The Evaluation of Transportation Policies based on the Quality of Mobility Index by Capability approach

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Abstract: This study aims to build the concept of QOM (Quality of Mobility), and to suggest a useful method for evaluating QOM among regions by an index. We propose the model in which QOM is evaluated by Capability approach, which has been put forward by Amartya Sen. In addition, QOM at present and in the future was analyzed in Yamaga City. As a result, the transportation service level in this city will decrease and the inequality will expand in the future. Therefore, some policies were prepared, and evaluated. As a result, we propose a policy based on persuading people to live in the city center and improving main roads.

Key Words: Capability approach, Structural equation modeling, Vector Product

1. INTRODUCTION

The depopulation trend continues and the population ageing phenomenon is going to be more serious in local cities of Japan. It is more important than ever before to integrate villages together to maintain the social base efficiency, and use social welfare facilities mutually among regions. How to maintain transportation service levels is very important to evaluate these factors. QOL (Quality of life) must be evaluated by concerning the maintenance of Infrastructure. In this paper, Quality of Mobility (QOM) is defined as an integrated index which evaluates the transportation service level. We propose a method for evaluating service levels and the equity in the entire region. First of all, 1) we propose a model by Capability approach, 2) outline of the model to calculate QOM is described. In addition, 3) the transportation policy is suggested by using this method for the local city.

2. EVALUATION TECHNIQUE BY CAPABILITY APPROACH

2.1 A Framework of Capability Approach

Capability approach has been put forward by Professor Sen. A person’s capability to achieve functioning that he or she has reason to value provides a general approach to the evaluation of social arrangements, and this yields a particular way of the assessment of equality and inequality.(Sen 1992) The core concepts of Capability approach are functionings and capabilities. Functionings are the “beings and doings” of a person, whereas a person’ capability is “the various combinations of functionings that a person can achieve. Capability is thus a set of vectors functionings, reflecting the person’s freedom to lead one type of life or another. (Sen 1992)

In Capability approach, there is no established measurement scale for functionings, and there isn't the method for aggregating functioning. Thus, there are a lot of literatures to model Capability approach. In non-statistical methods, there are HDI (The Human Development...
Index) (UNDP), Fuzzy-sets-theory (Oizilbash, 2002), and Analytic-Hierarchy-Process (Inoi, 2005). The feature of these is that value of functioning can be easily interpreted with subjective evaluations. However, there is a fault that depends on the evaluation depending on the evaluator. In statistical analysis, there are Factor Analysis (Lelli, 2001), Principal Components Analysis (Klasen, 2000), and Structural Equation Modeling (Kuklys, 2004). The feature of these is that information from the data itself is used to determine the weights. When we construct an index for composing QOM, functioning’s expression, functioning’s measurement, functioning’s ranking and functioning aggregation are difficult problem. We propose the method, by which we settle these four problems by using statistical analysis which can keep objectivity.

2.2 Functioning’s Expression
In the book “Commodities and capabilities”, Sen formalized the following relationship between commodities and capabilities: Taken,

The achieved function of person \( i \) is:

\[
b_i = f_i(c(x_i)) \tag{1}
\]

where \( x_i \): the vector of commodities possessed by person \( i \)
\( c() \): the function (not necessary linear) converting a commodity vector into a vector of characteristics of those commodities
\( f_i() \): a personal ‘utilisation function’ of \( i \) reflecting one pattern of use of commodities that \( i \) can actually make

The vector \( b_i \) reflects the beings and doing a person can achieve. Well-being then, can plausibly be seen as an evaluation of this \( b_i \), indicating the kind of being he or she is achieving. Because the list of functioning decides capability’s value, the list and description method of functioning become problems.

2.3 Functioning’s Measurement
The commodity and the happiness can be observed directly, but the functioning cannot be observed. The measurement method for the functioning is explained. By Capability approach, the happiness that he will enjoy is given by \( u_i \):

\[
u_i = h_i(b_i) = h_i(f_i(c(x_i))) \tag{2}
\]

where \( h_i() \): the happiness function of person \( i \) related to the functionings achieved by \( i \)

The functioning vector \( b_i \) can be expressed by using the model following equation 1, 2. In a word, the functioning is described by Latent Variable which exists in the middle of the commodities and the happiness by using Structural Equation Model. When the happiness is Endogenous Variable and the Commodities are Exogenous Variables, the functioning is conceptualised as Latent Variable which can only be measured with error of datas.
2.4 Method of Measuring Value of Functioning Vector
As Capability approach, the value of a single functioning vector $b_i$ is given by the real-valued functioning vectors $v_i(\cdot)$, which is person $i$’s valuation function.

\[ v_i = v_i(b_i) \]  

There are two problems for measuring value of functioning vector. As the first problem, it is difficult to compare functionings because the direction of the vector is too different to measure the value. For example, it is difficult to judge which the mobility of shopping or the mobility of going to the hospital is more important. According to Sen, evaluating a functioning vector can take the form of giving a scalar value to this vector. Because it is difficult to rank all functioning vectors, Sen has proposed a range of methods including "Dominance ranking" for extending incomplete orderings.

As the second problem, because functioning vectors is mutually related, the possibility of causing multicollinearity is high. Actually, each mobility purpose is consecutive in one day or one month, mobility purposes correlate mutually. For this, functioning vectors should be an independent variable in each other.

We propose the method for converting two or more functioning vectors $b_i$ into principal integrated vectors $b_i$ by using Principal Component Analysis. As a result of Principal Component Analysis, multicollinearity is eliminated. Moreover because Sums of Squared Loadings obtained by Principal Component Analysis shows the volume of information of converted functioning vector, the size of functioning vector $b_i$ can be assumed to be proportional to Sums of Squared Loadings.

2.5 Method of Aggregating Value of Functioning Vector
The procedure of functioning’s aggregation is explained. As Capability approach, the capability set of a person is given by the set $Q_i(x_i)$ of all the functioning vectors that are feasible for the person $i$:

\[ Q_i(x_i) = \{ b_i | b_i = f_i(\cdot), \text{for some } f_i(\cdot) \in F_i \text{ and for some } x_i \in X_i \} \]  

where $F_i$: the set of ‘utilization function’ $f_i(\cdot)$, any one of which person $i$ can in fact choose

The capability set $Q_i(x_i)$ represents the freedom of choice of a person, who can decide between several combinations of functionings what are the most valuable for him. Among all feasible vectors of functionings, one will be chosen and will be the achieved vector of functionings. The values of all functioning vectors present in a capability set are given by $V_i$:

\[ V_i(x_i) = \{ v_i | v_i = v_i(b_i), \text{for some } b_i \in Q_i \} \]  

Sen insists that the equality should be sought in the space of capability. Capability is a set of such functioning n-tuples, which means that capability is defined in the space of functionings. (Sen, 1993) Because functioning vectors $b_i$ intersect squarely, the value of set of functioning vectors is shown by the size of the space, which is composed of functioning vectors $b_i$, as shown in Fig.1. In a word, the value is calculated by the Product of the size of the converted functioning vectors $b_i$. 
3. MODELING OF QOM

3.1 Outline of Modeling of QOM

Fig.2 shows the model to calculate QOM. The right part of Fig.2 shows a model of transportation possibility, which is modeling according equation 1, 2. The left part shows a model of selected transportation possibility, which is modeling according equation 3, 5. The model is analyzed by using the questionnaire data in Yamaga City, Japan.

3.2 Factor of Transportation Possibility

Among all feasible vectors of functionings, one will be chosen. Thus, it is necessary to enumerate the selected functioning for the mobility. As to mobility, there are four items for the selection of transportation, the selection of the migration pathway, the selection for mobility to large-scale commercial facilities, and the selection for mobility to daily shopping.
mobility purpose and the selection of the target facilities. In this study, the selection for the mobility purpose and the selection of the target facilities are described in the functioning. All the transportation purposes are defined to nine purposes.

### 3.3 A Model of Transportation Possibilities

“The transportation possibilities” constitutes three concerns, “Mobility by travel time”, “Mobility by transportation selection” and “Comfort in transportation facilities”. The model of “Mobility by transportation selection” uses the effect value of the modal choice model. The relation between transportation frequencies and permissible times in a year is analyzed, and then the model of “Mobility by travel time” is built. The model of “Comfort in transportation facilities” is used to evaluate the comfort between the origin and the destination with a set of drivability data provided in the “Road drivability Map”. These three factors are integrated according to Structural Equation Model. Latent Variables of Structural Equation Model is defined as transportation possibility functionings. Table.1 shows the result by Structural Equation Model, because CFI value is a rough value, about 0.9 or more, so the accuracy is guaranteed.

<table>
<thead>
<tr>
<th>Transportation Purpose</th>
<th>Mobility by travel time (TCM)</th>
<th>Mobility by transportation selection (MCM)</th>
<th>Comfort in transportation facility (FCM)</th>
<th>CFI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commuting</td>
<td><strong>0.71</strong></td>
<td><strong>0.57</strong></td>
<td>-0.15</td>
<td>0.74</td>
</tr>
<tr>
<td>Business</td>
<td><strong>0.49</strong></td>
<td><strong>0.61</strong></td>
<td>-0.72</td>
<td>1.33</td>
</tr>
<tr>
<td>Daily shopping</td>
<td><strong>1.12</strong></td>
<td><strong>0.28</strong></td>
<td>-0.07</td>
<td>0.52</td>
</tr>
<tr>
<td>Large-scale commercial facility</td>
<td><strong>1.21</strong></td>
<td><strong>0.10</strong></td>
<td>-0.01</td>
<td>0.69</td>
</tr>
<tr>
<td>Community facilities</td>
<td><strong>0.99</strong></td>
<td><strong>0.08</strong></td>
<td>0.86</td>
<td>0.50</td>
</tr>
<tr>
<td>Hospital in a region</td>
<td><strong>0.48</strong></td>
<td><strong>0.28</strong></td>
<td>-0.29</td>
<td>1.40</td>
</tr>
<tr>
<td>Emergency hospital</td>
<td><strong>1.04</strong></td>
<td><strong>0.02</strong></td>
<td>-0.01</td>
<td>0.92</td>
</tr>
<tr>
<td>Sight seeing</td>
<td><strong>1.05</strong></td>
<td><strong>0.05</strong></td>
<td>0.82</td>
<td>1.00</td>
</tr>
</tbody>
</table>

$$\text{Table 1: Variables and CFI for adult males}$$

3.4 A Model of Selected Transportation Possibilities

The model of selected transportation possibilities is composed of two models. The first one is the model of “The ease of selecting plural destinations”. This model is a gravity model in which the appeal of the destination is given through a certain weight.

The second one is the model of “The ease of selecting transportation purposes”. Capability is described by a set of the vectors of functioning (the transportation possibility). The magnitude of Capability is same as the magnitude of Vector Product of these functioning’s vectors, which is defined as QOM. Through Principal Component Analysis on the values calculated by the model of “The ease of selecting plural destinations”, the values for various transportation purposes are synthesized to two principal ingredients. With these two principal perpendicular ingredients $x_{1i}, x_{2i}$, QOM can be expressed by the Cobb-Douglas Production Function in equation 6. Here, the ratio of Squared Loadings is assumed to be the share parameter in the Cobb-Douglas Production Function. For the adult male in Table.2, we can interpret the first principal component as non-daily mobility.

$$QOM = a x_{1i}^{\alpha} x_{2i}^{1-\alpha}$$ (6)
3.5 Setting of Evaluation Index
By using feasible maximum and smallest $QOM$ values, $QOMR$ is expressed as a percentage of $QOM$ value. The entire region is evaluated by three indices. The first index is the mean value ($QOMR$) of $QOMR$. It is used to evaluate the service level in the whole region. The second index is an Atkinson index ($AI$), which evaluates the inequality in equation 7. The third index ($QOMA$) is an index with an Atkinson type function for evaluating the service level and inequality of the region in equation 8. The Atkinson index ($AI$) is evaluated by specifying the parameter $\varepsilon$, which shows the evasion level of inequality.

$$AI = 1 - \left( \frac{\sum_{i=1}^{n} \left( \frac{QOMR_i}{QOMR} \right)^{1-\varepsilon} \right)^{1/(1-\varepsilon)}$$ (7)

$$QOMA = \overline{QOMR} \left( \sum_{i=1}^{n} \left( \frac{QOMR_i}{QOMR} \right)^{1-\varepsilon} \right)^{1/(1-\varepsilon)}$$ (8)

where, $n$ is population

4. EVALUATION OF TRANSPORTATION POLICY IN LOCAL CITIES

4.1 Outline of Target Area
Yamaga City is a local city that merged from four towns in 2003 and has a population of 50,000. It takes about one hour from this city to prefecture capital, Kumamoto City. This city is an independent region with simple transportation purposes such as work and school commuting.

4.2 Setting of Transportation Condition
The transportation policy is evaluated on the assumption of the following conditions.
1) The rank of the country and prefecture road is set by the data of “Road drivability Map”.
2) Input data that concerns the information of the car license and the car possession, etc. is obtained by the questionnaire survey.
3) The evaluated year is 2005 and 2030. The estimated population issued by National Institute of Population and Social Security Research is used.
4) The position of target facilities according to transportation purposes will not change in the future. Table 3 shows the target facilities and the public appeal according to transportation purposes.
### Table 3: Target facilities and public appeal

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Target facilities</th>
<th>Public appeal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commuting, Business</td>
<td>Districts in which number of employees is concentrated</td>
<td>The public appeal is proportional to the number of employees. The proportion will decrease as the population decreases in the future.</td>
</tr>
<tr>
<td></td>
<td>The public appeal is proportional to the number of employees.</td>
<td>The proportion will decrease as the population decreases in the future.</td>
</tr>
<tr>
<td>Daily Shopping, Community facilities in a region</td>
<td>Shops in this city and Community facilities in a region</td>
<td>The public appeal of each facility is assumed to be constant. The proportion will decrease as the population decreases in the future.</td>
</tr>
<tr>
<td></td>
<td>Shops in this city</td>
<td>The public appeal is constant.</td>
</tr>
<tr>
<td>Large-scale commercial facility, Large-scale hospitals, Large-scale community facilities</td>
<td>Downtown of the prefecture capital</td>
<td>The public appeal is constant.</td>
</tr>
<tr>
<td>Hospitals in a region</td>
<td>Hospitals in this city</td>
<td>The public appeal is constant.</td>
</tr>
<tr>
<td>Sightseeing</td>
<td>Kikuchi (sightseeing location)</td>
<td>The public appeal is constant.</td>
</tr>
</tbody>
</table>

### 4.3 Analysis of the Current State and the Trend in the Future

As an example of the analysis result, Fig. 5 shows the distribution of QOMR at the current state of the senior citizens. In urban area, QOMR is higher than the mean value 82%. But it is a very low in other regions. Fig. 6 shows the population composition rate according to the rank of QOMR. Persons in areas with a QOMR of around 20% are in a service level lower than the mean value (QOMR). Table 4 shows QOMR, Atkinson index (AI), and QOMA value of 2000 and 2030. QOMR decreases, AI increases. The result shows that the transportation service level will decrease and the inequality will expand. The important reason is that the public appeal of each facility decreases in proportion due to the population decrease in the future.

![Figure 4: Distribution of population of Yamaga City](image1.png)

![Figure 5: Distribution of QOM value at current state (The senior citizens)](image2.png)
4.4 Case Examination

We evaluated two scenarios to solve these problems presented in 4.3. The first scenario is to improve the road, and the second scenario is to distribute the population properly to each district. We evaluated three cases of the first scenario. The first case is that new roads don’t need to improve. The second case is to improve sections ranked “D” to “C” in the “Road drivability Map”, which is called “road in region”. The third case is to upgrade Ueki Bypass (10km) to the main road between Yamaga City and Kumamoto City, which is called “main road”.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2 or more lanes, gentle curves/slopes.</td>
</tr>
<tr>
<td>B</td>
<td>2 or more lanes, fully gentle curves/slopes.</td>
</tr>
<tr>
<td>C</td>
<td>One lane road with sharp curves.</td>
</tr>
<tr>
<td></td>
<td>2 or more lanes, many sharp curves and steep slopes.</td>
</tr>
<tr>
<td>D</td>
<td>One lane road with continuous sharp curves.</td>
</tr>
<tr>
<td></td>
<td>Road shoulders are always narrow.</td>
</tr>
</tbody>
</table>

The second scenario is to distribute the population properly to each district. We evaluated three cases about this scenario, shown in Table.6.

<table>
<thead>
<tr>
<th>Case</th>
<th>method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintain the current condition</td>
<td>The rate of change of the population according to the group’s age for the four towns is multiplied by the current population according to the age's group of each zone.</td>
</tr>
<tr>
<td>Maintain the population of mountainous districts</td>
<td>The rate of change of the population according to the group’s age for this city is multiplied by the current population according to the group’s age for each zone.</td>
</tr>
<tr>
<td>Concentrate the population around the city center</td>
<td>Population in the zone with QOMR less than 60% is transferred to the zone with QOMR more than 75%.</td>
</tr>
</tbody>
</table>

4.5 Evaluation Cases to Improve the Roads

In the condition of maintaining the current condition for future population, Fig.7 and Table.7 show the evaluation results of QOM in three cases to improve the road. By improving main roads between cities, a large effect of improving of QOMR is achieved, but the effect of
improving the inequality (AI) is small. On the other hand, improving roads around this region has a large effect on improving the inequality (AI), but a small effect on improving $QOMR$. However, the ratio of the low service population ($QOMR$ is 60% or less) is the same in both cases. In 2030, compared with 2000, the transportation service level ($QOMR$) will decrease and the inequality (AI) will expand. So the service level at the current state could not be maintained only by this road improvement method.

4.6 Evaluation of the Different Cases to Distribute the Population

Fig.8 shows the evaluation results of QOM in the future in three cases to distribute the population. In the case of concentrating the population around the city center, both $QOMR$ and the inequality (AI) are improved compared with the current state. However, in the case of maintaining the population in mountainous districts, $QOMR$ decreases and the inequality (AI) increase, much worse than the current state.

4.7 Direction of Transportation Policy of Yamaga City

In the future, the population will decrease, and the number of senior citizens will increase. The population will concentrate relatively in the city center and the public appeal of various facilities will decrease. As a result, the transportation service level will decrease and the
inequality will expand in the future. In the condition that the investment is limited, without investment waste, the administration is suggested to improve QOM, and keep equality in the entire region. This analysis shows that concentrating the population around the city center and improving the main road from Yamaga City to Kumamoto City is a good measure that should be considered in the policy.

5. CONCLUSION

In this research, we proposed model by Capability approach and we proposed the technique for evaluating transportation service levels by using models which based on Capability approach, such as model of the transportation possibilities and the model of selected the transportation possibility. As a result, the transportation service level can be evaluated by using the QoM value according to region attributes. Some policies are evaluated in Yamaga City, and we propose the policy of persuading individuals to the center part etc.

In the current transportation plan technique of person trip etc., the transportation demand is assumed to be an index for the evaluation. In the method that we propose, the transportation service level among regions is defined to be an index for the evaluation. Therefore, by this method, it becomes possible to evaluate a public transportation planning such as bus. Moreover, it becomes possible to evaluate the overall urban planning because we pay attention to a place of residence and target facilities.

REFERENCES


