AN INTRODUCTION TO URBAN SUSTAINABILITY EVALUATION SYSTEM "SURQUAS"

(SMART URBAN AREA RELOCATION MODEL FOR SUSTAINABLE QUALITY STOCK)

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ABSTRACT

In many developed cities, inevitable problems that affect urban sustainability have emerged, such as population aging and population decline, growing budget deficit in public finance, impact of global climate change, and others. Areas of urban sprawl, which have been expanded according to motorization and population growth, pose large infrastructure maintenance cost and environmental load, and such structures do not suit the lifestyle of elderly people. It is therefore necessary to examine urban sustainability in terms of global environmental issues, built-up area maintenance cost and residential quality of life, considering the change in population and its generational constitution.

We introduce the model system "SURQUAS" (Smart Urban area Relocation model for sustainable QUAlity Stock) for evaluating the sustainability of an urban area from the viewpoint of the triple bottom line (TBL) consisting of environmental, economic, and social aspects.

By applying SURQUAS to the Nagoya metropolitan area, the following results are shown. Both Environmental efficiency and Cost efficiency are high in the central portion of the Nagoya central area and the city surroundings. Moreover, they are also high in the areas along the railroad lines. This suggests that shrinking to the central area is one possible efficient urban structure considering TBL.

And, the scenario that will be achieved by 2050 due to the urban spatial structure reconfiguration was set, and influence on TBL was analyzed. The results indicate that, in both the mono-centric and poly-centric patterns, the reduction of CO_2 emission and built-up area maintenance cost was achievable. However, QOL declined in the mono-centric pattern, though the rate of reduction in urban maintenance cost was large. In contrast, all of the TBL were improved in the poly-centric pattern.

Keywords: QOL, environmental load, infrastructure maintenance cost, land use, TBL

1. BACKGROUND AND OBJECTIVE

Urban spatial structure is one of the most basic factors to regulate the daily economic and social activities of society. Therefore, strategies to configure this structure have a long-term impact from human activity to global environment and economic productivity.

As a result of declining population, increasing aging population and maturing economy, the existing built-up area in Japan will surpass the needs of the society in this century. Therefore, an expansion strategy that depends on motorization will not be suitable. However, many Japanese cities, after the period of rapid economic growth, have already expanded to urban sprawl backed by population growth and development of motorization.

It is thought that, in such a kind of sprawling city, there is much GHG emission due to vehicle travel demands and infrastructure maintenance/renewal activities, because large amounts of built-up area and infrastructure such as roads and water and sewerage systems are required compared with population. Therefore, urban structure reconfiguration is necessary for environmental load reduction, looking from a long-term perspective. On the other hand, it is also necessary to adapt the urban structure configuration to accommodate changes in global warming, such as increase in the strength of rainfall.

Based on such recognition, it is necessary to switch to a city management policy that includes the "Smart Shrink" strategy. This is a concept for forming a compact space that raises "land productivity" defined by the QOL indicator which is evaluated by citizen's sense, while coping with limitations from a global environment aspect under conditions of population decline.

Yet, quantitative analysis of "Compact City" that has recently attracted much attention for achieving low environmental load and high QOL is not enough by itself. So, we cannot conclude that the compact city is the only strategy that brings sustainability. First, it is necessary to demonstrate that the compact urban structure reduces GHG emission from the many activities in the urban area. In addition, it is also necessary to take into account the GHG emission from the disposal of existing buildings and from the construction of new buildings/infrastructure. As a matter of course, it will be necessary to examine cost-efficiency in comparison with the other policies, as great expense and labor will be required for these

urban spatial structure changes. Therefore, it is necessary to examine the policy on how to lead to the compact city and to figure out clearly the urban structure that we aim to have.
In the context of response to global warming problems, this research is aimed at developing a model system that can conduct multi-faceted verification of strategies for addressing problems such as dwindling population, declining birth rate, aging society and deteriorating social capital, while identifying and formulating urban spatial structure for sustainable provision of high QOL. The research also aims at verifying the effectiveness of applying such a model system to actual cities.

2. POSITIONING OF THIS STUDY

(1) About Urban Sustainability

There is an approach that measures concretely the sustainability of a city based on the TBL (Triple Bottom Line). The TBL evaluates human activity based on economics, society and environment. Basically, this approach was defined as the concept of CSR (Corporative Social Responsibility). Recently, it has been used as an indicator of sustainability in the EU and has attracted attention with an evaluation frame beyond CSR. In fact, the SUNCSD (Secretariat of the United Nations Commission on Sustainable Development) has reported many researches concerning sustainability based on TBL.
This study also discusses the sustainability of a city from this viewpoint: economic refers to the municipality's economic situation, environment is the loading from urban activity, and society is the QOL level and social disparity.

(2) Achievements of past studies and positioning of this research

Past studies have evaluated urban spatial structure from a viewpoint of sustainability, though they were conducted from a single perspective such as environment or finance[5)]. Verification of sustainability from a comprehensive viewpoint has not been sufficient. While Kim et. al.[4)-7)] sorted out indicators from the viewpoint of TBL, they used macro data of each city, and could not present a method for detailed analysis of urban spatial structure.
Even if a specified type of urban spatial structure, such as "Compact City", has been confirmed to be an efficient structure in terms of urban area maintenance cost with little GHG emission, urban reorganization for realizing such a city requires huge cost and GHG emission, through disposal of existing buildings and construction of new buildings and infrastructure. This point must also be considered in our research. In our preceding report[3)], a model system was established for estimating GHG emission in urban areas, using the method of Life Cycle Assessment (LCA). This system was aimed at quantitative and comprehensive estimation of GHG emission changes due to urban spatial structure,

pertaining to the construction, maintenance and management, operation, renewal and disposal of buildings and infrastructure in urban areas, and other activities conducted therein. In this research, we further aim at a model system that can analyze sustainable urban spatial structure from the TBL viewpoint, through incorporating methods for sustainability evaluation of the social and economic aspects of urban areas. We also attempt examination of a sustainable urban spatial structure, through applying such a model system to an actual city.

3. MODEL STRUCTURE OF SURQUAS

(1) Total Structure

Aiming to evaluate urban spatial structure from the triple bottom line (TBL) perspective, we construct the SURQUAS system which can forecast Environmental Load (EL), built-up area maintenance Cost (Cost) and Quality of Life indicator (QOL) at a high resolution level, and examine how urban configuration affects TBL.
The whole structure of a model system is shown in Figure 1. The cohort method is applied for predicting future population, housing, and infrastructure stock. We applied 4th mesh (about 0.263 km^2: 500 m * 500 m) as the resolution level. We could then analyze the relationship between urban spatial structure and environmental load, infrastructure maintenance cost and QOL indicator at a micro resolution level. The target period for this study is from 2005 to 2050, and we run the simulation once in every 5 years.
In this study, EL refers to the CO_2 emissions that affect the global environment. Local environmental loads such as traffic noise and air pollution shall be evaluated as a component of QOL.

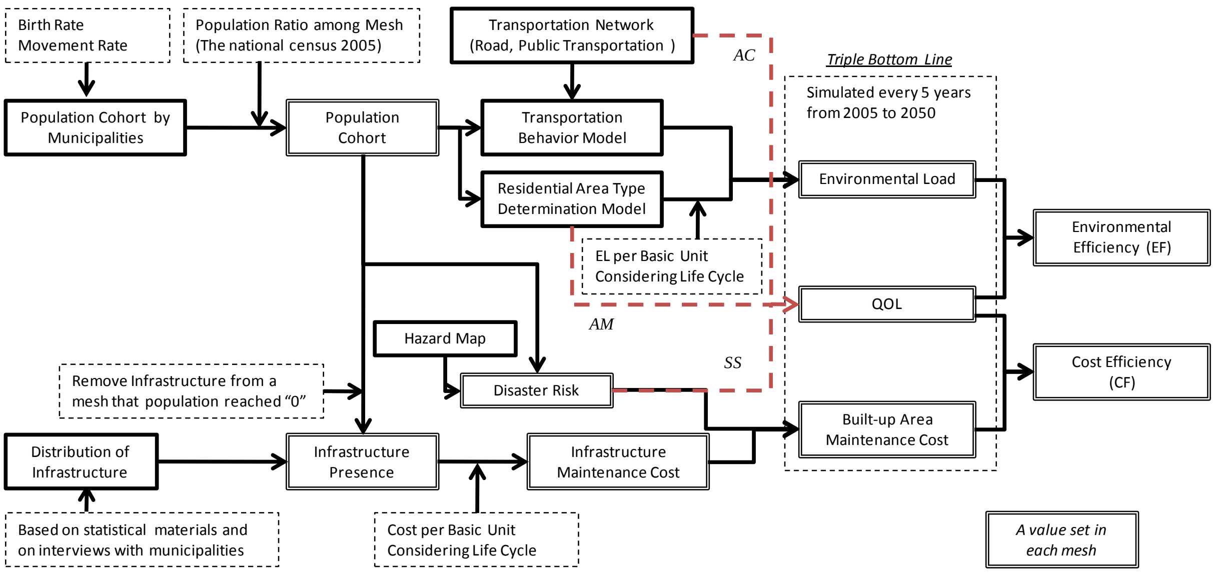

Figure 1 – Structure of SURQUAS

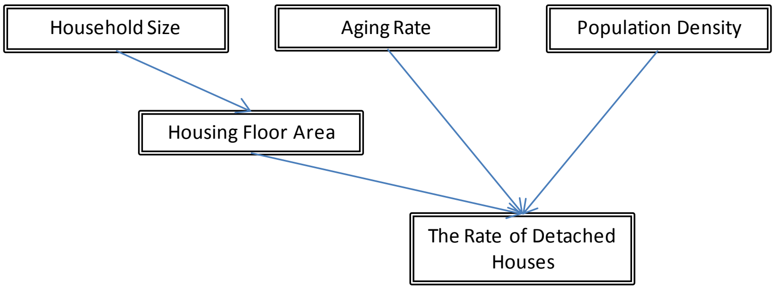

Figure 2 –Structure of Residential Area Type Determination Model

Table 1 –Estimation Target

Classifications	Facilities	Remarks	Life Time
Building (Housing)	Detached House	Wooden structure	56 years
	Apartments	RC structure	45 years
Transportation Faciliteis	Road	Asphalt pavement	10 years
Supply and Management Facilities	Sewage pipe		35 years
	Water pipe		35 years
Park	City planning Park		30 years
Transportation Activities	-	Passenger Transportation	-

Table 2 –Components of QOL

Component	Detail of Component	Indicator
AC : Accessibility	Employment	AC for Place of Work
	Education & Culture	AC for High-school
	Health & Medical	AC for Hospital
	Shopping & Service	AC for Retail
AM : Amenity	Living Space	Gross Floor Area for Living
	Town Scape	Number of Building Story
	Local Environmental Load	Green Space
	Neighborhood Natural Environment	Equivalent Sound Level
SS : Safety & Security	Earthquakes Risk	Loss of Life Expectancy Caused by Earthquake
	Flood Risk	Flood Depth Caused by Flood
	Risk of Crimes	Annual Number of Crimes
	Road Accident Risk	Number of Traffic Accidents

Table 3 –Estimation Results of Model Split Model

	Commuting		Private	
Constant	-1.43	(-44.7)	-1.51	(-30.1)
$\ln(AC_{\text{Public Transportation}})$	-5.50×10^{-1}	(-77.8)	-5.78×10^{-1}	(-63.5)
Population Density [Capita/ha]	-2.17×10^{-3}	(-18.6)	-3.41×10^{-3}	(-20.4)
Aging rate	-7.50×10^{-1}	(-8.36)	-1.75	(-14.4)
Ajs.R^2	0.711		0.651	
samples	4248		4248	

(t value)

Table 4 – Estimation Results of Residential Area Type Determination Model

	Housing Floor Area		The rate of detached houses	
Constant	3.27×10^{1}	(20.9)	-4.32	(-27.5)
Population Density [Capita/ha]	-1.89×10^{-1}	(-37.3)	-4.62×10^{-3}	(-8.72)
Aging rate	5.68×10^{1}	(15.4)	2.38	(8.40)
Household Size[Capita/Household]	2.41×10^{1}	(53.8)		
Housing Floor Area [m^2]			5.06×10^{-2}	(36.8)
Ajs. R^2	0.652		0.578	
samples	3718		3718	

(t value)

(2) Estimation method for CO_2 emissions

In this research, evaluation is conducted at the planning and conceptual stages including the urban spatial structure reorganization policy. In such evaluation, it is impossible to identify precise resource inputs etc. that are necessary for estimating environmental impact of huge buildings and infrastructure and of various activities in urban areas. Therefore, we assume a standard design for respective buildings and infrastructure, and estimate the environmental impact, construction cost and maintenance cost resulting from construction, maintenance and management, operation, renewal and disposal activities, per unit of such buildings and infrastructure (e.g. total housing floor area) ("basic unit"). Total environmental impact generation is estimated through summing up the multiplications of such basic units by quantities of activities in respective life cycle stages of buildings (e.g. renewal of housing etc.), which are tabulated on a mesh-by-mesh basis.

CO_2 emissions through passenger transportation activities are organized per basic unit per person per year, based on the results of Census 2000 and Chukyo Urban Area Personal Trip Survey in 2001. In this process, a trip-end type of logit model is used for estimating modal split, in order to measure the CO_2 reduction effect of modal shift. This model uses accessibility indicator as an explanatory variable. Accessibility indicator is one of the QOL components. Parameter estimation results assuming a linear model are indicated in Table 3.

(3) Estimation method for urban area maintenance cost

Urban area maintenance cost is estimated from infrastructure maintenance cost and expected damage amount in case of disaster (limited to flood at this point).

Infrastructure maintenance cost is estimated through setting infrastructure presence in each mesh, based on statistical materials and on interviews with municipalities, and multiplying these figures by cost per basic unit considering life cycles. Because this research is only targeted at life infrastructure, it is assumed that all infrastructures will be removed from a mesh whose population reached "0" due to population decrease or withdrawal policy.

Expected damage amount from flooding is given by multiplying flood damage amounts, which are the multiplications of assets and damage rates by flood depth, by the probabilities of flooding of differing scales. This refers to the Draft Flood Control Economics Research Manual[7)], formulated by the Ministry of Land, Infrastructure and Transport. This method enables the incorporation of rise in disaster risks due to escalating rainfall intensity, linked with climate change, into urban area evaluation.

(4) Estimation method for QOL indicator

QOL indicator is quantified as a weighted sum of items in Table 2. For weighting parameters, results of estimation by generation and by sex through conjoint analysis are used, based on a questionnaire survey on the selection of residential area[2)].

(5) Residential area type determination model

A mechanism model is developed on how area characteristics within each mesh (e.g. population density, aging rate) affect the formation of the residential area. This is to forecast what type of residential area will be formed in the future, in line with population decrease and aging. Here, the rate of houses in all residence types, and housing floor area, are included in the scope of estimation; the rate of houses is the most basic element in the residential area.

The rate of houses and housing floor area are considered to be determined in correlation. A correlative structure is therefore assumed, as indicated in Figure 2. Estimation of parameters is indicated in Table 4, based on respective assumed linear models and Census 2005 data.

4. RESULT AND DISCUSSION

In this study, by applying SURQUAS to the Nagoya metropolitan area, we estimate the environmental load, QOL and maintenance cost in great detail to discuss a sustainable urban configuration.

(1) Case Study Area

As shown in Figure 3, in this research, the Nagoya metropolitan area was defined as municipalities within a 20 km radius from the center of Nagoya city (the number of municipalities was 31 as of February 2010).

Figure 4 shows an estimate of the future population in the Nagoya metropolitan area; this number was estimated by the cohort model. It is expected that population would decrease from 4.62 million in 2005 to 3.68 million in 2050 and population aging rate would increase from 18% in 2005 to 39% in 2050.

As for spatial distribution of population change in 2050 compared to 2005, population would decrease across the whole region; however, population growth exists in eastern areas of Nagoya city such as Nisshin city, Nagakute town, and in neighbouring Nagoya city such as Toyoyama town and Jimokuji town. Population decrease is symmetrically pronounced in the western area of Nagoya city and in inner Nagoya city. In these areas, the present aging rate and low social increase in population lead to those results. As described above, each municipality has its own characteristics; therefore, an appropriate policy is demanded for each district.

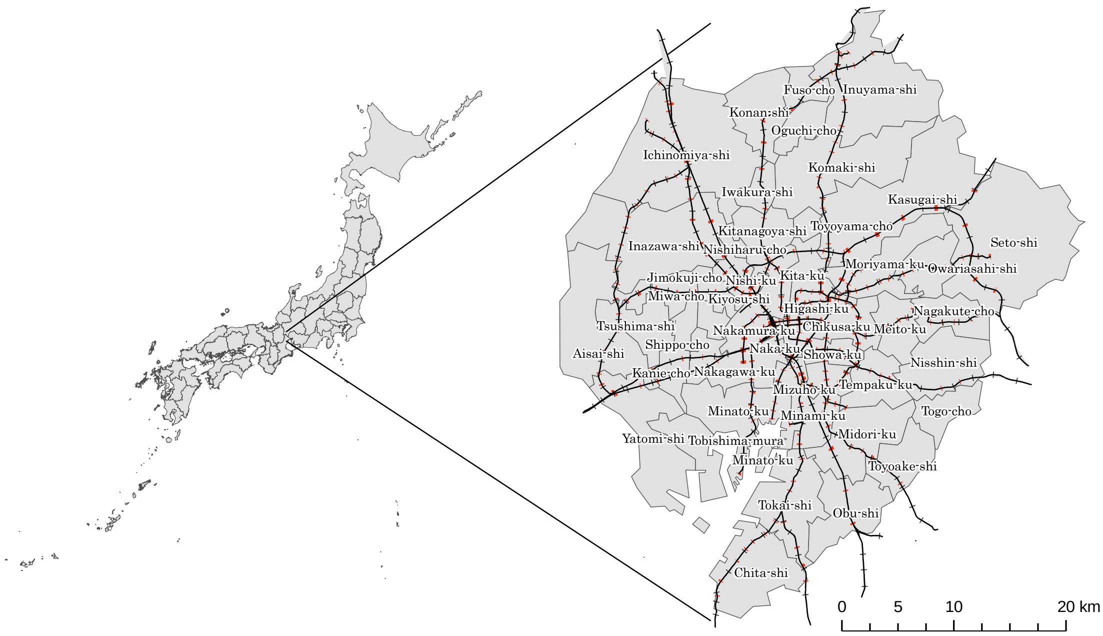

Figure 3 – Case Study Area

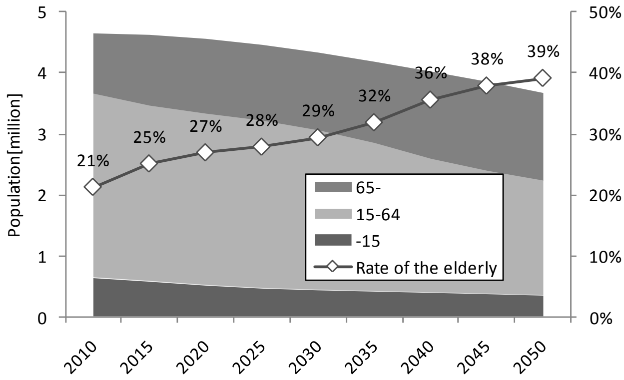

Figure 4 – Population Forecast for the Nagoya Metropolitan Area

(2) Spatial distribution of TBL in 2050

Figures 5, 6 and 7 show the per capita environmental load, infrastructure maintenance cost and QOL in 2050, when the population ratio between the meshes in the municipal district town and village are set to change like the current state.

Per capita CO_2 emission

Per capita CO_2 emission is high in both the center of the city and the suburbs, and in a low level zone spread in the middle like a doughnut. Also, it is low along the railroad line. The reason why CO_2 emission is high in the suburbs is high car availability and commodious housing. The reason why per capita CO_2 emission per resident population is high in the center of the city is the high proportion of RC block housing that has high CO_2 emission in the construction phase. The trend is especially remarkable in the high-end residential zone in Nagoya city.

Per capita built-up area maintenance cost

This cost is low in Nagoya city but high in the suburbs and new town areas. Especially, there are a lot of high-cost districts in the west of the metropolitan area, because the expectation of damage cost due to flood risk is very high in these areas. This trend increases every year, because rainfall intensity is strengthening due to climate change. Per capita cost of built-up area maintenance is also high in the central portion of Nagoya city, because this area is commercial and there is little night life.

QOL

QOL is low in the western district where flooding levels are dangerously high. This makes it difficult to supplement with other indicators. The high QOL district exists in both the city center and the suburbs. QOL in the city center is high because of the wide floor space per person. On the other hand, there is a district in the suburban area that receives the same level of evaluation. From the generational aspect, the senior citizen evaluates the district with low danger of flooding. The influence of safety level is strongly received by the senior citizen. From the gender aspect, no clear trend was found.

Efficiency evaluation

Figures 8 and 9 show the results of environmental efficiency (EF) and cost efficiency (CF). Both EF and CF are high in the central portion of the Nagoya central area and the city surroundings. Moreover, they are also high in the areas along the railroad lines. This result suggests that shrinking to the central area is one possible efficient urban structure considering the three elements (environment, society, and economy).

Discussion

The results of estimation of TBL evaluation indicators suggested the following, toward the examination of strategy for conversion to a sustainable urban spatial structure.

Because QOL decline and cost increase due to flood risks are obvious, it is the primary requirement to withdraw from flood risk areas and complete counter-disaster infrastructure. In examining these, climate change must also be taken into consideration.

Dispersion of CO_2 emission per capita between districts is small, probably because there is a trade-off relationship between emission from housing, which is larger in urban areas, and emission from passenger transportation, which is larger in suburban areas, resulting in an averaged amount in general.

The high rate of RC-structured housing complexes is the cause of large CO_2 emission in the central urban district. Therefore, excessive centralization involves the risk of CO_2 increase.

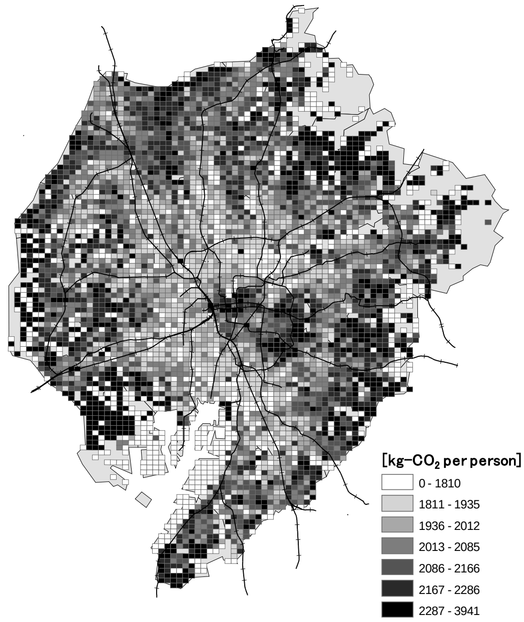

Figure 5 – Per Capita CO_2 Emission

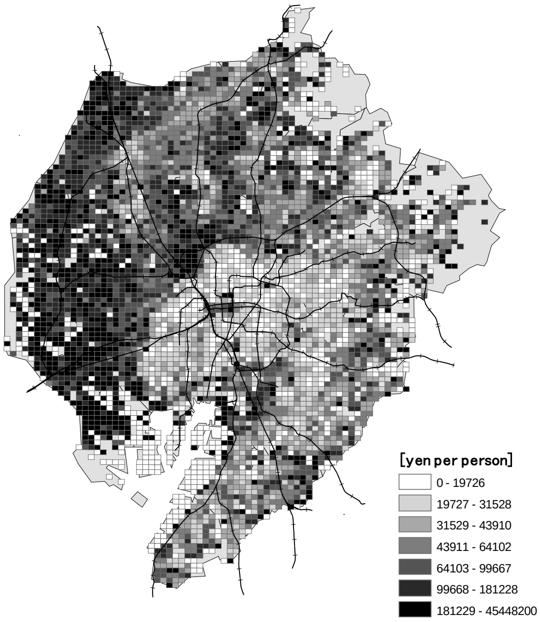

Figure 6 – Per Capita Built-up Area Maintenance Cost

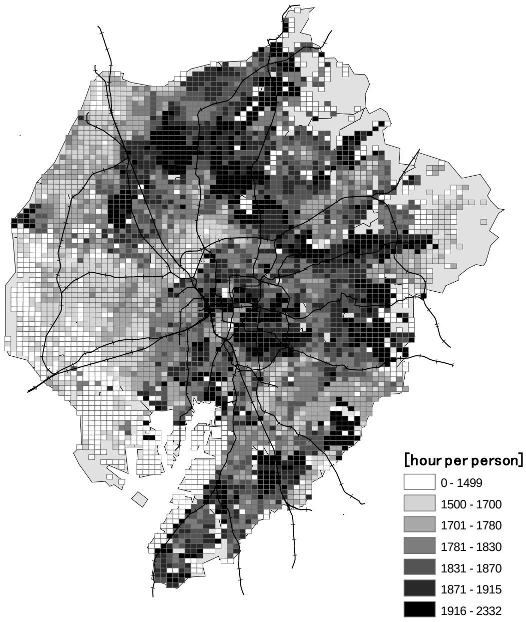

Figure 7 –QOL

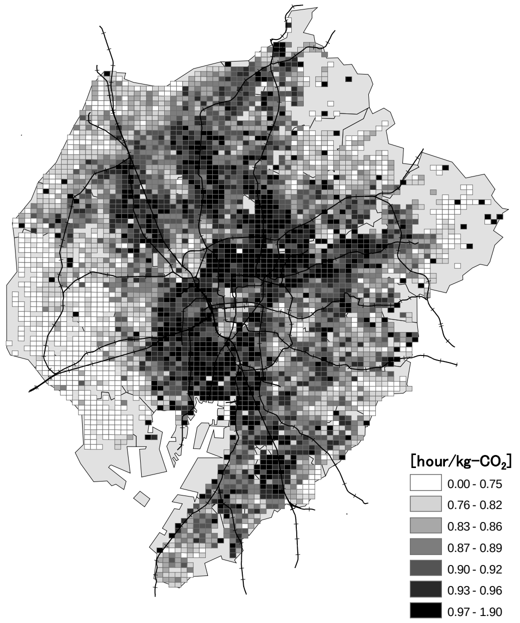

Figure 8 – EF (Environmental Efficiency)

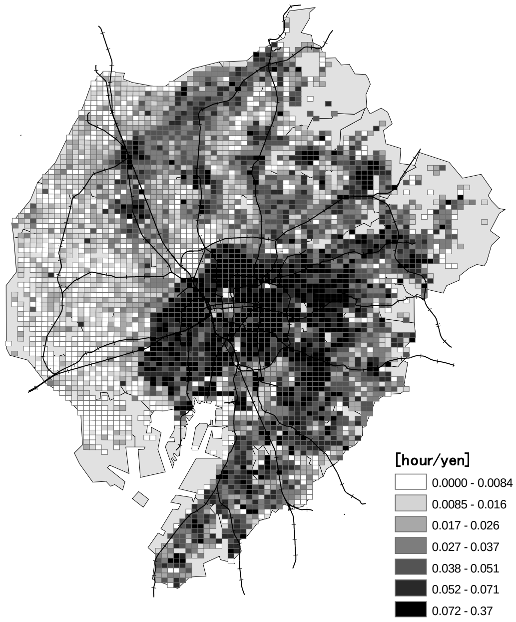

Figure 9 – CF (Cost Efficiency)

5. SCENARIO ANALYSIS ABOUT URBAN RECONFIGURATION

(1) Condition settings

A scenario that will be achieved by 2050 due to the urban spatial structure reconfiguration is set, and its influence on TBL was analyzed.

With regards to the policy for centralizing residential areas, two patterns of urban spatial structure were set: 1) single-polar centralization of population in central Nagoya (mono-centric scenario), and 2) multi-polar centralization retaining balanced distribution throughout the urban area (poly-centric scenario). Districts where the center of the mesh is included within an 800-meter range from railroad stations were selected as sites for centralization. Population was relocated in steps from districts (meshes) with low environmental efficiency, until a specified population capacity shown in Table5 was filled.

Table 5 –Assumption of Population Density
at the Area within 800-meter Range from Railroad Stations

	Inside of Nagoya - shi	Outside of Nagoya - shi
Mono - centric scenario	200 [Capita / ha]	50 [Capita / ha]
Poly - centric scenario	100 [Capita / ha]	100 [Capita / ha]

(2) Result

Figure 10-14 shows the results. The results indicated that, in both the mono-centric and poly-centric patterns, the reduction of CO_2 emission and built-up area maintenance cost was achievable. However, QOL declined in the mono-centric pattern, though the rate of reduction in urban maintenance cost was large. In contrast, all of the TBL were improved in the poly-centric pattern.

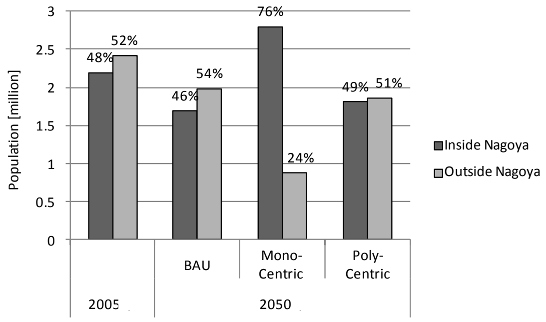

Figure 10 – Population Distribution Difference

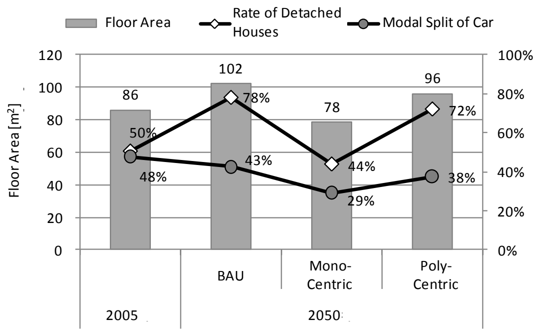

Figure 11 – Major Indexes Difference

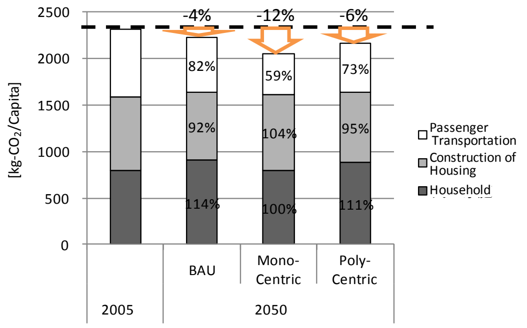

Figure 12 – CO_2 Emission Difference

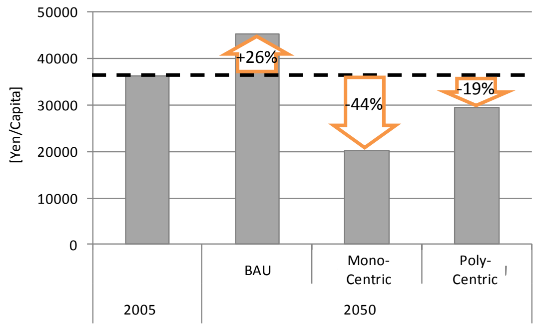

Figure 13 –Built-up Area Maintenance Cost Difference

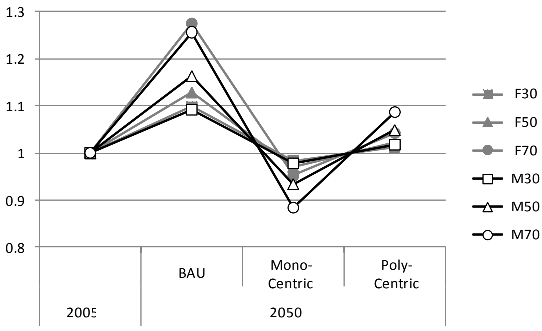

Figure 14 QOL Difference

6. CONCLUSION

In this study, aiming to evaluate urban spatial structure from the triple bottom line (TBL) perspective, we constructed the SURQUAS system which can forecast Environmental Load (EL), built-up area maintenance Cost (Cost) and Quality of Life indicator (QOL) at a high resolution level, and examine how urban configuration affects TBL.

By applying SURQUAS to the Nagoya metropolitan area, the following results were shown. Both Environmental efficiency and Cost efficiency were high in the central portion of the Nagoya central area and the city surroundings. Moreover, they are also high in the areas along the railroad lines. This suggests that shrinking to the central area is one possible efficient urban structure considering TBL.

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