which the LOS of public transport in each grid is fixed to the year 2000. Here, NBM, PM, and CO2 mean the strategic target of net benefit maximisation, profit maximisation and CO2 minimisation respectively, and the net benefits are defined as sum of the profits of public transport operators and users' benefits. In this figure, even in the case of 'trend' urban structure and BAU public transport LOS, the CO2 emissions are reduced about five million ton due to the population decreasing and aging. In case of the 'compact' urban structure, the emissions are reduced more: around one million tons of CO2 emissions are reduced than the case of 'trend' urban structure for every strategy. Among the four transport strategies, CO2 minimisation naturally shows the largest reduction, but profit maximisation has also larger reduction than BAU. On the other hand, the reduction of NBM is almost same with BAU. It means the public transport LOS improvement does not necessarily contribute to the CO2 reduction in national average.

Figure 5 shows the financial balance of public transport. Here, the current value is the estimation for the year 2000. BAU indicates heavy deficit reflecting the transport demand decrease, and it is highly improved in PM. CO2 minimisation also reduce the deficit substantially, because the service is reduced at unprofitable region.

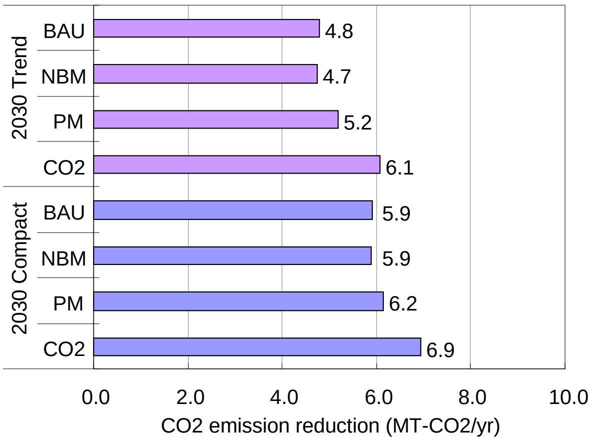

Figure 4. CO2 emissions reduction from year 2000

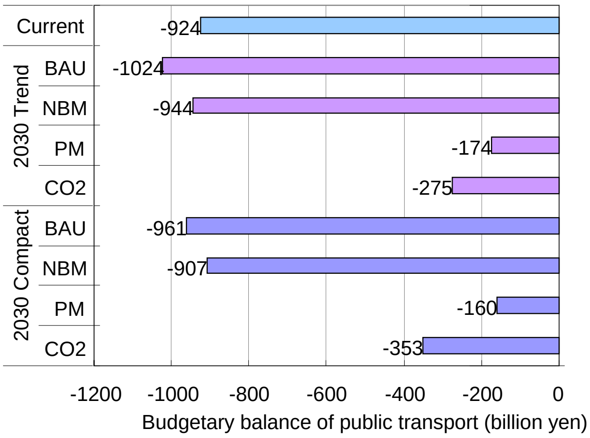

Figure 5. Financial balance of public transport

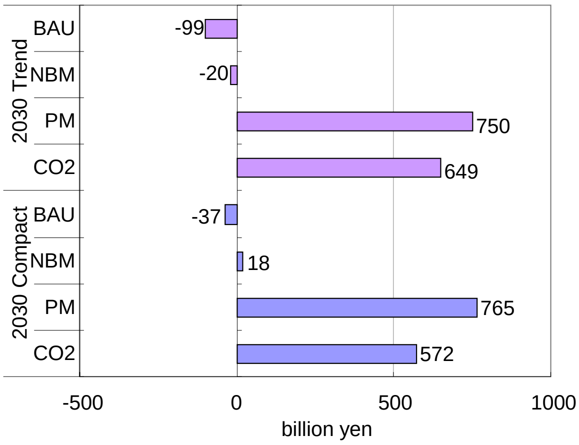

Figure 6. Change of operators' profits from 2000

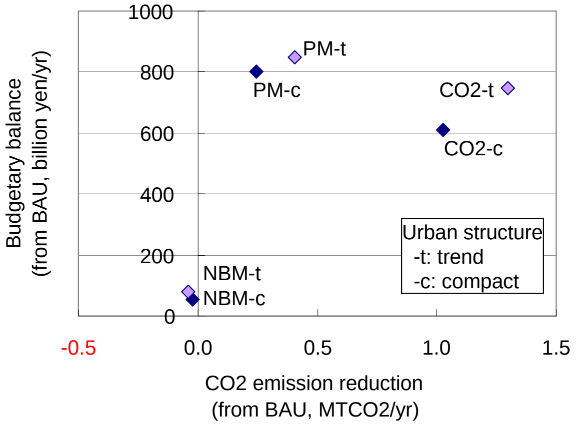

Figure 7. CO2 emissions reduction and change in financial balance of public transport

Figure 6 is the difference of the profits from that in the year 2000. It indicates that the PM as well as CO2 minimisation policy will largely improve financial balance compared to BAU and NBM. In addition, Figure 7 shows the position of each scenario regarding CO2 reduction and profits of public transport operators. Its vertical axis is the difference of profits and the horizontal axis is the difference of CO2 emissions from BAU.

Figure 8 shows the users' benefits of each case, which is defined as difference of generalised cost between the year 2000 and the target scenario[2], where the generalised cost is given by equation (5). For both urban structure scenarios, NBM gives high positive value and PM gives negative value. CO2 minimisation strategy gives higher benefits than BAU. It means that the LOS pattern to minimise CO2 emissions gives higher benefits than the current pattern, even the former emits less CO2 than latter. These results show that the 'compact' scenario brings lower user's benefits than the 'trend' scenario in national total. The position of each scenarios are shown in figure 9, where the horizontal axis is difference of CO2 emissions and vertical axis is the difference of benefits from BAU.

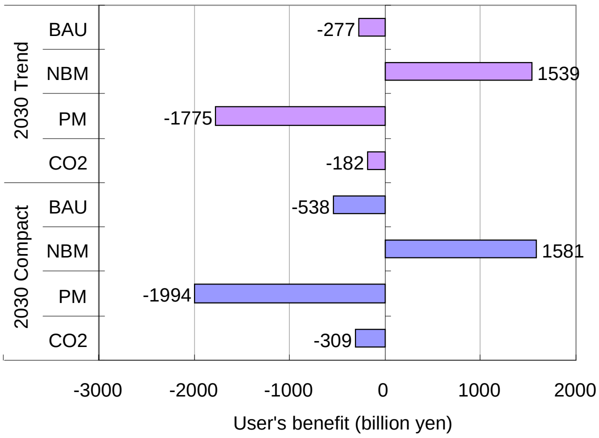

Figure 8. Users' benefits

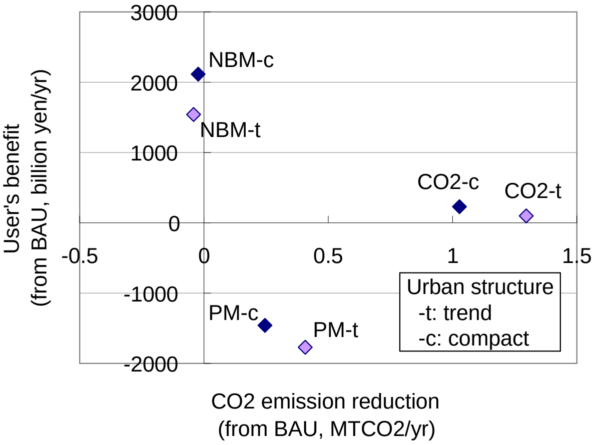

Figure 9. CO2 emissions reduction and benefits

The results above can be summarised as follows.

1. Profit maximisation strategy will reduce CO2 emissions but decrease users' benefits.
2. CO2 minimisation strategy can improve financial balance of public transport operation and give slight improvement of users' benefits.
3. Urban compaction will be effective for CO2 emissions reduction but possibly reduce users' benefits.

From the first and second results, the profit maximisation and CO2 minimisation strategy will have positive relationship regarding their objective. It can be interpreted that the complex strategy of profit maximisation and CO2 minimisation may give effective solution for CO2 reduction, with creating the common understanding among stakeholders that "the investment on environment improvement will promote the economic development" in the transport sector.

However, it should be noted that CO2 minimisation strategy is expected to increase users' benefits, but the PM will decrease them.

The third result is not seen in past studies. It is caused by the compiling method in this study; the national total is defined as sum of the results of all cities estimated separately. Therefore, the result summarised above may not be applicable for individual cities. In the next section, the results are compared among cities to discuss the regional conditions of CO2 reduction and benefit improvement as well as the difference of urban compaction impact.

Regional difference in outcomes

In this section, we examine the CO2 reduction and users' benefits of 269 urban areas taking the case of CO2 minimisation strategy and discuss the condition in which the city compaction is effective with regard to these indices. The examined urban areas, which are set based on Urban Employment Areas (Kanemoto and Tokuoka; 2002), are shown in figure 10.

Figure 11 and 12 show the regional pattern of CO2 emissions reduction and users' benefits respectively. Figure 13 shows the difference between 'trend' and 'compact' scenarios.

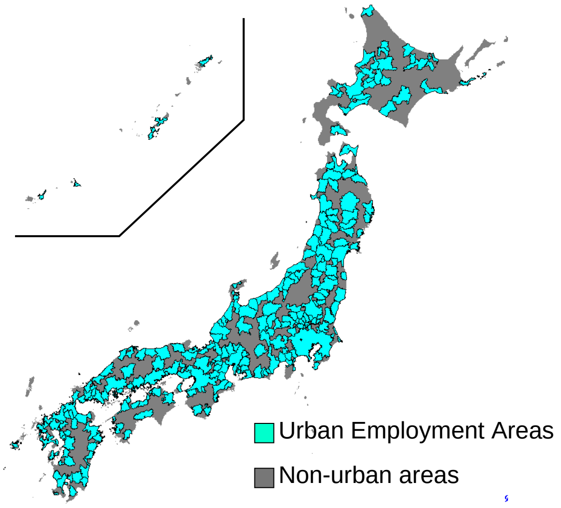

Figure 10. Urban Employment Areas

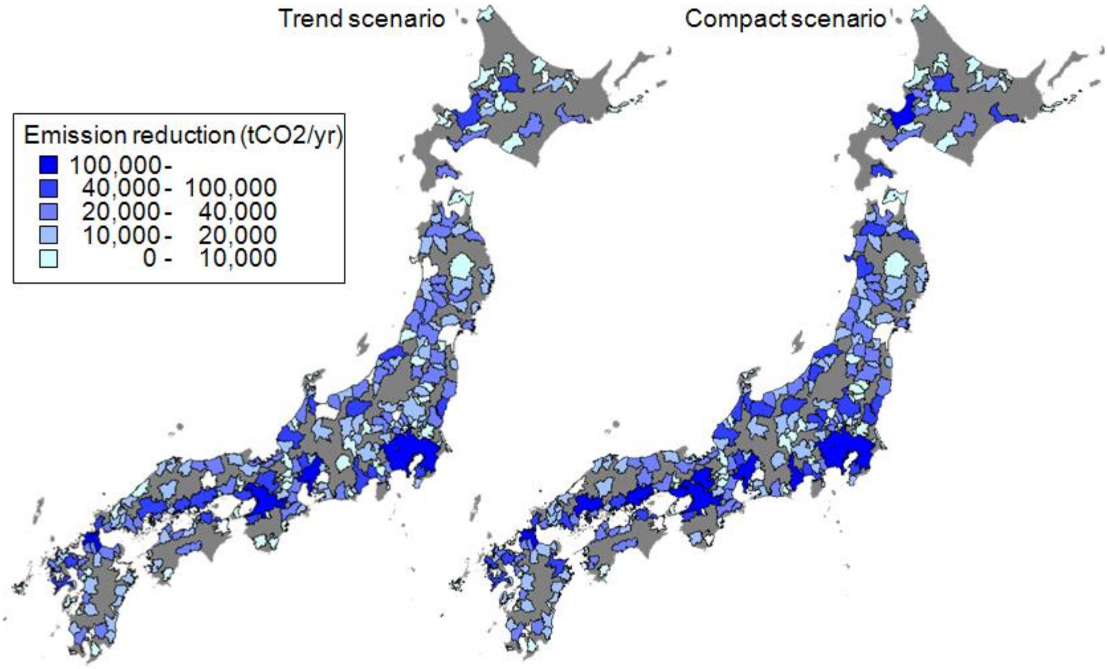

Figure 11. CO2 emissions reduction (left: trend, right: compact)

Figure 11 indicates that the CO2 emissions are reduced significantly in metropolitan regions for both 'trend' and 'compact' scenarios; however the impact of urban compaction somewhat differs among three metropolises. Specifically, urban compaction has a positive impact on CO2 reduction in Osaka and Nagoya, but a negative one in Tokyo(Figure 13, left). This difference is caused by the fact that population density in the Tokyo metropolitan region is higher than enough even in the 'trend' scenario, and therefore urban compaction would bring more traffic and CO2 emissions (see Appendix).

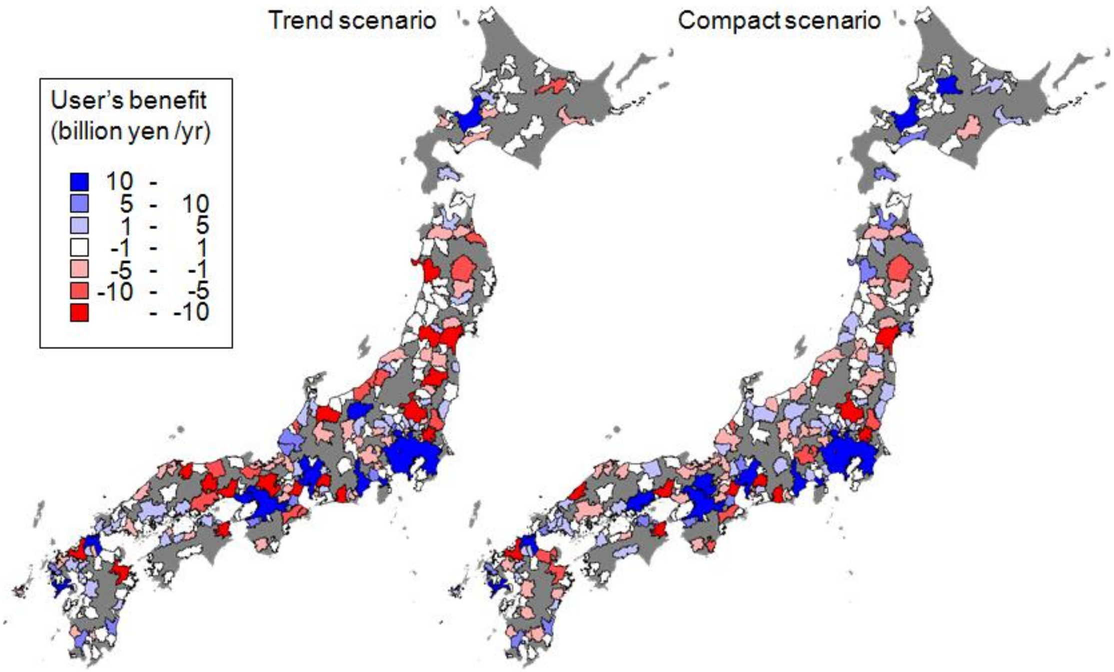

Figure 12. Users' benefits (left: trend, right: compact)

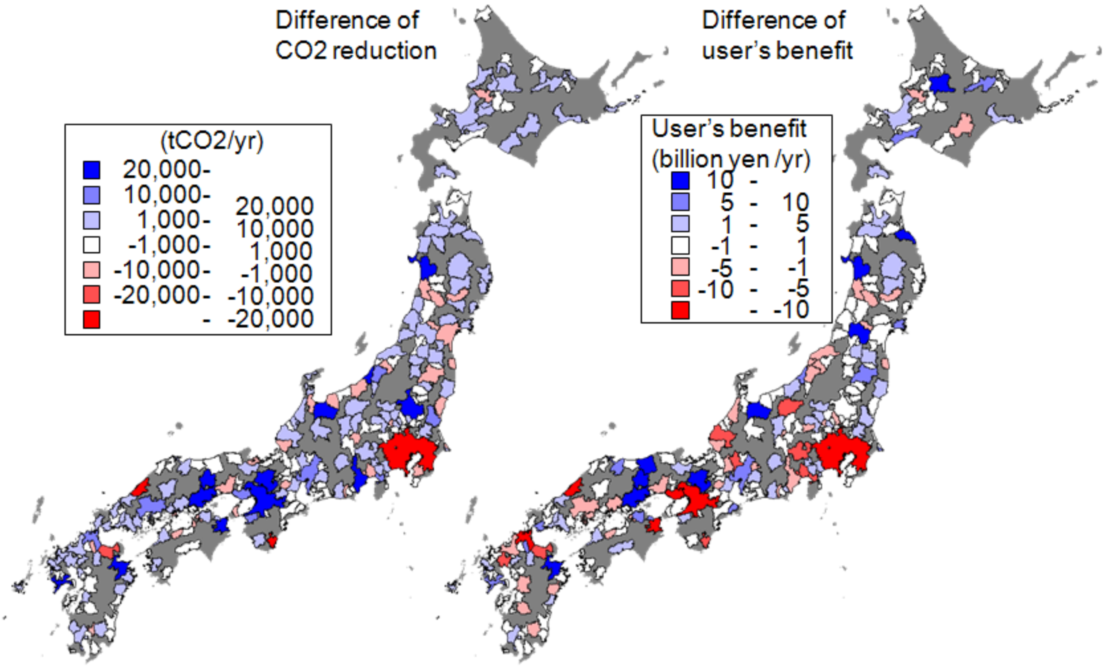

Figure 13. Difference between 'compact' and 'trend' (left: CO2, right: benefits)

The ‘compact’ scenario provides a higher CO2 reduction than the ‘trend’ scenario in most cities. It means that the urban compaction will be effective for CO2 reduction in many cities, except Tokyo and some regional cities.

Users’ benefits, shown in figure 12, is positive for both scenarios in the three largest metropolitan regions, Tokyo, Osaka, and Nagoya. Considering figure 11 and 12 together, both emissions reduction and users’ benefits will be achievable in these areas. However, many of regional cities loses its users’ benefits. This reflect the possibility of lower emission factor of private car than public transport in terms of passenger-km due to the travel demand decline concurrent with population decrease. The ‘compact’ scenario has fewer cities whose users’ benefits are negative and alleviates the negative range of benefits from ‘trend’ scenario.

Taking a closer look at the difference of urban scenarios in figure 13, there are 123 urban areas (45.7%) with a positive effect of urban compaction on both emissions reduction and benefits and 74 areas (27.5%) with a positive effect on CO2 emissions reduction but negative effect on benefits.

Among three metropolitan regions, Tokyo and Osaka has lower benefits but Nagoya has higher benefits in ‘compact’ scenario than ‘trend’ scenario. In the former two areas, the LOS of public transport is enough high and the elasticity of benefits with respect to the LOS would be low. In addition, the compaction would increase the volume of private car use at congested grids and the average travel time would increase. As a result, users’ benefits in ‘compact’ scenario are estimated lower than those in ‘trend’ scenario. On the other hand, in Nagoya, improvement of the public transport LOS is estimated to exceed the cost increases due to congestion.

Regarding the other regional cities, the total benefits of ‘compact’ scenario are higher than that of ‘trend’ scenario. It means that the lower benefits of ‘compact’ scenario in CO2 minimisation strategy for nationwide shown in figure 8 reflects the congestion cost in large metropolises like Tokyo and Osaka.

Altogether, the impact of urban compaction seems to differ depending on the urban situation. The impact on CO2 emissions reduction and users’ benefits in Tokyo area is both negative and, on the contrary, that in Nagoya is both positive. In Osaka, the impact on CO2 emissions reduction is positive and that on users’ benefits is negative. In most regional cities, it is indicated that the CO2 minimisation strategy declines users’ benefits, but the urban compaction alleviates the negative impact. Therefore, if the regional effective strategies are applied to each area, the nationwide total of CO2 emissions and users’ benefits are expected to be higher than those shown above.

It should be noted that the grid LOS of private car is fixed to 2000. Under this assumption, change of grid congestion caused by the compaction and population change is not considered. This simplification may have both positive and negative bias on the CO2 emissions and users' benefits in the evaluation of urban compaction impact. If the road congestion increases, the emission factor of private car will increase, on the other hand, the demand may shift to railway that would reduce the emissions. Accumulating the residential or business location along the public transport routes may increase the citywide LOS on average, and the users' benefits regarding travel can be increased. However, the compaction would enhance the scarcity of land and possibly reduce the benefits from housing. For more comprehensive assessment of CO2 emissions and users' benefits, integration with analyses of endogenous road congestion and land use economy can be effective.

in addition, if we consider the improvement of private car LOS by road construction or introduction of advanced ITS, the urban compaction may have chance to improve the users' benefits even in the large metropolises like Tokyo and Osaka.

CONCLUSION

In this study, we proposed a cross-assessment model as an analytical tool for vision-led and consensus-led decision making towards the sustainable urban transport strategy to meet the requirements of both low-carbon and aged society. It was applied to the impact analysis of public transport and urban structure strategies in 269 urban areas in Japan at year 2030, and the outcomes including financial balance of public transport operation, users' benefits, and CO2 emissions reduction are compared among the strategies and urban areas.

The results of national average outcomes indicated that 1) profit maximisation of public transport will reduce CO2 emissions, but may decline users' benefits, 2) CO2 minimisation policy will have positive effect on users' benefits as well as the emissions reduction, 3) urban compaction will reduce emissions but it may decline benefits. These results can be interpreted that both targets of the financial balance improvement of public transport and CO2 emissions reduction is achievable simultaneously. However, the users' benefits could be both positive and negative depending on the strategy, because the impact of transport strategies and urban compaction is different among the urban areas due to the regional conditions.

The comparative analysis among metropolitan regions derives following possible findings; 1) CO2 minimisation strategy is effective for the emissions reduction and benefit improvement at large cities, but the relationship of these two outcomes are trade-off at small cities, 2) urban compaction at small cities may alleviate the trade-off relations between the emissions reduction and the user's benefit improvement, 3) too dense compactness at large cities may increase the congestion, consequently increase CO2 emissions and decline the benefits.

Using the cross-assessment model, we found that the three value factors do not necessarily conflict with each other. In particular, it was shown that the CO2 emissions reduction target can contribute to the improvement of financial balance and users' benefits in national total. In addition, the results of comparative analysis among urban areas implies that the urban-transport strategies considering each regional conditions is expected to bring higher emissions reduction and benefits.

As limitations of this study, the endogenous variable in this model is only limited to the frequency of public transport in each grid, and the other factors such as transport fare, infrastructures, location patterns, and road speed are given exogenously. In addition, various simplified assumptions are used in the estimation including trip distribution and the emission factors. It should be noted that modifications of the presumptions and the model structure possibly derive different result from this study.

NOTE

[1] The cross-assessment in this study aims to explore synergistic solutions combining different value systems by assessing the impact of measures pursuing each value factor on all outcome factors (figure 14). We assume every transport strategy is achievable by government policy measures, but it does not represent the value system of the government. Decision is usually made based on the consensus among stakeholders whose value systems are different from each other. Each of the three strategies in this study is based on a particular value factor, and the impacts on all of the outcomes are evaluated.

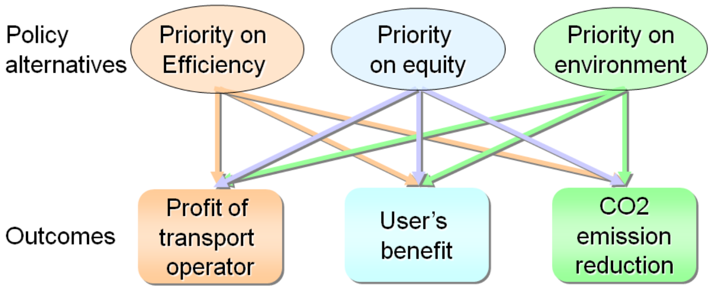

Figure 14. Concept of cross-assessment in this study

[2] In BAU scenario, the grid pattern of public transport LOS is same as the year 2000, but the location of activities is different. Therefore, the total generalised cost in 2030 is different from year 2000 even in the BAU case.

APPENDIX

Settings of model parameters

Combined model of trip generation and distribution

Home-based travel demand between i and j is denoted by Q_{ij}^{H}, and it is defined as the following function:

$$Q_{ij}^{H} = \begin{cases} \delta \cdot D_i^N \cdot g\left(D_i^N\right) & \text{if } \sqrt{D_j^D} \cdot f\left(L_{ij}\right) \geq \max\limits_{j'}\left(\sqrt{D_{j'}^D} \cdot f\left(L_{ij'}\right)\right) \\ 0 & \text{else} \end{cases} \tag{a1}$$

Here, δ is trip generation per person (2.46 for non-elderly and 1.71 for elderly), D_i^N is night time population at origin, D_j^D is daytime population at destination, f is distance decay factor, g is share of motorised transport (sum of public transport and private car), L_{ij} is distance. With this expression, we assume an origin zone takes only one destination depending on the day-time population in destination zone and distance from there. This simplification greatly reduces the calculation load with keeping the trip concentration pattern to certain zones like CBD.

Using the home based travel demand, the dairy travel demand is expressed as follows.

$$Q_{ij}=Q_{ij}^{H}+Q_{ji}^{H} \tag{a1}$$

The distance decay factor is estimated for elderly and non-elderly people based on the person trip survey for the Tokyo metropolitan region in 1998. Two functions are assumed considering the fitting to the data; quartic for the trip less than or equal to 10km, and exponential for the trip more than 10km. The automobile dependence is modelled as a function of night time population based on national person trip survey. They are formulated as follows and the estimated parameters are shown in Table 1.

Distance decay function:

$$f\left(L_{ij}\right)=\sum_{p=0}^{4}\gamma_p \cdot L_{ij}^{\,p} \quad \text{(10 km or less)} \tag{a2}$$

$$f\left(L_{ij}\right)=\exp\left(\gamma_0+\gamma_1 \cdot L_{ij}\right) \quad \text{(more than 10km)} \tag{a3}$$

For parameter estimation, value of f is set as: $Q_{ij} \Big/ \sqrt{D_i^N \cdot D_j^D}$

Automobile dependence function :

$$g\left(D_i^N\right)=1-\left\{\eta_0 \cdot \ln\left(D_i^N+\eta_1\right)+\eta_2\right\} \tag{a4}$$

Table 1. Parameters of distance decay function and automobile dependence function

	Distance decay			
	Non-elderly		Elderly	
	≤ 10km	>10km	≤ 10km	>10km
γ_0	0.23	-2.28	0.11	-2.97
γ_1	□0.23	-0.05	0.14	-0.12
γ_2	0.05		-0.042	
γ_3	0.007		0.005	
γ_4	-0.0004		-0.0002	
R^2	0.98	0.94	0.99	0.80

	Motorised share	
	Non-elderly	Elderly
η_0	0.05	0.02
η_1	1.00	0.04
η_2	0.30	0.49
R^2	0.49	0.11

It should be noted that the parameters of distance decay function and automobile dependence function are estimated using the data averaged by distance zone and population density class respectively. Due to data limitations, the distance decay parameter r estimated in Tokyo is applied to all urban areas. Reflecting the results of the National Person Trip Survey which shows that the travel time in large cities is longer than that in small cities, this model would possibly overestimate travel length.

Modal choice model

The modal choice at each origin grid is defined by equation (10). The parameters are estimated to minimise the difference between aggregated estimation over the urban area and the data of the national person trip survey. In the estimation, we set the time value is 40 yen / minute, fares of train and bus are 18 yen /km and 31 yen / km respectively, variable cost for private car is 10.5 yen /km, its fix cost is 400 yen /trip, and the parking cost is defined as a function of population density based on consumers price statistics.

Using the choice probability of each OD trip, the share of transport mode k in urban area M is formulated as follows.

$$\Pr_{Mk} = \sum\nolimits_{i\in I_M} Q_i^O \cdot P_{ijk} \Big/ \sum\nolimits_{i\in I_M} Q_i^O \qquad \text{(a5)}$$

Here, I_M is the set of grid codes which is comprised in urban area M, Q_i^O is travel demand generated at grid i. The model parameters are estimated to minimise the difference between this estimated share and the data of modal share R_{Mk} from person trip survey.

$$\min_{\boldsymbol{\theta}} \left\{ \sum\nolimits_{M,k} \mu_M \left(\Pr_{Mk}(\boldsymbol{\theta}) - R_{Mk}\right)^2 \right\} \qquad \text{(a6)}$$

Here, μ_M is the weight considering population scale and it is defined as $\Sigma_M \; \mu_M = N$ (N is number of urban area). The estimated parameters and its t-values are shown in Table 2. The correlation between the statistics and estimations are shown in Figure 15.

Table 2. Estimated parameters of modal choice model

		Parameters	t-value
Non-elderly	Generalised cost	-1.01	-21.4
	Bus dummy	-1.64	-46.5
	Private car dummy	0.98	23.8
Elderly	Generalised cost	-0.86	-26.8
	Bus dummy	-0.19	-4.3
	Private car dummy	1.16	25.9

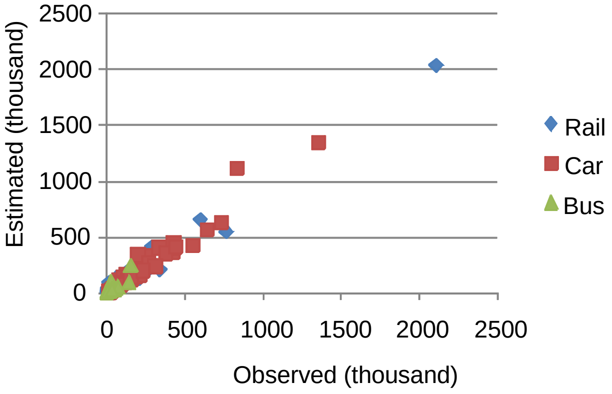

Figure 15. Data and estimation of travel demand by modes

Cost for transport service provision

Both operation cost and the LOS is assumed as functions of number of vehicles in operation. For train service, if a total number of operation days is denoted by Y, then annual operated vehicle distance L_{Am}, operational cost C_{Om}, vehicle maintenance cost C_{Mm}, and labor cost C_{Wm} can be defined as follows.

$$L_{Am} = Y \cdot H \cdot v_m \cdot n_m \tag{a7}$$

$$C_{Om} = \zeta_{O0} + \zeta_{O1} \cdot L_{Am} \tag{a8}$$

$$C_{Mm} = \zeta_{V1} \cdot \mu \cdot n_m \tag{a9}$$

$$C_{Wm} = \zeta_{W1} \cdot L_{Am} \tag{a10}$$

Here, μ is number of vehicles for a train. The capital cost for infrastructure C_{Im} and vehicles C_{Vm} are estimated as follows based on the interest rate r, unit cost of infrastructure construction c_I, that of vehicles c_V, and their useful life T_I, T_V.

$$C_{Im} = c_I \cdot l_m \cdot \frac{r \cdot (1+r)^{T_I}}{(1+r)^{T_I} - 1} \tag{a11}$$

$$C_{Vm} = c_V \cdot \mu \cdot n_m \cdot \frac{r \cdot (1+r)^{T_V}}{(1+r)^{T_V} - 1} \tag{a12}$$

In brief, the annual cost of train operation is sum of C_{Om}, C_{Mm}, C_{Wm}, C_{Im}, C_{Vm}, and it can be simplified as follows.

$$C_{Rm} = \alpha_{R0} + \alpha_{R1} \cdot n_m + \alpha_{R2} \cdot l_m \tag{a13}$$

Here, based on Ishida et.al. (1999), we set ζ_{O0}=3000, $\zeta_{O1}=1.26 \times 10^{-4}$, $\zeta_{V1}=3.10 \times 10^{-3}$, ζ_{W1}=0.192, $c_I=14.5 \times 10^3$, c_V=150, r=0.054, T_I=42.7, and T_V=13. The cost terms are expressed as million yen. Additionally, daily operation hour H is 18 hours, operation days D is 365, vehicle speed for train v_m is 35km/h. Then the parameters in equation (a13) are expressed as follows.

$\alpha_{R0}=\zeta_{O0}=3000$

$\alpha_{R1}=(\zeta_{O1}+\zeta_{W1}) \cdot D \cdot H \cdot v_m + (\zeta_{V1} + c_V \cdot R_V) \cdot \mu = 44.2 \times 10^3 + 16.4 \cdot \mu$

$\alpha_{R2}=c_I \cdot R_I = 876$

Here, the annual depreciation rates for infrastructure and vehicles are R_I and R_V respectively. Number of vehicles for a train μ is assumed to be 5.8, and the rail length at the grid where the rail service is operated is set to one km. The operation cost of bus service is set to 373.8 yen / km based on the data of private bus company.

For the private car, the waiting time in equation (4) is set to zero, and the travel time at a mesh is defined as $t_{mk}=l_m/v_m$ (l_m: route length of a grid, v_m: travel speed). Here, l_m is one km for all grids, and v_m is set for each grid based on road traffic census. Note that the speed is fixed and does not depend on the change of the traffic in this study.

CO2 emission factor

We set the emission factor of each transport mode based on the transport energy and and operation statistics. Here, the energy source of trains depends mainly on electricity and diesel fuel accounts for quite a small share, therefore, their CO2 emissions during operation is very small. Though, CO2 is emitted at the stage of electricity generation which should be counted to compare the efficiency among the transport modes. In this study, the CO2 emissions are accounted on a *well to wheel* base; it includes the emissions from the operation of transport as well as the production of energy source. The emission factors are summarised in Table3.

Table 3. Energy efficiencies and CO2 emission factors

Transport mode	Energy efficiency	TTW emission factor	WTT emission factor	WTW emission factor
	MJ/km	kg-CO_2/km	kg-CO_2/km	kg-CO_2/km
Train	10.10	0.082	1.389	1.471
Bus	12.33	0.891	0.073	0.965
Private car	3.35	0.237	0.037	0.274

This table indicates that the private car is the most energy efficient in terms of vehicle-km. The occupancy ratio of private car is 1.37 in 1999, and it is converted to the emissions as 0.2kg-CO2/passenger-km. Therefore, if the average occupancy ratio is less than 5.4 for bus and 7.4 for train vehicle, then their emissions are larger than that of private cars.

Regional impact of compact city scenario

As shown in the left of Figure 13, the ‘compact’ scenario gives larger CO2 emissions than ‘trend’ scenario in the Tokyo metropolitan region under CO2 minimisation strategy. Figure 16 shows the difference in road traffic and CO2 emissions between ‘compact’ scenario and ‘trend’ scenario. In this figure, both traffic and emissions in Tokyo are larger in the ‘compact’ scenario. In Osaka and Nagoya, the traffic is larger but CO2 emissions are less. This result indicates that, in the latter two areas, the compaction induces longer travel but promotes modal shift reducing emissions. On the other hand, in Tokyo, it implies that the modal shift is not enough promoted to reduce the emissions. Regarding the average of the other regional cities, ‘compact’ scenario produces less traffic and CO2 emissions than ‘trend’ scenario.

In this study, the population is set to decline proportionally over the space in ‘trend’ scenario, contrarily the population decreases from the lowest population grid in ‘compact’ scenario. As shown in the equation (a1), the attractiveness as destination is defined as proportional to the square root of daytime population. With these settings, some grids lose its relative attractiveness under the ‘trend’ scenario, and consequently the number of destination will be reduced and the traffic will probably concentrate to fewer destination grids. On the other hand, under the ‘compact’ scenario, the high population grids keep their attractiveness. As a result, the ‘compact’ scenario possibly has more traffic on the private car preferred OD than the ‘trend’ scenario has.

To sum it up, the traffic volume, modal share, and CO2 emissions depend on the spatial pattern of attractive destination grid and population at origin grid. In case of Tokyo area, the ‘compact’ scenario brings more traffic and CO2 emissions than the ‘trend’ scenario in this analysis. It suggests that, in ‘compact’ city policy, we have to consider not only reduction of urban area but also the realignment of urban structure including location pattern of business district.

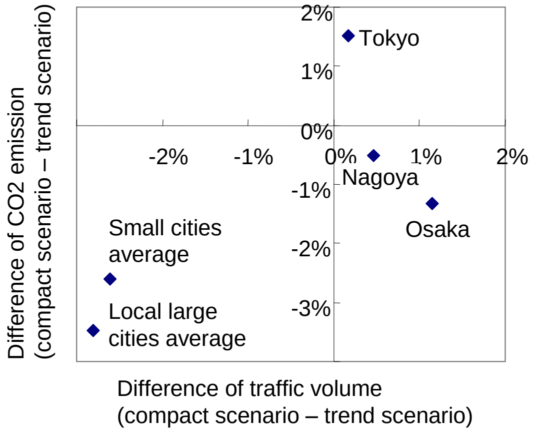

Figure 16. Difference of traffic volume and CO2 emissions between ‘compact’ and ‘trend’ scenarios

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