MSS Evaluating Reliability Spatial Resolution

Technology Reports

"Mobile Spatial Statistics" Supporting Development of Society and Industry
— Population Estimation Technology Using Mobile Network Statistical Data and Applications —

Evaluating Reliability of Mobile Spatial Statistics

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In order for MSS to provide useful population statistics yielding basic information for disaster planning, urban planning and other types of planning, it is important to provide accurate estimations of the actual population within a given area. In this article, we define the reliability of MSS as its ability to estimate the actual population in an area accurately, and evaluate the reliability of MSS by measuring the differences between estimates it provides and the actual population. This reliability has typical features such that it fluctuates with the geographic detail (the spatial resolution) of the area where the population is being mode. Accordingly, in this article, we evaluate the reliability of MSS for various spatial resolutions, and clarify the spatial resolutions at which the reliability of MSS can be guaranteed.

1. Introduction

Mobile Spatial Statistics (MSS) is a new type of population statistics which estimates the actual population in areas throughout Japan based on operational data from a mobile phone networks. The reliability of MSS refers to the degree to which they can estimate these actual populations accurately, and this reliability is limited due to various characteristics of the mobile phone networks.

For example, the level of geographic detail (hereinafter referred to as "spatial resolution") over which MSS can provide accurate estimations of actual population is highly dependent on the placement of the base stations producing the operational data that is the basis for MSS. The placement of the base stations tends to differ by the population density in the area where the service is being provided, so the reliability of MSS is very different in regions where base stations are placed sparsely than where they are placed densely.

Accordingly, in this article we focus on spatial resolution in evaluating the reliability of MSS. Through this evaluation, we shed light on the reliability of MSS and the spatial resolutions for which reliability can be guaranteed. Typical spatial resolutions we examine are standard grids (1 km and 500 m grids) and administrative boundaries (at prefectural and municipal levels).

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To evaluate the reliability of MSS focusing on spatial resolution, it is necessary to measure the differences between actual populations and those estimated by MSS, while controlling the conditions of spatial resolution. This requires accurate actual population data for each level of spatial resolution, so we use National Census population values for residential population*1, which is similar to actual population only at night time, as correct data in evaluating reliability.

Below, we summarize how the reliability of MSS is evaluated, the results of this evaluation, and the knowledge gained from these results.

2. Evaluation Method

With this evaluation, we clarify the degree of reliability of MSS quantitatively, for various levels of spatial resolution that are used in fields where MSS can be applied*2, including administrative units such as prefectures and cities, and grids from 1st-order (approximately 80 km square) to 4th-order (approximately 500 m square).

1) Evaluation Data

To properly evaluate the reliability of MSS as statistical values, correct actual population must be prepared, and the estimated values produced by MSS must be compared to this correct data. Correct data for MSS should be the correct actual population in the area, where MSS is being used to estimate the population, during the time period over which the estimation is being made.

However, the population statistics produced by MSS are a new type of statistic that is different from any existing population statistics, so it is extremely difficult to obtain correct data that can be used to accurately test the reliability of MSS. One possible way to obtain such correct data would be to manually count the number of people present. However, it would not be practical to actually count all of the people accurately within a given area in a given time period, even for a section of a 500 m grid (the smallest unit area examined in this evaluation).

Accordingly, for this evaluation, we focused on estimations of actual population made during time periods late at night, when most people are in their homes, and accordingly the actual population would be close to values of residential population. We then used the residential population values from the 2005 National Census*3[1], which are reliable, as approximations of the true values for actual population. We selected the period between 4:00 and 5:00 am for evaluating MSS, which we found to be most similar to the residential population in a preliminary study. The actual time periods used in the evaluations were on weekdays during February, 2012.

The residential population value from the National Census is created from the results of the National Census, which is done once every five years, and indicates the residential population on the census day (October 1 of the census year). In principle, the National Census is created from a complete survey and is the most reliable source of population statistics for Japan. However, as comparative data to evaluate the reliability of MSS, it must be noted that the night-time populations used are from residential populations as of October 1, 2005, so the following differences must be taken into consideration.

- Differences between actual population and residential population

  The actual population late at night, when most people are at home, is close to the residential population, but there are actually differences between the two, due to overnight stays, business trips, vacations, late-night work and other factors.

- Differences with the passage of time

  Approximately 6.5 years passed between conducting the 2005 National Census and the time period used for evaluating MSS estimations, and the population may have changed during that time.

- Differences with seasonal changes

  The National Census was conducted on October 1, while the estimations using MSS were done in February, so depending on the region, populations could be affected by seasonal fluctuations.

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*1 **Residential population**: Population reflecting approximately how many people live in a given area.

*2 **Fields where MSS can be applied**: NTT DOCOMO is conducting research on uses for MSS in the fields of urban development [2], disaster prevention [3], regional revitalization [4], and other public sector fields.

*3 **2005 National Census**: A national census was also conducted in 2010, but as of the time of writing population data on grid units from the 2010 Census had not yet been published, so the 2005 data was used.

Therefore it should be noted that, if National Census populations are used, as data approximating the correct data, in quantitatively evaluating the reliability of MSS, differences shown in the evaluation results can be regarded as larger than differences with the true actual populations. Concrete examples of these effects are explained in the evaluation results.

2) Evaluation Indices

As described earlier, in this evaluation we compared residential population from the National Census (hereinafter reffered to as "census population") with actual population values late at night, estimated using MSS (hereinafter reffered to as "estimated population"), and used the size of these differences to evaluate the reliability for spatial resolution. Here we introduce deviation rate as an index for quantitatively evaluating the size of these differences.

Deviation rate is an evaluation index used when comparing two population values for a given area (census population and estimated population), indicating how much they deviate from the ideal state (when both are the same) (**Figure 1**). Assume that for a given area, i, the census population is s_i, the estimated population is t_i, and the average of the two is μ_i ($\mu_i=(s_i+t_i)/2$). The deviation rate, δ_i, for area i is defined as the difference between the estimated population, t_i, and the average, μ_i, relative to μ_i ($\delta_i=(t_i-\mu_i)/\mu_i$). Substituting in $\mu_i=(s_i+t_i)/2$ gives the following equation for deviation rate, δ_i.

$$\delta_i=\frac{t_i-s_i}{s_i+t_i} \qquad (1)$$

Fig. 1 provides an intuitive understanding of the concept, with deviation rate, δ_i, represented by the ratio between the length, β_i, from the (s_i, t_i) coordinate dropped perpendicularly to the line $s_i=t_i$ to the length, α_i, along the line $s_i=t_i$ from the origin to this intersection point.

As can be seen from the defining equation, the deviation rate, δ_i, is normalized between −1 and 1, with values nearer to zero indicating smaller differences between the two values, and values near −1 or 1 indicating larger differences. Positive values of deviation rate indicate that the estimated population is larger than the census population, and negative values indicate that it is smaller.

3) Evaluation Details

We analyzed the observations as follows in order to show the relationship between the reliability of populations estimated using MSS and spatial resolution.

(1) Overall trends in reliability of estimated populations at each spatial resolution
(2) Geographic trends for estimated populations related to 3rd and 4th-order grids.
(3) The relationship between population density and estimated population reliability for 3rd and 4th-order grids.

First, to evaluate (1) Overall trends in reliability at each spatial resolution, we evaluated what sorts of deviation rate distributions were shown at various levels of spatial resolution commonly used in fields of application for MSS.

- Administrative units (prefectural level, municipal level)
- Standard grid units (1st-order to 4th-order grids)

Note that the sizes of the 1st to 4th-order grids are as follows:

- 1st-order grids: Approximately 80 km square
- 2nd-order grids: Approximately 10 km square
- 3rd-order grids: Approximately 1 km square
- 4th-order grids: Approximately 500 m square

In evaluating the 3rd and 4th-order grids, we limited the evaluation to estimated populations of 500 or more to eliminate the effects of disclosure limi-

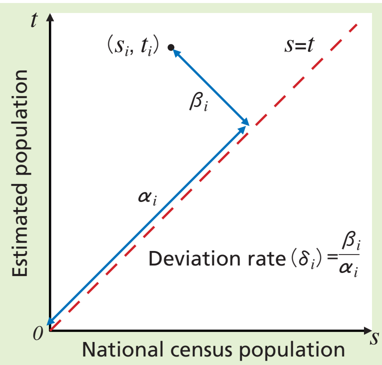


Figure 1 Intuitive illustration of deviation rate

tation processing and of areas where estimation of the population is difficult, such as mountainous areas.

In (2), geographical trends for 3rd and 4th-order grids, we examined any trends with respect to reliability of population estimations made using MSS at the finer spatial resolutions provided by the 3rd and 4th-order grid units.

Finally, in (3), evaluating the relationship between estimated population and reliability of population estimations on the 3rd and 4th-order grids, we evaluated the reliability of the estimations for given estimated population values.

3. Evaluation Results

We give the results of the evaluations, (1) to (3), below.

(1) Overall trends in reliability of estimated populations at each spatial resolution

We first calculated the deviation rates for estimated population values at each spatial resolution, as discussed in Chapter 2. To understand overall trends, at each spatial resolution we calculated the areas over which the deviation rate was ±20% or less, and ±10% or less, as shown in **Table 1**.

As can be seen in Table 1, when using a deviation rate of ±20% as the threshold, 70% or more of the evaluation area falls within the threshold for all spatial resolutions. In particular, for the administrative units (prefectural and municipal units), almost all areas fell within the standard, except for some town and village areas on islands, in sparsely populated areas, and areas that had experienced considerable depopulation with time, as is discussed further below.

All of the prefectural-level areas also fell within the ±10% standard for deviation rate, but for other spatial resolutions, the proportion dropped as the spatial resolution increased. For the 3rd and 4th-order grids in particular, as a simple proportion, less than half of the area satisfied the standard. One possible reason for this is that in many cases the distances between base stations is not adequate to estimate accurately at these spatial resolutions, but it is also necessary to carefully consider the effects of changes over time since the National Census was taken, among other factors. As an example, the population of Yashio City in Saitama increased by approximately 10%, from 75,507 to 82,971, between 2005 and 2010 due to the opening of the new Tsukuba Express rail line. On the other hand, some areas affected by the Great East Japan Earthquake can be expected to have dropped greatly in population since 2005. Even if the estimated populations given by MSS are taken to reflect the actual populations in these areas, the evaluation yielded deviation rates that are large.

The size of the deviation rates and the proportion of area falling within that deviation rate for each spatial resolution is shown in graph form in **Figure 2** (The cumulative probability distribution of deviation rates, with absolute value of deviation rate shown on the x-axis, and cumulative probability on the y-axis). In the figure, the area proportion for a deviation rate of ±20% or less from Table 1 are shown on the graphs for each spatial resolution where they

Table 1 Overall trends in reliability by level of spatial resolution

Area unit	Area size	Total number of areas	Ratio of areas with deviation rate ±20% or less	Ratio of areas with deviation rate ±10% or less
Prefectural-level boundaries	Area of each prefecture	47	100.0%	100.0%
Municipal-level boundaries	Area of each city	2,337	96.1%	77.1%
1st-order grids	Approx. 80 km square	138	92.0%	80.4%
2nd-order grids	Approx. 10 km square	3,459	81.0%	55.8%
3rd-order grids	Approx. 1 km square	34,264	70.0%	43.4%
4th-order grids	Approx. 500 m square	48,667	71.8%	42.8%

intersect with the line at x =20%. From these results, the area proportion rises quickly for deviation rates up to ±20% for cities and 1st and 2nd-order grids, and up to ±30% for 3rd and 4th-order grids, and rise only slowly after that. Thus, for deviation rates of ±30%, 80% or more of the area satisfies that standard at all spatial resolutions, including 3rd and 4th-order grids.

(2) Geographic trends were evaluated for estimated populations on 3rd and 4th-order grids

Next we focus on 3rd and 4th-order grids, with higher spatial resolution, and evaluate geographic trends in deviation rate for each area.

Figure 3(a) shows a visualization of the distribution of deviation rates on a map of the area around Tokyo, for each segment of a 3rd-order grid. Fig. 3(b) shows the same visualization for a 4th-order grid.

Fig. 3(a) shows that most of the flat areas, with some exceptions, yield a deviation rate in the ±10% range. Also, it is clear that deviation rates are more scattered in the mountainous and sea-side areas. Fig. 3(b) shows mainly the same tendencies as Fig. 3(a), but shows more scattering overall than Fig. 3(a). It also shows more scattered deviation rates along rivers with wide river beds, such as the Arakawa and Tamagawa, which were not prominent in Fig. 3(a).

Another characteristic appearing in

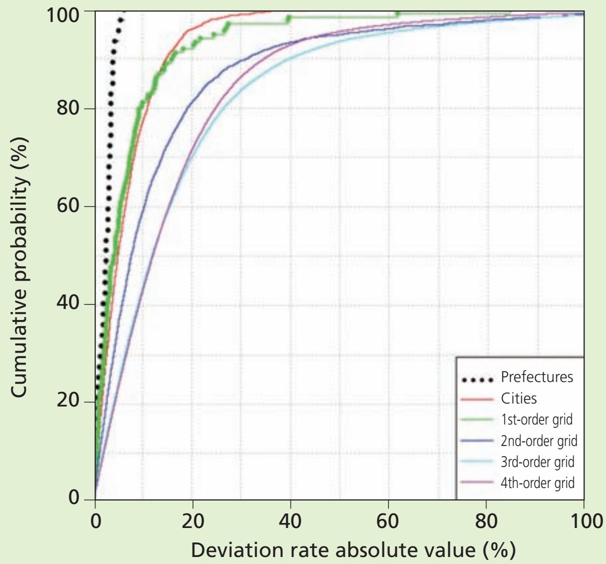
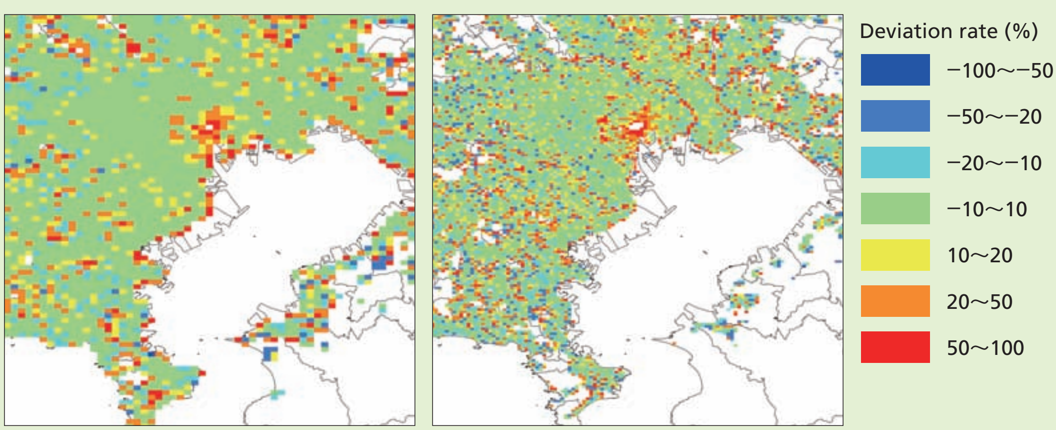


Figure 2 Area proportion vs. absolute value of deviation rate



Administrative boundary map source: MLIT National geographic data (2011 Administrative boundaries)

(a) 3rd-order grid

Administrative boundary map source: MLIT National geographic data (2011 Administrative boundaries)

(b) 4th-order grid

Figure 3 Distribution of deviation rates in the Tokyo area

both Fig. 3(a) and Fig. 3(b) is that deviation rates are noticeably higher in the central areas of Tokyo (around Chiyoda and Chuo wards). The estimated populations are significantly larger than the census populations. This phenomenon is due mainly to the differences in definition between residential population and actual population.

As discussed earlier, the night-time population from the National Census expresses the residential population, while MSS estimates values for the actual population, which is the number of people in an area at the time of the survey regardless of whether they are at home or not. In areas like Chiyoda Ward, the residential population is low due to the so-called donut phenomenon, but there is a concentration of offices, stores, hotels and other non-residential facilities, and many people are present during the night, whether they are on regular business trips, sight-seeing or working late. Thus, the increase in deviation rates in central urban areas shown in Fig. 3(a) and Fig. 3(b) can be attributed to these circumstances.

(3) Relationship between population density and reliability of estimated populations for 3rd and 4th-order grids

Finally, we evaluated the relationship between reliability of populations estimated using MSS and population density. As with evaluation of geographic tendencies, this evaluation was done for 3rd and 4th-order grids.

Figure 4(a) illustrates the relationship between estimated populations and deviation rates on the 3rd-order grid, with populations estimated using MSS on the horizontal axis, and deviation rates on the vertical axis. Each grey point represents a single grid section. Curves approximating percentiles on either side of the deviation rate distributions are also shown in. These curves show that there is a relationship between the estimated population and the amount of scattering in the deviation rates. Fig. 4(b) shows that on the 4th-order grid.

The lines indicating percentiles in deviation rate in Fig. 4 approach a deviation rate of zero in both positive and negative regions as population values increase, showing that scattering in deviation rates decreases as population increases. In other words, as the estimated population in an area increases (higher population density), MSS can provide a more actual population estimate. This reflects the fact that as population density increases, more base stations must be installed to spread out the

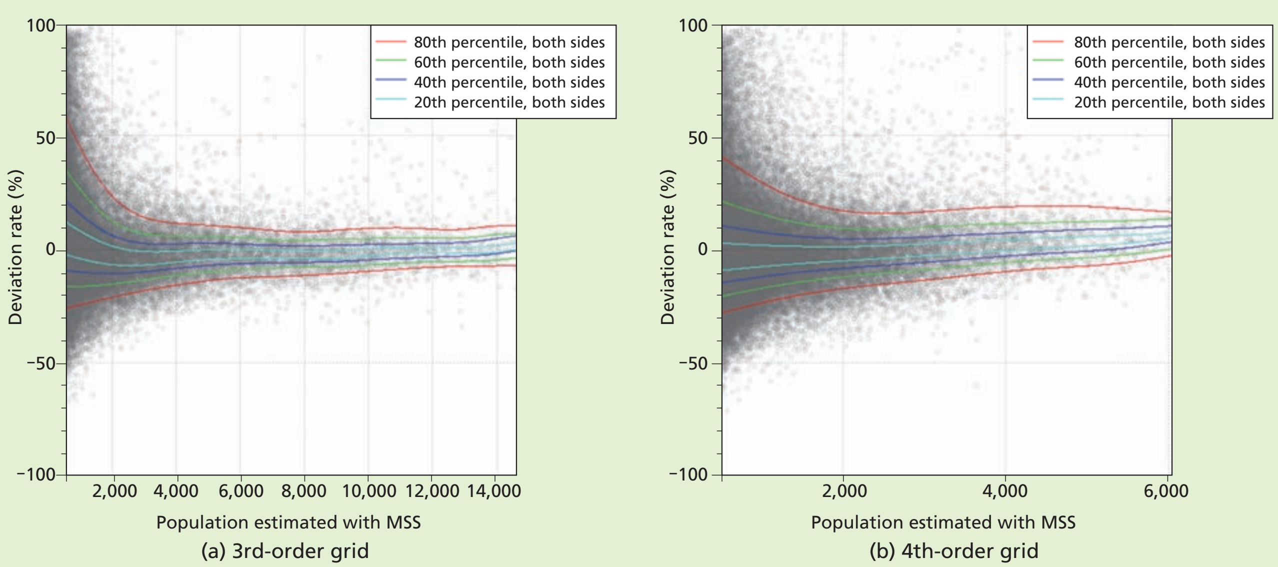


Figure 4 Deviation rate trends according to population density

communications load and as a result, the spatial resolution of MSS increases.

Fig. 4(a) also shows that on the 3rd-order grid, the curves rapidly approach a deviation rate of zero for population values from zero to approximately 3,000, and for areas with greater population, 80% of areas are within a deviation rate of ±10%. In other words, we can say for example, that MSS is reliable on the 3rd-order grid for Densely Inhabited Districts (DID)*4.

On the other hand, Fig. 4(b) shows that for the 4th-order grid, the scattering of the deviation rates decreases more slowly as the estimated populations increases, and for areas with population greater than approximately 2,000, the deviation rate is within ±20% for 80% of the areas. Densities comparable to densely inhabited districts, with 4,000/km^2, correspond to populations of approximately 1,000 per section on the 4th-order grid (approximately 500 m square), so depending on the application, MSS are promising for application in areas with population densities higher than so-called densely inhabited districts.

4. Conclusion

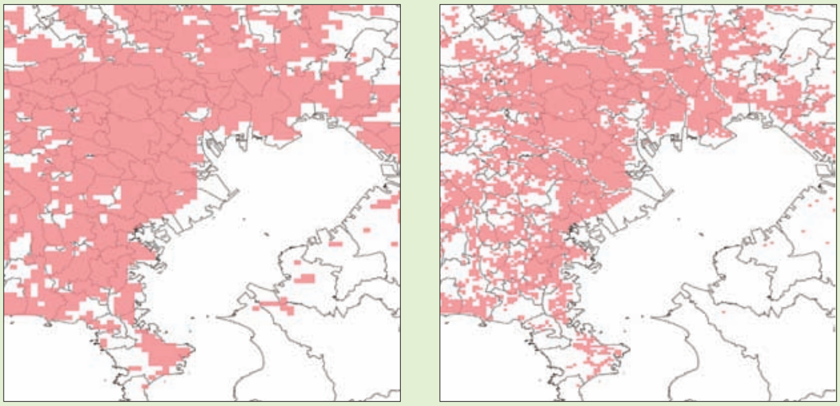
In this article we have evaluated the reliability of MSS, focusing on its relationship to spatial resolution.

As a result we have gained the following knowledge.

- MSS is reliable for administrative units at the prefectural and municipal levels, as well as 1st and 2nd-order grids.
- It is also reliable on the 3rd and 4th-order grids in areas of relatively concentrated population above a certain level, such as the flat areas around Tokyo. However, extra care may be necessary in handling estimated values for areas where the geography changes or the population is more scattered, such as coastal and mountain areas and along rivers.
- With the 3rd-order grid in particular, estimations are reliable in areas defined as densely inhabited. Regions that provide reliable results on the 3rd-order grid, in other words densely inhabited districts, are shown in **Figure 5**(a).
- Results on the 4th-order grid are more reliable as the population becomes denser, but population densities approximately twice that defined as densely inhabited are desirable. Regions that provide reliable results on the 4th-order grid, in other words with approximately twice the density of so-called densely inhabited districts, are shown in Fig. 5(b).

As discussed above, however, this evaluation was done comparing with populations from the 2005 National Census, so the results of this evaluation may indicate the accuracy as worse than it actually is. In particular, we observed strong effects due to population changes during the time since the census was taken, and also due to differences in the definitions of residential population and actual population.

In the future, we will study ways of evaluating the reliability more accurately by eliminating these effects and will use the knowledge gained in this evaluation to study more-reliable mobile spa-



Administrative division map source: MLIT National geographic data (2011 Administrative boundaries)

(a) 3rd-order grid

Administrative division map source: MLIT National geographic data (2011 Administrative boundaries)

(b) 4th-order grid

Figure 5 Areas where MSS is highly reliable

*4 **DID**: This is defined in the National Census as follows. The population of the area itself is 5000/km^2 or greater, and there are adjoining areas with population density of 4,000 /km^2 or greater.

tial estimation methods.

References

[1] MIC Statistics Bureau: "2005 National Census."
http://www.stat.go.jp/english/data/kokusei/index.htm.

[2] T. Odawara et al.: "Using Mobile Spatial Statistics in Field of Urban Planning," NTT DOCOMO Technical Journal, Vol. 14, No. 3, pp. 31-36, Jan. 2012.

[3] T. Suzuki et al.: "Using Mobile Spatial Statistics in Field of Disaster Prevention Planning," NTT DOCOMO Technical Journal, Vol. 14, No. 3, pp. 37-45, Jan. 2012.

[4] T. Nagata et al.: "Using Mobile Spatial Statistics for Local Revitalization," NTT DOCOMO Technical Journal, Vol. 14, No. 3, pp. 46-50, Jan. 2012.