MODELLING AND FACTOR ANALYSIS OF BUILDING LOT CONSOLIDATION IN BUILT-UP AREAS

TOSHIHIRO OSARAGI & TAKESHI INOUE
Department of Architecture and Building Engineering, Tokyo Institute of Technology, Japan

ABSTRACT
In the field of urban planning, building lots constitute a crucial area of study due to their role as the fundamental unit of land use. Consolidation of lots is advocated from the perspectives of environmental planning and disaster prevention, particularly in established urban areas of Japan where fragmentation of standard lots is prevalent. This study develops a stochastic model to depict the likelihood and probability of lot consolidation into larger spatial units. The model's unknown parameters are calibrated using GIS data provided by a local government ward in Tokyo, Japan. The analysis reveals that the probability of lot consolidation hinges primarily on relationships with neighbouring lots, geographic location and intrinsic lot characteristics. Furthermore, the spatial distribution of lot consolidation probability is visualised based on the estimated model.
Keywords: building lot consolidation, random utility theory, property of lot, property of place.

1 INTRODUCTION

Land subdivision is often perceived as constraining land use flexibility and diminishing the inherent potential of land, whereas land consolidation is viewed as enhancing land productivity, efficiency, and forming a basis for sustainable economic activities. Despite these characteristics, land subdivision tends to occur more readily compared to land consolidation. Research into land consolidation has been extensive, particularly focusing on agricultural land. For instance, Molnárová et al. [1] conducted a comprehensive review illustrating that land consolidation projects, implemented across diverse natural and socio-economic contexts globally, play a significant role in mitigating land degradation. Jiang et al. [2] emphasised the role of land consolidation in promoting rural sustainability, examining historical, political, legal, procedural, and public engagement perspectives. Pašakarnis and Maliene [3] asserted that land consolidation represents an effective proactive land management strategy, addressing issues of land fragmentation and potentially contributing to broader sustainable development goals if implemented judiciously. Crecente et al. [4] conducted economic, social, and environmental evaluations, comparing areas subjected to consolidation versus those that were not, demonstrating that land consolidation supports the preservation of agricultural land. Shan et al. [5], in a technologically advanced study, developed a theoretical framework based on six years of remote sensing data before and after land consolidation implementation. Their study offered theoretical guidance and methodological references for scientifically rigorous, objective, direct, and comprehensive long-term monitoring and evaluation. Additionally, Poropat [6] investigated land consolidation in urban contexts, proposing a planned model for consolidating building land while employing empirical and mathematical methodologies. Land consolidation was analysed through the integration of equations governing ownership rights allocation and application processes outlined in spatial planning documents.

Land in the city, especially in residential areas, is being divided into lots of ever-decreasing sizes [7]. From the point of view of improving the living environment and regional emergency management, however, it is desirable to consolidate small and narrow lots to form larger ones. Lot consolidation is one of the most important issues in land use, and it is

WIT Transactions on Ecology and the Environment, Vol 262,
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/SDP240241

essential for urban planners to have an accurate grasp of it. Much research has been done on this issue. Sakamoto [8] closely examined lot consolidation in Oshima-cho, Koto Ward, Tokyo and calculated the probabilities of change in lot condition and usage. Sakamoto and Osada [9] also analysed real cases of lot consolidation along streets that had been widened. Nakamura and Okata [10] studied mixed-zone districts with commercial and residential structures and analysed relations between the businesses and the supply of housing. Hayashi et al. [11] analysed the relationship between real estate tax systems and lot consolidation. Still, most of the available studies in this field are quite limited in the scope of the districts used, and no studies have used data from wide areas to examine the phenomena of lot consolidation.

This study examines the Setagaya Ward (containing about 150,000 lots) in Tokyo in an attempt to identify the characteristics of lot consolidation. Fundamental principles in the background of lot consolidation are extracted. The authors employ GIS data to classify the patterns in the consolidated lots and identify several fundamental aspects of lot consolidation. A model of consolidation probability is constructed to describe how likely a consolidation is to occur. This model is then used to predict how likely this is for a lot or the ways in which lots are most likely to be combined, and the kinds of districts in which this can be expected.

2 BASIS OF LOT CONSOLIDATION

2.1 Source data and extraction of basic consolidation patterns

GIS data for Tokyo incorporating land use regulations and building information and GIS data incorporating lot shapes in Setagaya Ward (1991, 1996) were examined to extract data on lot consolidation over time for the years given. The overwhelming majority (over 85%) of consolidations involved just two lots each. Therefore, this paper focuses on the combination of pairs of lots.

Many lots have quite complicated shapes, and they can be combined in a multitude of ways. There are several viewpoints from which one can approach classifying patterns in consolidation: one can focus on the boundary line shared by the two lots; one can examine how the lots face adjoining streets and the lot shapes; or one can observe the characteristics of the resulting lots. In the present study, it was assumed that the relationship between the two lots was an essential factor in consolidation, so differences in the boundary line shared by the lots were examined. Three combination patterns were identified (Fig. 1). This approach allows us to describe the relationship between the two lots and to describe the main

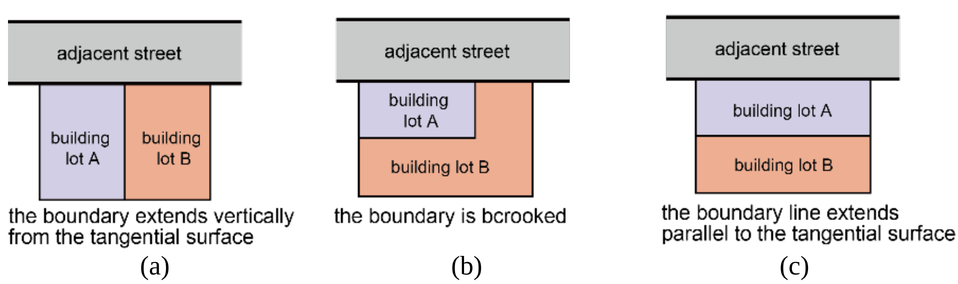
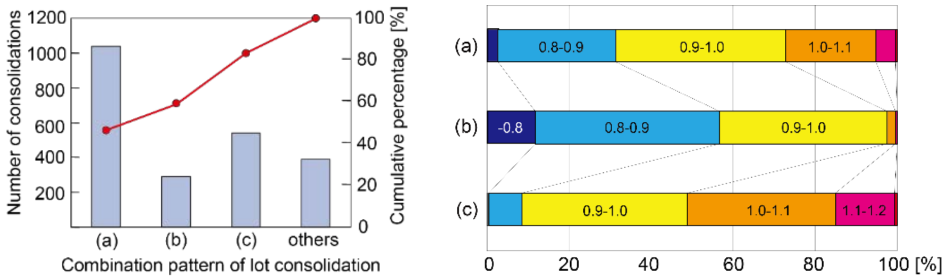


Figure 1: Three combination patterns of lot consolidation. (a) Expansion of lot area; (b) Improvement of lot shape; and (c) Improvement of lot connections to adjacent streets.

objectives of consolidation patterns: (a) expansion of lot area, (b) improvement of lot shape, and (c) improvement of lot connections to adjacent streets.

Fig. 2(a) shows the results of this classification. Over 80% of the consolidations could be classified into one of these patterns. Pattern (a) was the most common; the main objective was comparatively simple, to increase the lot area. The objective in Pattern (b) was to improve the lot shape, besides adding area, and that in Pattern (c), another common case, was to improve lot connections to adjacent streets.



(a) (b)

Figure 2: (a) Number of consolidation occurrences by consolidation pattern; and (b) Change in the perimeter–area ratio for the three patterns.

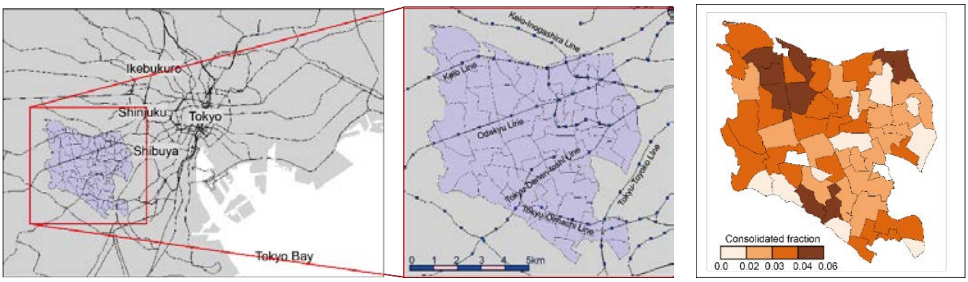
A basic goal shared by all the above patterns was to simplify the shape of the lot. Fig. 2(b) shows the distributions of change in the perimeter–area ratio (perimeter divided by the square root of area) for the three patterns, expressed as a ratio (i.e., perimeter–area ratio after merging divided by perimeter–area ratio before merging). Many cases showed change ratios lower than 1; this was true for over 95% of Pattern (b), with their particularly odd shapes. This figure illustrates how vital the issue of lot shape improvement was. Over 70% of Pattern (a) showed change ratios less than 1, for improved lot shapes. Fewer than 50% of the Pattern (c) cases showed change ratios less than 1, a much lower fraction than seen in Patterns (a) or (b). This affirms that there is another important goal in consolidation besides improvement of lot shape, i.e., improving lot connections to adjacent streets.

3 MODELLING OF CONSOLIDATION PROBABILITY AND MODEL RESULTS

3.1 Creating analysis data

Lot consolidation is rare in the central parts of Tokyo. About 4% of the lots in Setagaya Ward (Figs 3(a) and (b)) were consolidated during the study period (6,157 of 148,197 as of 1991, including consolidations of three or more lots). If data for all the lots in the ward were considered in this analysis, the distinguishing characteristics of the lots that had been merged could easily be lost amid the great diversity of the lots that were never merged. Therefore, the data were sampled as follows.

The 'actually consolidated fraction' is the fraction of lots in any given district that have been consolidated. Fig. 3(c) provides the spatial distribution of the actually consolidated fraction among the districts in the ward. This value varied widely, between 0.014 and 0.051. Some districts were quite different from neighbouring districts. This variety suggests that the action of consolidation could have been affected not only by characteristics of the lots directly



(a) (b) (c)

Figure 3: (a), (b) Study area; and (c) Spatial distribution of actually consolidated fraction.

involved, but also by characteristics of the district in which the lots were located. Therefore, pairs of non-consolidated lots were randomly selected from each district in the same percentage as the actually consolidated lots in the same district.

3.2 Formulation of the model

Below, observations are made about the character of a lot of interest i and its neighbouring lot j, and an equation is created to express the probability of consolidation of any two adjoining lots. This is termed the model of consolidation probability.

The probability that lot i will be subject to consolidation depends on the character (1) of the lot itself, (2) of the candidate lot j for consolidation, and (3) of the combination of the two lots. The potential for consolidation of lot i and neighbouring lot j, U_{ij}, is described by the following equation, containing the explanatory variable x_{kij} describing the characters of the lot formed by the consolidation of lot i and of neighbouring lot j, and the unknown parameters a_0 and a_k:

$$U_{ij} = a_0 + \sum_k a_k x_{kij}. \tag{1}$$

Suffix k represents a label of an explanatory variable. If we assume a Gumbel distribution for the error term of potential U_{ij}, we obtain the following logit model from the random utility theory:

$$P_{ij} = \frac{1}{1+exp[-U_{ij}]} \tag{2}$$

If we relate the above to the actual consolidation of lots, it means that the owners of two adjoining lots must have the intention of the action to take place. In other words, consolidation is likely if both probabilities P_{ij} and P_{ji} are high, and unlikely if either is low. Thus, the probability Q_{ij} is estimated from the product of P_{ij} and P_{ji}:

$$Q_{ij} = P_{ij}P_{ji}. \tag{3}$$

3.3 Method for calculations using the model

The binary variable d_{ij} (1, Consolidation; 0, No consolidation) is used to express whether or not the consolidation is consummated. The joint probability calculated by the above

www.witpress.com, ISSN 1743-3541 (on-line)

consolidation probability using the observed data is treated as a likelihood function L with unknown parameters:

$$L = C \prod_{i,j \in S} Q_{ij}^{\delta_{ij}} (1 - Q_{ij})^{(1-\delta_{ij})} \tag{4}$$

where C is positive constant, and S is the set of pairs of lots. The unknown parameters of the model can be estimated by maximising the non-linear likelihood function given in eqn (4). This was attempted with the conjugate gradient method by maximising the logarithm of the function [12], ln [L]. It is not guaranteed, however, that ln [L] is monomodal, and a solution method is at some risk of identifying a local solution. Therefore, random initial values were selected for a_0 and a_k over 100 trials, and the best result was used. Continuous quantity variables do not necessarily have a linear effect on the results, so the variables were categorised into several classes and treated as categorical variables. The statistically significant explanatory variables identified by the step-up procedure (Table 1) were incorporated into the model.

Table 1: List of factors that may influence land consolidation.

1. Lot area (m^2)	6. Building presence/absence	11. Legal building-to-land ratio (%)	16. Ratio of lot area
2. Perimeter area ratio	7. Building use	12. Legal floor area ratio (%)	17. Difference in number of adjacent streets
3. Length of frontage (m)	8. Zoning	13. Actual building-to-land ratio (%)	18. Increase in number of streets
4. Depth length (m)	9. Building area (m^2)	14. Actual floor area ratio (%)	19. Change in perimeter area ratio (%)
5. Number of adjacent streets	10. Gross floor area (m^2)	15. Front road width (m)	20. Road length change ratio (%)

Note: Lot area ratio = (larger area)/(smaller area).
Dummy variable: 1 if two lots have the same number of adjacent streets; 0 if they have different numbers of adjacent streets.
The ratio of area to the perimeter and adjacent length = (value of before consolidation)/(value of after consolidation).
Note that 1 to 15 are variables that express the characteristics of lot *i*, 16 and 17 are variables that express the relationship with the adjacent lot *j* and 18 to 20 are variables that express the characteristics of the lot formed after the consolidation.

Generally, the greater the number of types of explanatory variables and the more detailed the classifications of these variables, the more powerful the model is for describing its real-world counterpart. However, if one is not cautious in increasing the number of explanatory variables and categories, not only will the model become oversized and complicated, some actual structures in the data may be overlooked or mischaracterised. Therefore, the Akaike information criterion (AIC) [13], [14] was employed to determine which explanatory variables would be employed. The AIC provides an evaluation of a model for both compatibility and conciseness.

3.4 Compatibility of the model

Table 2 shows the explanatory variables used and Fig. 4(a) shows the distribution of estimated values for the consolidation probability Q_{ij}. The occurrence of consolidation and non-consolidation was predicted correctly for about 75% of the lots. This model showed a generally good predictive ability.

Table 2: Explanatory variables employed.

Order	Variable	Category
1	Change of perimeter area ratio	−0.9 / 0.9–1.0 / 1.0–1.1 / 1.1–1.2 / 1.2–1.3 / 1.3+
2	Total floor area	0–50 / 50–100 / 100+ (m^2)
3	Building use	Commercial / Residential / Industrial / Other
4	Number of adjacent streets	0 / 1 / 2
5	Land use zoning	1st Residential / Other Residential / Others
6	Ratio of expansion of lot area	1.0–1.2 / 1.2–1.6 / 1.6+ (m^2)
7	Lot area	0–50 / 50–100 / 100+ (m^2)

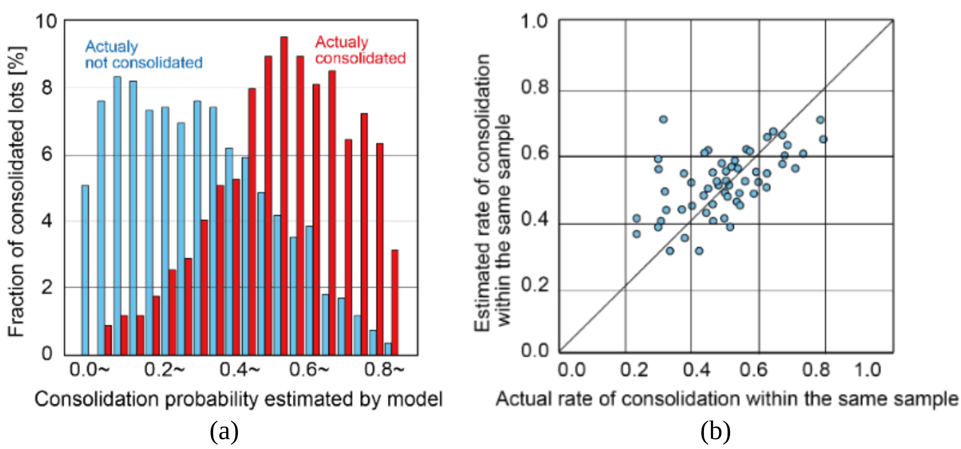


Figure 4: (a) Distribution of estimated values for the consolidation probability; and (b) Accuracy of estimating the actual consolidation rate.

The occurrence of consolidation or non-consolidation was predicted using Q_{ij} for each district, and the estimated rate of consolidation (estimated number of consolidations within a sample) and the actual rate of consolidation (actual consolidations within the same sample) are compared in Fig. 4(b). The estimates were not bad, but never very accurate. Eqns (1)−(3) had some ability to predict whether or not a lot pair i and j would be merged, but this model does not take sufficient account of the differing characteristics of districts. The following section describes an attempt to improve the model by incorporating explanatory variables that express district characteristics.

4 EXPANSION OF LOT CONSOLIDATION PROBABILITY MODEL

4.1 District characteristics

It is quite possible that the district surrounding lot i influences that lot's likelihood to be combined with another lot. Therefore, in addition to the explanatory variable y_{li}, which expresses the district characteristics, the potential U_{ij} for lot i to be merged with neighbouring lot j is expressed as follows:

$$U_{ij} = a_0 + S_{ij} + R_i, \tag{5}$$

where $S_{ij} = \sum_k a_k x_{kij}$, $R_i = \sum_l b_k y_{li}$, and l is a suffix expressing the explanatory variable for the district characteristics. S_{ij} here is the same variable as the second term in eqn (1) and could be called the 'affinity of the second lot to consolidation' (below, the 'affinity component'). R_i is the component related to district characteristics (below, the 'district characteristics component'). The district characteristics component comprehends a wide variety of parameters (y_{lj}); for example, the economic vigour of the district, the advantages of its location, the characteristics of its inhabitants, the living environment, or the urban environment.

A preliminary analysis is attempted in order to extract the variables with the deepest connections to lot consolidation. District variable d_{im} (1 if lot i belongs to district m, otherwise 0) is introduced to describe the district in an explanatory variable of the model. The potential U_{ij} is defined as follows:

$$U_{ij} = a_0 + \sum_k a_k x_{kij} + \sum_m c_m d_{im} \tag{6}$$

The coefficient of correlation between the actually consolidated fraction in the sample and the estimated number from the model in eqn (6) was 0.99. The coefficient c_m for the district variable expressed the characteristics of the districts quite well. The district coefficient c_m was then considered as a variable reflecting the likelihood for consolidations to occur in a district. Variables strongly correlated with c_m were considered for candidates for this y_{lj}. The 26 explanatory variables were added by the step-up procedure in order to determine the explanatory variable y_{li}.

4.2 Results of model run: observations

4.2.1 Lot contiguity component, affinity component

The reader can see the following conclusions from the estimated values for the parameters of the affinity component S_{ij} (Table 3).

The *change of the perimeter–area ratio* was a quite powerful predictor; the lower this value, the greater the likelihood of lots being merged. In other words, lot mergers resulting in a lot shape being closer to square, i.e., a 'regular shape', were more likely to occur. *Total floor area* and *building use* were also employed. Land use affected the choice to consolidate lots; empty lots, lots with small buildings, and industrial and commercial lots tended to be consolidated. Residential-use lots were only seldom consolidated. The number of streets to which a lot is connected is a statistically significant parameter. Lots unconnected to streets tended to be consolidated, and lots connected to two or more streets were also relatively prone to consolidation. When the *land use zoning* was exclusively residential, consolidation was

www.witpress.com, ISSN 1743-3541 (on-line)

Table 3: Estimated parameters of the S_{ij} model with regional characteristics (a_k).

Explanatory variables	**Category**	**Estimated parameters**
1. Change of the perimeter–area ratio	Less than 0.9	4.00417
	0.9–1.0	3.11427
	1.0–1.1	2.51048
	1.1–1.2	1.72462
	1.2–1.3	0.98300
	1.3 or more	0.00000
2. Total floor area	0–50 m^2	1.25073
	50–100 m^2	0.50633
	100 m^2 or more	0.00000
3. Building use	Commercial	0.85623
	Residential	−1.19761
	Industrial	1.08998
	Other	0.00000
4. Number of adjacent streets	0	0.97059
	1	−0.18358
	2 or more	0.00000
5. Land use zoning	First residential	−0.53208
	Other residential	−0.21477
	Other	0.00000
6. Ratio of expansion of lot area	1.6 or more	0.35548
	1.2–1.6	0.29122
	1.0–1.2	0.00000
7. Lot area	0–50 m^2	0.84357
	50–100 m^2	0.08880
	100 m^2 or more	0.00000
Constant term		−1.84443

relatively rare. The *ratio of expansion of lot area* suggests that adjoining pairs of lots of different sizes are prone to be consolidated, and the *lot area* suggests that the smaller a lot is, the more likely it is to be merged.

4.2.2 District characteristics component

Table 4 shows the estimated values of the parameters of model calibration for district characteristics component R_i.

Number of train stations in radiating pattern indicates that merging of lots is more common in districts with large numbers of stations, i.e., districts with good transportation connections, or in districts with high levels of commercial activity. *Equivalent green area ratio* indicates that districts containing little greenery in their environments have higher rates of lot consolidation. Districts with low *minimum required building-to-land ratios* tend to show a relatively steady progression of lot consolidation. At the same time, districts with low *minimum required building-to-land ratios* also showed relatively high rates of consolidation. The variable of *number of commercially zoned buildings within 200 m of the station* showed the same trend as *equivalent green area ratio*; districts with no railway stations or with few

Table 4: Estimated parameters of the regionality model R_i (b_l).

Explanatory variable	Category	Parameter
1. Number of train stations in radiating pattern	2 or more	0.91119
	1	0.21639
	0	0.00000
2. Equivalent green area ratio	Less than 10%	1.07943
	10–30%	1.26421
	30% or more	0.00000
3. Minimum required building-to-land ratios	30%, 40%	0.31814
	50%	0.01768
	60%	0.00000
4. Number of commercially zoned buildings within 200 m of the station	Less than 50	−0.21516
	50–100	0.24395
	100 or more	0.00000
5. Fraction of wooden multiple-dwelling buildings among residential buildings	Less than 2%	−0.45557
	2% or more	0.00000
6. Fractions of residents owning residences	Less than 55%	−0.25926
	55% or more	0.00000
7. Fraction of dwellings occupied by lone residents over 64 years old who have surviving immediate family	Less than 25%	0.12263
	25% or more	0.00000

commercial buildings near the stations showed lower rates of consolidation. The variable of *fraction of wooden multiple-dwelling buildings among residential buildings* showed relatively high consolidation rates where there were many wooden-construction rental residences. Districts with high *fractions of residents owning residences* showed higher rates of consolidation, and those with high fractions of rental units had lower rates of consolidation. Lastly, the variable of *fraction of dwellings occupied by lone residents over 64 years old who have surviving immediate family* predicted lower rates of consolidation in districts with high numbers of elderly residents living alone.

Thus, lot consolidation was found to be strongly affected by a variety of characteristics of districts, such as commercial activity, the greenness of the environment, or the circumstances of the residents. Urban development enhances the activity of the surrounding districts. This tends to promote lot consolidation, but a tendency was also found for the pace of consolidation to slow in over-developed areas.

4.3 Compatibility of district characteristics model

Fig. 5 compares the actually consolidated fraction in each district with the estimated fraction. The compatibility of this model had been improved over that shown in Fig. 4(b). Thus, addition of the district characteristics component R_i had enabled the model to express relevant aspects of the district. Still, consolidation remained underestimated in some districts (Tamagawa Den'en Chofu and Tamazutsumi). These districts actually showed the same level of consolidation as other districts; underestimates were blamed on the conditions of the lot being somewhat better than in other districts.

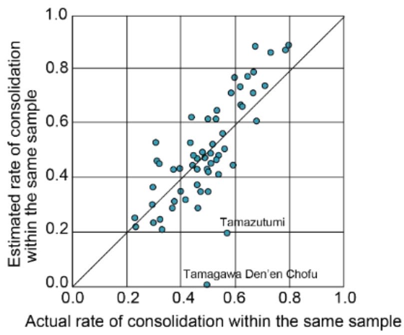
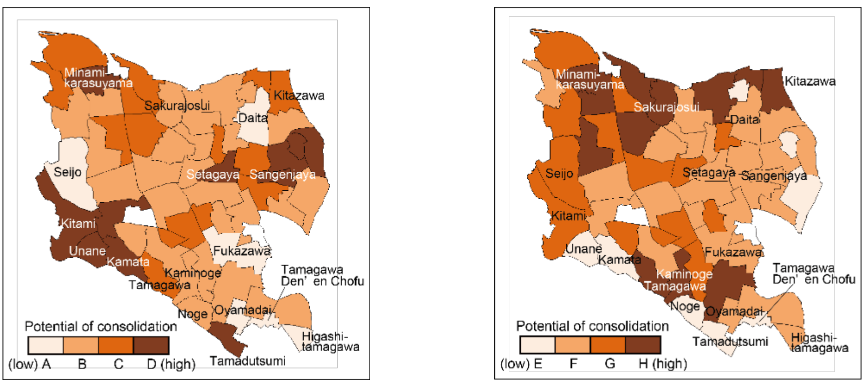


Figure 5: Accuracy of estimating the actual integration rate.

4.4 Characteristics of spatial distribution of consolidation potential

The model of consolidation probability was applied to the entire set of lots. The estimated values for parameters a_k and b_l were inserted to find the values for affinity component S_{ij} and district characteristics component R_i, which determined the potential U_{ij} for lot consolidation. The value of S_{ij} depends on the candidate neighbouring lot j, however, so here, the lot j that provides the maximum value of Q_{ij} is selected as the lot for consolidation. The means within district m are designated S^m, R^m. The levels of S^m and R^m are plotted in Fig. 6, A–H in the legend correspond to A–H in Fig. 7, described below.



(a) (b)

Figure 6: (a) Spatial distribution of S^m; and (b) Spatial distribution of R^m.

Fig. 6(a) reveals that Seijo and Fukazawa, as well as south-eastern locations such as Higashi-tamagawa, Tamagawa Den'en Chofu, and Oyamadai, have relatively low values for affinity component S^m. Districts with low S^m have relatively good characteristics for placing residences. It is essential to maintain this situation for the districts to the greatest extent possible. Meanwhile, S^m showed high values in Setagaya, Sangenjaya, and other locations in the densely populated central part of Setagaya Ward. It was also high in Kitami, Unane, and other localities in the southwest. While districts with high S^m have relatively unwelcoming characteristics for the consolidation of lots, consolidation should be pursued in these areas.

Examining the district characteristics component R^m in Fig. 6(b), we see low values in Unane, Kamata, Noge, and other locations in the south of the ward. This is because there is relatively low commercial activity in these areas compared to parts of the north including Kitazawa, Sakurajosui, and Minamikarasuyama, and other parts of the south such as Tamagawa and Kaminoge.

Fig. 7 shows how S^m and R^m vary with each other. The averages of S^m and R^m, M_S and M_R, are placed at the centre of the chart, and the chart is divided into 16 sectors by multiples of the respective standard deviations σ_S and σ_R. The higher the values of S^m and R^m, the higher the potential for lot consolidation, i.e., the greater the likelihood of consolidations in the given district. No districts were found with low S^m and high R^m (sector (A, H)); like Seijo, with its image as a location with a pleasant environment, is plotted near this sector. There are also few districts with high values of both S^m and R^m; Minami-karasuyama is the only district in sector (D, H). Many districts have high S^m and low R^m (sector (D, E); generally, districts with high S^m tended to have low R^m). Since S^m is high in these districts, many lots are available for consolidation, but the low R^m means that consolidation is unlikely.

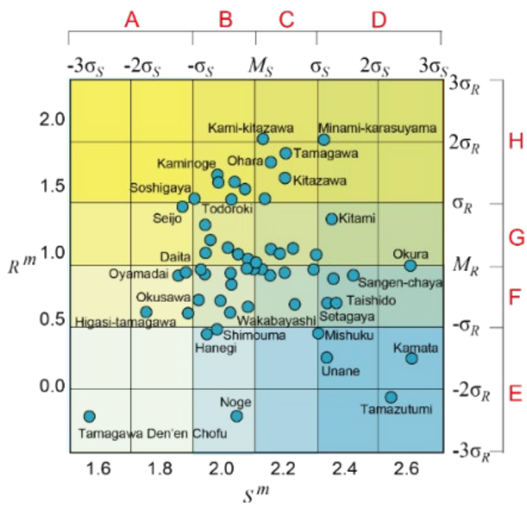


Figure 7: Relationships between S^m and R^m.

The issue in urban planning is to promote lot consolidation in districts like those plotted in the lower right quarter of Fig. 7. To the extent Table 4 can be trusted, it predicts difficulties in direct control of the variables that describe R^m; however, the value of R^m is closely connected with the economic vitality of a district, so there is potential to raise R^m by a judicious upgrading of land use classification. A close observation of the ranges of S^m and R^m show that R^m has a wider distribution. Thus, R^m may have a greater influence over the probability of consolidation than S^m. Factors related to the variables making up R^m and new policies need to be investigated in order to raise the potential for consolidating lots.

5 SUMMARY AND CONCLUSIONS

This was an investigation into the factors affecting the consolidation of city lots. A model was constructed to describe the probability of any two contiguous lots being merged. Setagaya Ward in Tokyo, Japan was selected for analysis as a typical example of a densely populated and developed urban region. A model was developed and employed to assess Setagaya Ward. It was shown that lot consolidation is determined by the characteristics of the region and by the relationship of the lot with the candidate neighbouring lot and is also greatly influenced by the characteristics of the immediately surrounding district.

It has been assumed that the decision to merge neighbouring lots is dominated by the motives of property owners and other individual factors, but many common tendencies in consolidation were found. The model constructed here was used to show district-by-district spatial distributions of characteristics affecting the likelihood for lots to be combined. This model will allow the user to extract locations where lot consolidation is likely or unlikely to occur, allowing planners to investigate policies that are based on the promotion of lot consolidation.

ACKNOWLEDGEMENTS

A portion of this paper was published in Osaragi and Inoue [15], which was written in Japanese and in a format of non-available automatic translation. The authors believe that the manuscript added the latest research reviews and much discussion would be of great value to publish in English.

REFERENCES

[1] Molnárová, K.J., Sklenička, P., Bohnet, I.C., Lowther-Harris, F., van den Brink, A., Moghaddam, S.M., Fanta, V., Zástěra, V. & Azadi, H., Impacts of land consolidation on land degradation: A systematic review. *Journal of Environmental Management*, **329**, 2023.

[2] Jiang, Y., Tang, Y.T., Long, H. & Deng, W., Land consolidation: A comparative research between Europe and China. *Land Use Policy*, **112**, 2022.

[3] Pašakarnis, G. & Maliene, V., Towards sustainable rural development in Central and Eastern Europe: Applying land consolidation. *Land Use Policy*, **27**(2), pp. 545–549, 2010.

[4] Crecente, R., Alvarez, C. & Fra, U., Economic, social and environmental impact of land consolidation in Galicia. *Land Use Policy*, **19**(2) pp. 135–147, 2002.

[5] Shan, W., Jin, X., Ren, J., Wang, Y., Xu, Z., Fan, Y., Gu, Z., Hong, C., Lin, J. & Zhou, Y., Ecological environment quality assessment based on remote sensing data for land consolidation. *Journal of Cleaner Production*, **239**, 2019.

[6] Poropat, A., Planned building land consolidation in the context of land subdivision of a unique plot. *Tehnicki Vjesnik-Technical Gazette*, **24**(3), pp. 887–895, 2017.

[7] Osaragi, T., stochastic models describing subdivision of building lots, design and decision support systems in architecture and urban planning. *Procedia Environmental Sciences*, **22**, pp. 352–356, 2014.

[8] Sakamoto, I., 敷地条件を考慮した都市の土地利用推移に関する基礎的考察. *Journal of the City Planning Institute of Japan*, **14**, pp. 19–24, 1979. https://doi.org/10.11361/journalcpij.14.19.

[9] Sakamoto, I. & Osada, N., Empirical study of the site-combination in the built-up area. *Journal of the City Planning Institute of Japan*, **19**, pp. 325–330, 1984. https://doi.org/10.11361/journalcpij.19.325.

[10] Nakamura, H. & Okata, J., The relationship between project decision makers and a housing supply of the lot-consolidation in the mixed land use central business district: A case study on the lot-consolidations in Kanda Sakae District, Chiyoda-ku. Tokyo. *Journal of the City Planning Institute of Japan*, **33**, pp. 775–780, 1998.

[11] Hayashi, Y., Kato, H., Sugihara, K., Tanaka, Y. & Yoshioka, M., A model analysis and visualization evaluation system with promotion of site combination due to control and taxation and regulation to real estate in an existing urbanized area. *Proceedings of Infrastructure Planning*, **23**, pp. 475–478, 2000.
[12] Press, W.H., Teukolsky, S.A., Vetterling, W.T. & Plannery, B.P., *Numerical Recipes in Fortran 77: The Art of Scientific Computing*, 2nd edn, Cambridge University Press: Cambridge, 1992.
[13] Akaike, H., Information theory and an extension of the maximum likelihood principle. *Proceedings of the 2nd International Symposium on Information Theory*, eds N Petron & F. Csak, Akademiai kaido: Budapest, pp. 267–281, 1972.
[14] Akaike, H., A new look at the statistical model identification. *IEEE Transactions on Automatic Control*, **19**(6), pp. 716–723, 1974.
[15] Osaragi, T. & Inoue, T., Modeling and analysis of lots consolidation in established city area. *Journal of Architecture and Planning*, **70**(592), pp. 147–153, 2005.