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A Decision Support Method for School Relocation Planning

Yukio Sadahiro* and Saiko Sadahiro**

*****Department of Urban Engineering, University of Tokyo
**Faculty of Education, Chiba University

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Abstract: Children have been gradually decreasing in European and Asian developed countries. Schools have to be closed or integrated to keep the educational environment and economical efficiency. School relocation planning, however, is not an easy process because it involves various sectors and professions. Due to the diversity of participants and ambiguity in plan evaluation, it takes quite a long time to reach a final agreement. To treat this problem, the present paper proposes a new method of decision support for school relocation planning. The method aims to help the discussion of school relocation problem from various perspectives rather than directly suggest the candidates for the final decision. School relocation problem is formulated as a capacitated set covering problem, and its solutions are analyzed to reveal the properties of the school relocation problem. Numerical measures are introduced to evaluate the effect of desirable conditions on school location. Schools are then divided into subgroups in each of which a relocation problem can be discussed independently. The method is applied to a relocation planning of elementary schools in Chiba City, Japan. It illustrates a concrete usage of the method proposed as well as provides empirical findings.

Keywords: Decision support, school relocation planning, location optimization

1. Introduction

Due to a decrease in birth rate, children have been gradually decreasing in European and Asian developed countries. Every school has fewer children, which is not desirable in both economical and educational aspects. Small schools are economically inefficient because of the basic cost of school management. Schools should be large enough to assure the social interaction among children at school (Bruno and Andersen, 1982; Winblad and Dudley, 1997; Helen, 2002). School relocation is pressing to keep the school size at an appropriate level.

To devise a school relocation plan, location optimization is often utilized (Clarke and Surkis, 1968; Bruno and Andersen, 1982; Greenleaf and Harrison, 1987; Molinero, 1988). School relocation is formulated as a location optimization problem with constraints. Its solution gives a set of existing schools to be kept open that is optimal in a certain aspect.

School relocation, however, requires consideration of various elements other than school size (Valencia, 1984; Bondi, 1987; Pizzolato *et al*., 2004). Accessibility to schools is critical for both the safety and health of pupils especially at the primary and secondary education levels (Autunes & Peeters, 2000; Cooper *et al*., 2005; Sallis & Glanz, 2006; Falb *et al*., 2007; Smith, 2009). Schools should be close enough to pupils so that they can walk or cycle rather than are driven to schools. Racial and ethnic balance is also critical, especially in the United States (Knutson *et al*., 1980; Woodall *et al*., 1980). Existing school districts and local communities need consideration to avoid drastic change of the social environment of pupils.

Problem formulation requires the above elements to be evaluated quantitatively and incorporated as either an objective function or constraints. However, it is often quite difficult to measure the importance of all the elements in an objective and quantitative way. It is practically impossible to represent them as a single objective function and constraints.

One possible solution to this problem is to utilize multiobjective optimization (Ross, 1980; Lee *et al*., 1981; Min, 1988; Current *et al*., 1990; Malczewski and Jackson, 2000). Multiple objective functions are formulated and Pareto optimal solutions are sought at each of which any objective function cannot be improved without worsening the others. Efficient algorithms have been proposed in the literature to solve the problem (Shaffer, 1985; Coello, 1999; Ehfgott, 2000; Deb, 2001; Lotov *et al*., 2004; Lozano and Villa, 2009). Interactive multiobjective optimization tools help decision makers to seek solutions closer to their own preference (Deb and Chaudhuri, 2005; Branke *et al*., 2008).

Unfortunately, multiobjective optimization is still not enough for collaborative school relocation planning. Some elements cannot be evaluated fully quantitatively. The diversity of participants makes it difficult to formulate a single set of objective functions and constraints. Evaluation of school plans is often ambiguous and inconstant. Consequently, even if a problem is formulated, it still contains ambiguity and uncertainty so that its Pareto optimal solutions cannot be directly used as candidates for the final plan.

To resolve these problems, this paper proposes a new method of decision support for school relocation planning. Considering the diversity and ambiguity mentioned above, this paper aims to keep the flexibility in planning process. An emphasis is on the understanding and discussion of the properties of school relocation problem rather than the proposal of candidates for the final decision.

Section 2 outlines the methodology of decision support. School relocation problem is formulated as a capacitated set covering problem. Its solutions are analyzed to reveal the properties of school relocation problem, especially the effect of constraints on school location. Schools are then divided into smaller subgroups in each of which a single relocation problem can be discussed independently. This makes it easier to evaluate and compare alternative plans, and consequently, to reach a final agreement. To discuss the benefits and limitations of the method, Section 3 applies the method to a school relocation planning in Japan. Section 4 summarizes the conclusions with a discussion.

2. Decision support method

2.1 General setting

In this paper, we focus on the relocation of public elementary and secondary schools to cope with a decrease in children. Our objective is to reduce existing schools in order to keep the economic efficiency of school management and the educational environment of pupils. For the present, we consider only the simple closure of schools, leaving the opening of new schools out of the scope.

School relocation planning requires various elements to be considered as mentioned earlier. Examples include school size, class size, school accessibility, racial and ethnic balance, school districts, teachers’ quality, outdoor setting, traffic condition, and so forth. Among these elements, this paper focuses on the most important two elements, that is, school size and school accessibility. Other elements either one or both

School size is crucial to keep the quality of education (Winblad & Dudley, 1997; Helen, 2002). Schools should be neither too small nor too large for effective education. Social interaction among pupils often becomes insufficient in small schools. Small schools are also economically inefficient, and as a result the quality of teachers and educational facilities declines due to cost limitation. In large schools, on the other hand, school management often goes beyond the ability of school masters and principals.

School accessibility is also critical in school relocation. Pupils have to take school buses or to be driven by car to attend distant schools. Walking to school is desirable from an ecological perspective and is effective for keeping the physical and mental health of pupils (Autunes & Peeters, 2000; Cooper *et al*., 2005; Sallis & Glanz, 2006; Falb *et al*., 2007). In addition, school districts should be as small as local community areas. It permits local communities to participate in school education and to provide an environment of social education for pupils.

Concerning the school size and accessibility, desirable criteria are often suggested by government ministries or research institutes. They are typically represented as the minimum and maximum number of pupils, and the maximum distance from home to school. They are usually desirable conditions rather than strict constraints that must be always satisfied. We call them *desirable conditions* hereafter, and discuss their effect on school location.

2.2 Formulation of the problem

Suppose a set of existing schools $\Lambda=\{S_i,\ i\in[\mathcal{M}]\}$, where $[\mathcal{M}]=\{1, 2, ..., M\}$. The number of pupils is reported based on spatial units such as census tracts whose representative points are denoted by $\Phi=\{R_j,\ j\in[\mathcal{N}]\}$, where $[\mathcal{N}]=\{1, 2, ..., N\}$. The number of pupils in unit j is n_j. The distance between school S_i and representative point R_j is denoted by d_{ij}. The capacity of school S_i is C_i.

Three desirable conditions are given a priori: the minimum and maximum number of pupils and the maximum distance from home to school. In school relocation, however, it is not meaningful to consider the minimum number of pupils as a constraint. The maximum number of pupils is usually equal to the capacity of school. Consequently, the school capacity and the maximum distance from home to school are considered in the following. The latter is denoted by $d_{\max}$.

School relocation problem is formulated as a simple capacitated set covering problem (Current and Storbeck, 1988; Bar-Ilan *et al.*, 1993; Caprara *et al.*, 1999). The number of schools is minimized under the constraints defined by the desirable conditions. Pupils who do not have any accessible school at present are not considered. Whether school S_i is kept open or closed is denoted by binary function x_i. The allocation of pupils at R_i to S_i is also denoted by binary function y_{ij}. The problem is then formulated as

Problem M$_1$:

$$\min_{x_i, y_{ij}, i \in \mathfrak{m}, j \in \mathfrak{n}} \sum_{i \in \mathfrak{m}} x_i \, .$$

subject to

$$\sum_{j \in \mathfrak{n}} n_j y_{ij} \le x_i C_i \quad \left(\forall i \in \mathfrak{m}\right)$$
$$y_{ij} d_{ij} \le d_{\max} \quad \left(\forall i \in \mathfrak{m} \ \forall j \in \mathfrak{n}\right).$$
$$\sum_{i \in \mathfrak{m}} y_{ij} = 1 \quad \left(\forall j \in \mathfrak{n}\right)$$

The problem is NP-hard (Megiddo & Supowit, 1984). Nevertheless, recent solvers can find the exact optimal solution for capacitated set covering problems of considerable size (Caprara *et al.*, 2000; Berman *et al.*, 2010). If the problem involves numerous schools and representative points, heuristic methods are available such as those based on greedy algorithm, Lagrangian relaxation and genetic algorithm (Bar-Ilan *et al.*, 1993; Caprara *et al.*, 1999; Berman *et al.*, 2010).

Solving Problem M$_1$, we obtain the minimum number of schools and a set of schools to be kept open. This solution, however, is not enough for practical use. One reason is that not only a single set of schools minimizes the number of schools. There can be numerous sets of schools that give the solution of Problem M$_1$. Another reason is that Problem M$_1$ considers only two conditions as constraints and omits other elements. There may be better solutions if other elements are taken into account.

To treat these problems, we relax Problem M$_2$ and derive further alternative plans that reduce the number of schools to a reasonable level. This enhances the flexibility and assures the diversity in school relocation planning. A new problem is formulated as follows:

Problem M$_2$:

Enumerate a sufficient number of solutions $\mathbf{x}$ satisfying

$$m_{\min} \le \sum_{i \in \mathfrak{m}} x_i$$

subject to

$$\sum_{j\in\mathfrak{n}} n_j y_{ij} \le x_i C_i \quad (\forall i \in \mathfrak{m})$$
$$y_{ij} d_{ij} \le d_{\max} \quad (\forall i \in \mathfrak{m}\ \forall j \in \mathfrak{n}).$$
$$\sum_{i\in\mathfrak{m}} y_{ij} = 1 \quad (\forall j \in \mathfrak{n})$$

Let $\{x_i\}=\{\eta_i\}$ be a solution of Problem M_1. A naive method to solve Problem M_2 is based on the swap of 0 and 1 in set $\{\eta_i\}$. From the initial set $\{\eta_i\}$, we swap 0 and 1 in turn until it fails to satisfy the constraints. We then turn 0 to 1 on one element in the initial set $\{\eta_i\}$ and do the same swap procedure. We repeat this process until a sufficient number of alternatives are obtained.

Unfortunately, this method works effectively only for a small scale problem. A more efficient method is to employ a modular approach (Nakagawa, 1990). The method has been applied to a variety of integer programming problems including multiple-choice knapsack problem and nonlinear integer programming and is found to yield solutions in a practical computing time (for details, see Nakagawa and Iwasaki, 1999; Nakagawa *et al.*, 2002, 2005).

2.3 Evaluation of the effect of desirable conditions

Using the alternative plans obtained above, we then analyze the properties of school relocation problem. A focus is on the relationship between desirable conditions and the flexibility of school location.

The effect of desirable conditions is reflected in the necessity of schools. If, for instance, a number of pupils are clustered in a small area and the desirable school size is small, many schools have to be kept open to serve all the pupils. However, if large schools are permitted, schools can be further reduced for economic efficiency.

The effect of desirable conditions is evaluated in two aspects. *Size demand* indicates the strength of school necessity originating from the size condition and the relationship between pupil and school distributions. Size demand becomes high if the desirable school size is small or a few schools are surrounded by many pupils. *Accessibility demand* is the strength of school necessity based on the relationship between the school accessibility condition and the distributions of pupil and schools. A high accessibility condition or a sparse distribution of schools increases the accessibility demand.

The above demands are evaluated by two numerical measures. Let Ψ be the set of T alternative plans $\{\Omega_1, \Omega_2, ..., \Omega_T\}$. Plan Ω_k consists of a set of binary variables $\{\sigma_{1k}, i\in[\mathcal{M}]\}$ and $\{\delta_{ijk}, i\in[\mathcal{M}], j\in[\mathcal{N}]\}$ that indicate whether schools are kept open or closed and the allocation of pupils to schools.

Adoption rate is the ratio of alternative plans in which a school is kept open. The adoption rate of school S_i is denoted by ra_i:

$$ra_i = \frac{1}{T}\sum_k \sigma_{ik} \ . \tag{1}$$

Occupancy rate is the ratio of the total number of pupils to the total capacity of a school:

$$ro_i = \frac{\sum_k \sum_j n_j \delta_{ijk}}{TC_i}.\tag{2}$$

The adoption rate is based on both the size and accessibility demands while the occupancy rate is related only to the size demand. The former becomes large if either the size or accessibility demand is high, while the latter becomes large only if the size demand is high. The following inequality holds between the two rates:

$$ro_i \leq ra_i.\tag{3}$$

The two measures cannot evaluate the strength of the two demands separately because the adoption rate is related to both demands. If the two rates are high, whether the accessibility demand is high or not is not known.

To complement the rate measures, we propose another two measures. They are calculated independent of the alternative plans obtained from Problem M_2.

Let ξ_{ij} be a binary function indicating whether school S_i is accessible from representative point R_i:

$$\xi_{ij} = \begin{cases} 1 & \text{if } d_{ij} \leq d_{\max} \\ 0 & \text{otherwise} \end{cases}.\tag{4}$$

If pupils are randomly allocated to one of their accessible schools, the number of pupils allocated to school S_i is given by

$$c(S_i) = \sum_j \frac{n_j \xi_{ij}}{\sum_l \xi_{lj}}.\tag{5}$$

This variable indicates the potential number of pupils. If it is larger than C_i, new schools may have to be built to serve all the pupils. Consequently, by dividing $c(S_i)$ by C_i, we can evaluate the strength of size demand:

$$\begin{aligned} ds_i &= \frac{c(S_i)}{C_i} \\ &= \frac{1}{C_i} \sum_j \frac{n_j \xi_{ij}}{\sum_l \xi_{lj}}. \end{aligned}\tag{6}$$

We call this the *size demand measure*.

The strength of accessibility demand is evaluated by the *accessibility demand measure*. It is the ratio of the number of pupils allocated to school S_i to that of pupils accessible to S_i:

$$\begin{aligned} da_i &= \frac{c(S_i)}{\sum_j n_j \xi_{lj}} \\ &= \frac{1}{\sum_j n_j \xi_{lj}} \sum_j \frac{n_j \xi_{lj}}{\sum_l \xi_{lj}}. \end{aligned}\tag{7}$$

If a school is surrounded by pupils of many accessible schools, its accessibility demand measure becomes small. The measure becomes large if pupils have only a few accessible schools.

The range of the above two measures is as follows:

$$\begin{gathered} 0 \le ds_i \\ 0 < da_i \le 1 \end{gathered} . \tag{8}$$

Size demand measure does not have any upper limit while distance demand measure is equal or smaller than one. The demand measures are independent with each other so that they can separately evaluate the strength of size and accessibility demands for schools.

In addition to the above measures, it is useful to pay a special attention to schools that serve pupils who have only one accessible school. We call them *indispensable schools*. Note, however, that schools whose accessibility demand measure is equal to one are indispensable schools while the converse does not always hold. A school is indispensable even if it has only one pupil who has only one accessible school. Similarly, the adoption rate cannot be used as an indicator of indispensable schools. Schools of high size demand can appear in all the alternative plans even if they are not indispensable schools.

2.4 School grouping

This subsection proposes a method of dividing schools into subgroups in each of which school relocation planning is discussed independently. School grouping is effective especially when numerous schools are involved in relocation planning. This makes it easier to understand the properties of individual schools and to devise a school relocation plan.

School grouping starts with the construction of Delaunay triangulation of existing schools. Outer edges twice longer than $d_{\max}$ are eliminated.

On this triangulation, every school pair connected directly by a single link is examined. We extract school pairs that are independent or complementary with each other. Two schools S_i and S_j are *independent* if they are included in alternative plans independently with each other. The schools are *complementary* if either S_i or S_j is included in each plan.

For each neighboring pair of schools, we count the frequency of alternatives as follows:

f_{ij}: The number of alternatives where both S_i and S_j are kept open.
f_{i0}: The number of alternatives where S_i is kept open while S_j is closed.
f_{0j}: The number of alternatives where S_i is closed while S_j is kept open.
f_{00}: The number of alternatives where both S_i and S_j are closed.

The contingency table is given by

$$\begin{array}{cc|c} f_{ij} & f_{i0} & F_i \\ f_{0j} & f_{00} & M\text{-}F_i \\ \hline F_j & M\text{-}F_j & M \end{array}$$

The probability of each case happening is

p_{ij}	p_{i0}	P_i
p_{0j}	p_{00}	$1\text{-}P_i$
P_j	$1\text{-}P_j$	1

If S_i and S_j are included in alternative plans independently with each other, the following equations hold:

$$\begin{aligned} p_{ij} &= P_i P_j \\ p_{i0} &= P_i\left(1-P_j\right) \\ p_{0j} &= \left(1-P_i\right)P_j \\ p_{ij} &= \left(1-P_i\right)\left(1-P_j\right) \end{aligned} \quad . \tag{9}$$

Independent pairs of schools are extracted by the chi-square or Fisher’s exact test. The latter is used when the table contains a cell of very small count. In either test, the null and alternative hypotheses are:

H_0: The schools are included in alternative plans independently with each other.
H_1: The schools are included in alternative plans not independently with each other.

The null hypothesis is accepted if the statistic is small enough.

Complementary schools can also be extracted by a statistical test. The null and alternative hypotheses are:

H_0: The schools are included in alternative plans independently with each other.
H_1: Either of the schools is included in every alternative plan.

To extract complementary schools, $f_{i0}+f_{0i}$ is used as a statistic. Its distribution is evaluated under the null hypothesis and the null hypothesis is rejected if the statistic is extremely large.

For each neighboring pair of schools, the two statistical tests are performed. The result is visualized as a map such as shown in Figure 1. Complementary schools are connected by bold lines while independent schools are connected by dotted lines.

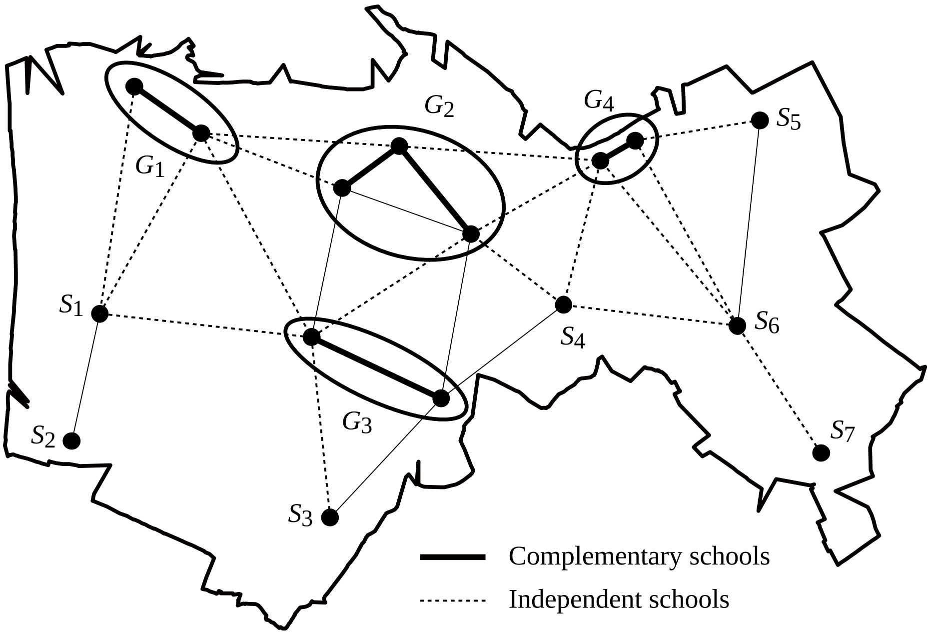

Figure 1 Complementary and independent schools. Ellipses indicate school groups in each of which relocation plan is considered independently. Schools are indicated by school groups (G_i) or individuals (S_i).

If a school is independent from all its neighboring schools, whether to keep the school open can be determined separately from others. If two schools are complementary with each other, one should be kept open and the other should be closed.

Complementary schools connected by bold lines in Figure 1 form school groups. Dotted lines give the boundary between groups. More than two schools may be connected by bold lines, which form a larger school group.

In groups G_1 and G_4 schools are connected by bold lines within the groups and by dotted lines between neighboring schools. These groups are highly independent of other schools so that their relocation plan can be discussed separately from that of others. Since either group consists of two complementary schools, discussion focuses on which school is more desirable to be kept open.

In group G_3, two schools are connected by bold lines within the group but they are not independent of their neighbors. This group is weakly independent of others so that its relocation plan should be discussed with that of neighboring groups and schools.

Group G_2 is also not independent of its neighbors. Since the group consists of three complementary schools, two options are available: two schools at the ends of bold lines or one school at the middle. Discussion should be made with relocation planning in G_3.

Schools S_1 and S_2 can be regarded as a school group, though they are not complementary with each other. Since they are independent of their neighbors, their relocation plan can be discussed separately from others. Similarly, whether to keep school S_7 open can be determined independently of others. It depends on the necessity of S_7 represented by the numerical measures proposed earlier.

3. Application

This section applies the proposed method to school relocation planning in Inage and Wakaba wards in Chiba city, Japan. These wards are located 30 kilometers away in an eastern suburb of Tokyo.

Inage ward has 7831 pupils and 16 schools, while Wakaba ward has 7965 pupils and 20 schools. The average number of pupils of a school is 489 and 398 pupils, respectively. Pupils have been decreasing in both wards since 1981. School reduction has been being discussed to keep educational environment of schools and economic efficiency of educational finance.

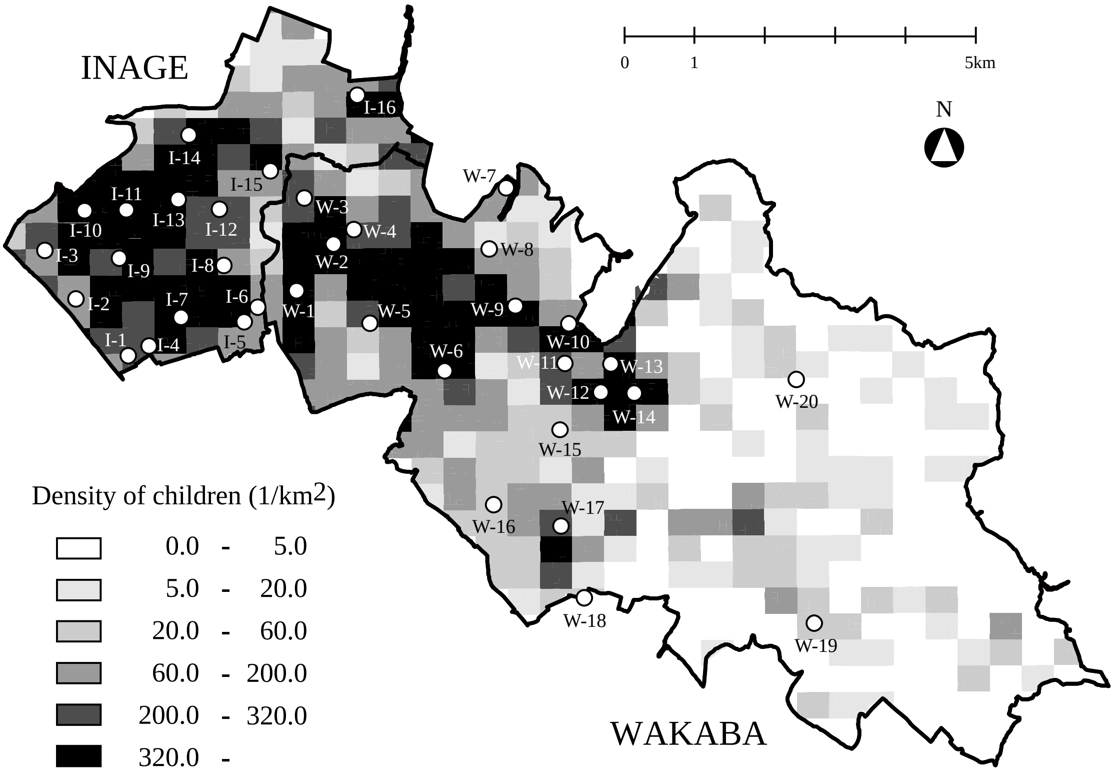

Figure 2 Public elementary schools and the density distribution of children aged 6-12.

The Ministry of Education, Culture, Sports, Science and Technology provides standards of school capacity and distance from home to school. The maximum capacity of elementary schools is 720 pupils, which assumes three classes of forty pupils in each grade. The maximum distance from home to school is four kilometers. This distance, however, is too long in urban and suburban areas since most pupils go to school by walk in such areas. We thus adopt C_i=720 and $d_{\max}$=2km in this paper. Pupils go to schools in the same ward as their home is located. School districts are determined by the local board of education.

Under the above condition, we solved the Problem M_1 defined in Section 2. The solutions are 11 and 15 schools in Inage and Wakaba wards, respectively. We then solved the Problem M_2 to obtain 100 alternative plans in each ward. Since the problem is relatively small, the naive swapping method worked efficiently. All the 100 alternatives minimize the number of schools in each ward.

Figure 3 shows the distribution of adoption rate. Wakaba ward has many indispensable schools especially in the east and south due to the poor condition of accessibility. Schools W-19 and W-20 have even pupils who walk more than 2km from home to school. Schools I-15, W-1, and W-7 are 1.0 in adoption rate but not indispensable schools. Since Figure 3 does not tell the reason for this, other measures are examined further in the following.

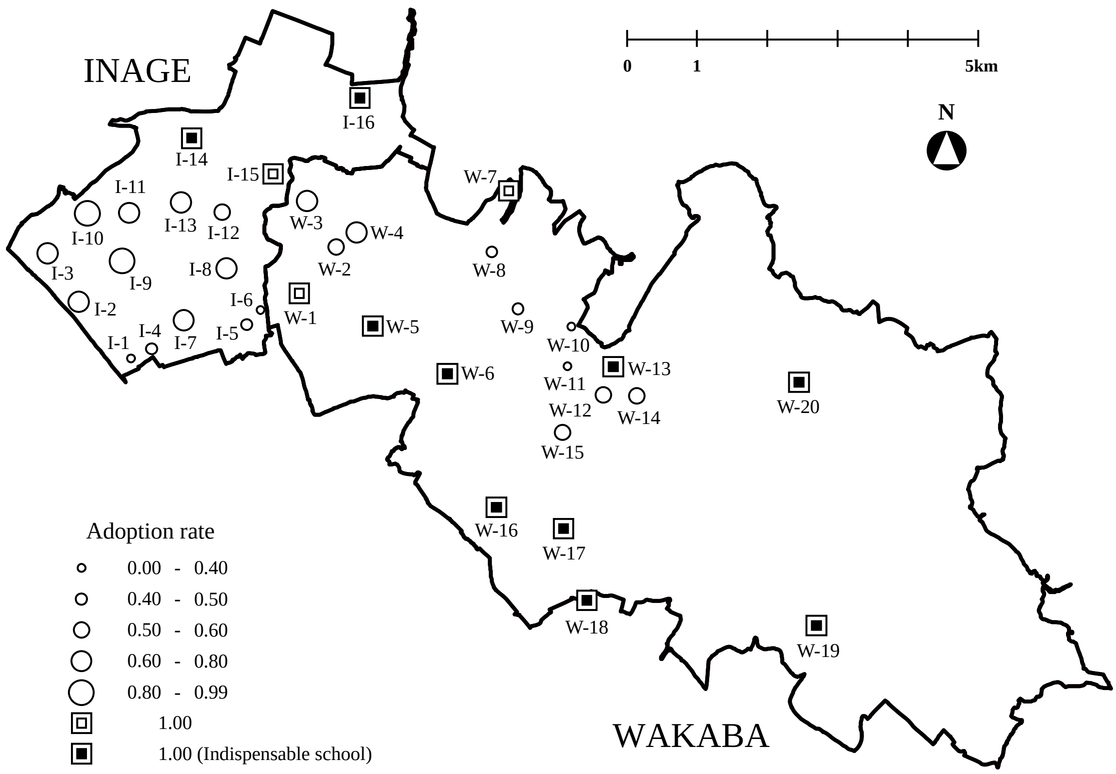

Figure 3 Adoption rate of elementary schools.

Figure 4 shows the distribution of occupancy rate. Schools of low occupancy rate are concentrated in the center of Wakaba ward and the south of Inage ward. Some indispensable schools such as I-14, I-16, W-5, and W-6 are high in occupancy rate, while others including W-17, W-18, W-19 and W-20 are very low. The former are highly necessary for both the size and accessibility demands while the latter are necessary only for the accessibility demand. The latter suggest inefficiency in school management caused by the strict application of accessibility condition.

Schools I-15 and W-1 are both 1.0 in occupancy rate. Their high adoption rate can at least be explained by the size demand.

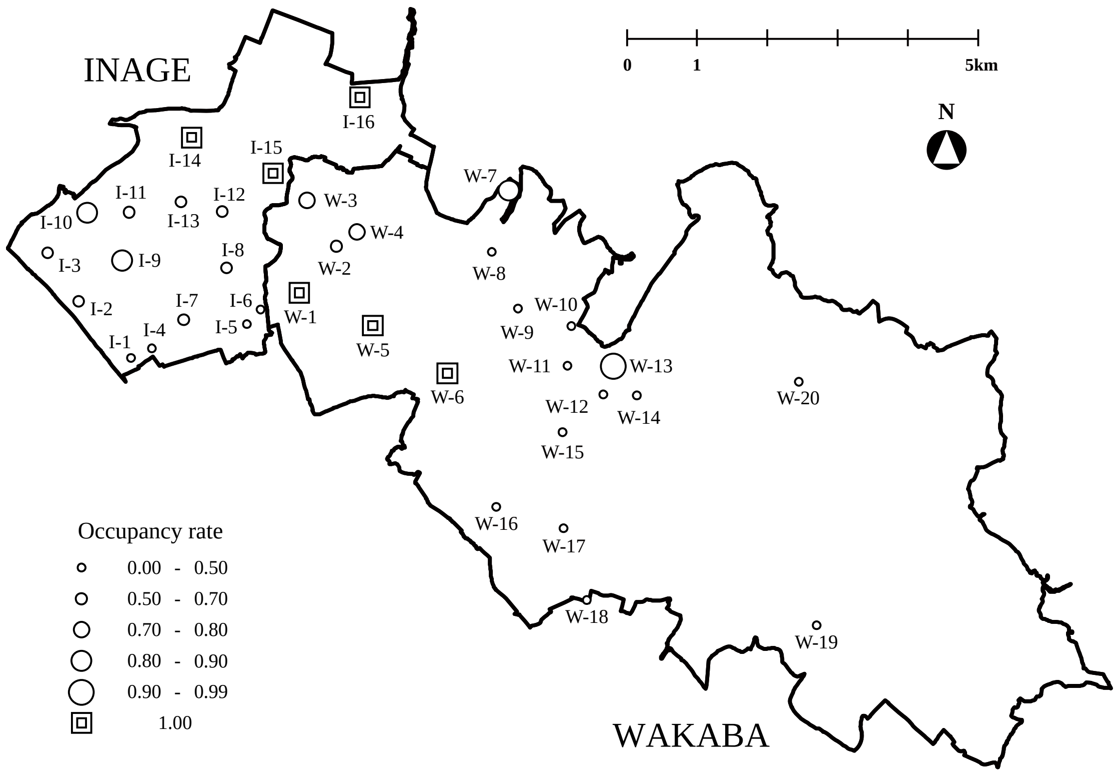

Figure 4 Occupancy rate of elementary schools.

Figure 5 shows the distribution of accessibility demand measure. Low accessibility demand of schools I-14, W-6 and W-13 implies that they are necessary only for a few pupils who have only one accessible school. School W-7 is 1.0 in adoption rate but is not an indispensable school. Its high accessibility demand indicates that W-7 is necessary to serve its surrounding pupils having few accessible schools.

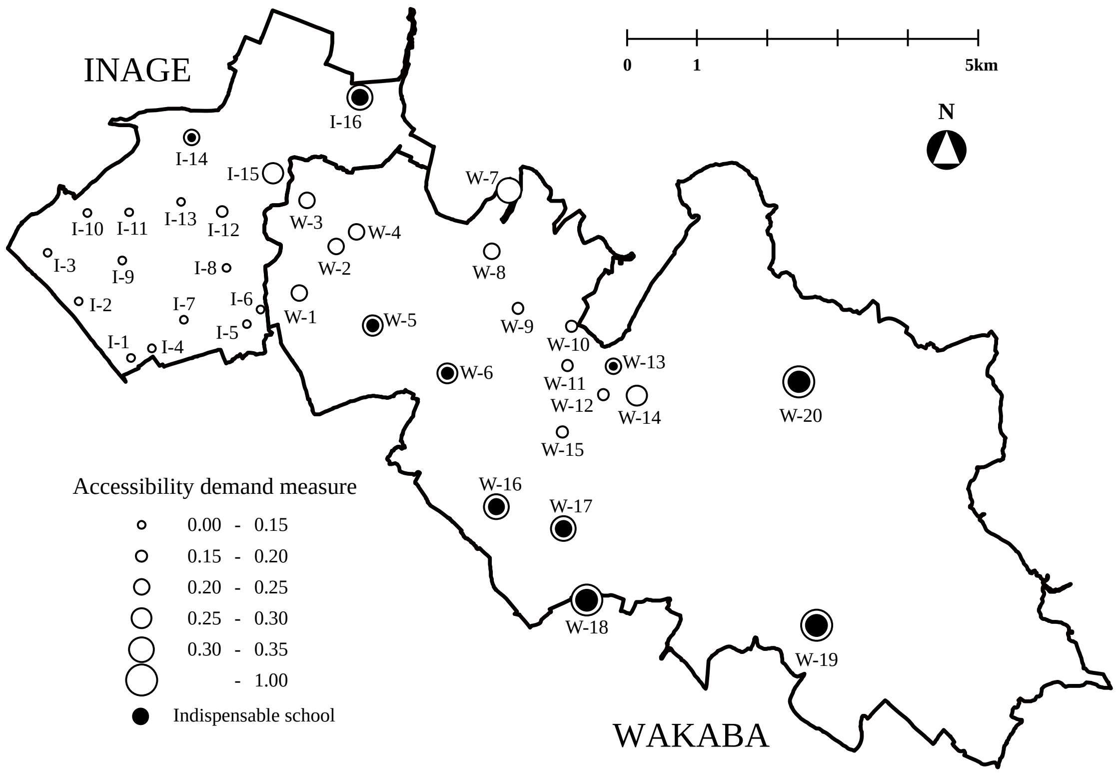

Figure 5 Accessibility demand measure of elementary schools. White circles containing black ones indicate indispensable schools.

Figure 6 shows the distribution of size demand measure. Its overall impression is quite similar to that of Figure 4. Schools I-15 and W-1 are high in size demand while W-7 is quite low. This is consistent with our considerations in Figure 4 and 5.

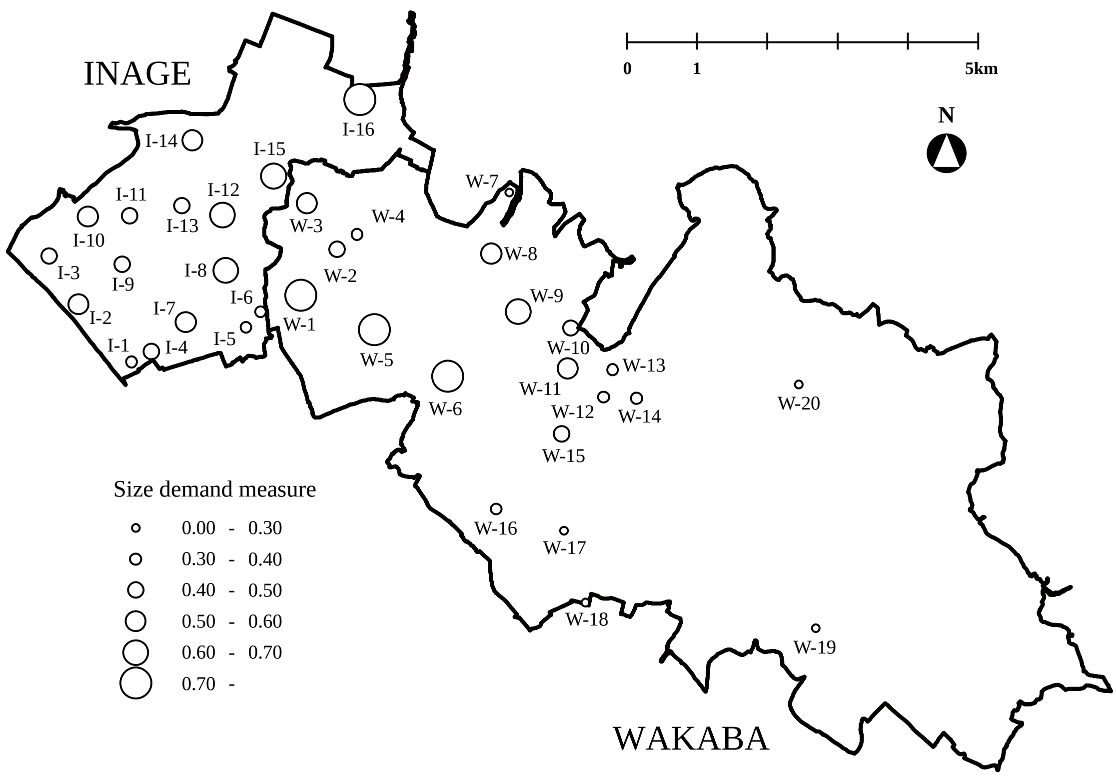

Figure 6 Size demand measure of elementary schools. White circles containing black ones indicate indispensable schools.

We then divide schools into subgroups in each of which we discuss the school relocation plan in detail.

In Inage ward, we divided schools into five groups (Figure 7): G_1={I-1, I-2, I-3, I-4, I-7, I-8, I-9, I-10, I-11, I-12, I-13}, G_2={I-5, I-6}, G_3={I-14}, G_4={I-15}, G_5={I-16}.

Among the five groups, schools I-14 (=G_3) and I-16 (=G_5) are independent of all their neighbors. Since they are indispensable and high in occupancy rate, it is quite natural to keep these schools open. School I-15 should also be kept open due to its high occupancy rate and accessibility demand, irrespective of whether its neighboring school I-12 is kept open or closed.

Schools in group G_1 form a "Christmas twinkle light" relation. If I-1 remains open, its neighbors I-2 and I-4 will be closed and the next neighbors I-3 and I-7 will remain open. As a result, 5 or 6 out of 11 schools will be kept open in group G_1. If school I-15 is kept open, a reasonable choice is schools I-2, I-4, I-8, I-13, I-9, and I-10.

Schools in G_2 are not independent of their neighbors. Since their demand is quite low in both size and accessibility, either one or both should be closed. The choice depends on the relocation plan in group G_1.

In Wakaba ward, five groups were obtained besides eight indispensable schools: G_1={W-1, W-2, W-3}, G_2={W-4, W-8}, G_3={W-7} G_4={W-9, W-10, W-11, W-15}, G_5={W-12, W-14}. In groups G_2 and G_5 one school should be kept open in each group while two schools should be chosen in G_4. School W-7 is necessary due to its high demand in accessibility. Concerning group G_1, W-1 is relatively important because it is high in size demand. Schools W-2 and W-3 are low in occupancy rate so that it is enough to keep one of them.

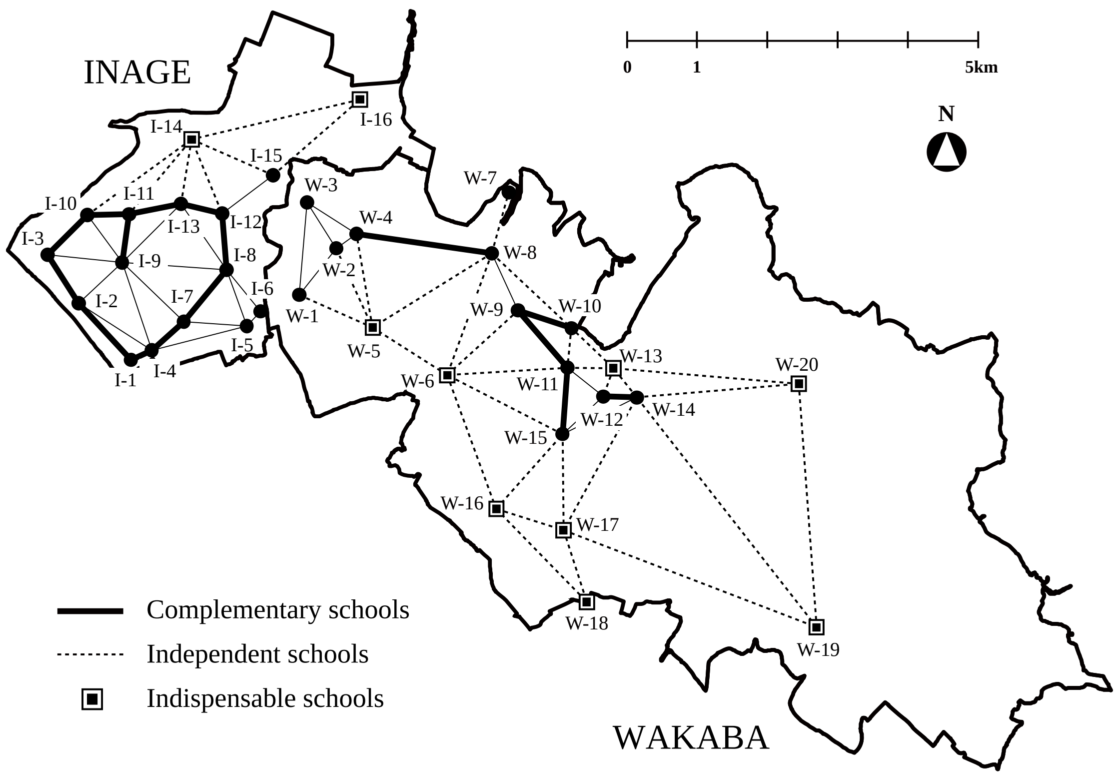

Figure 7 Complementary and independent elementary schools.

So far we have discussed the school relocation plan with implicitly assuming that the size and accessibility conditions must be strictly satisfied. In reality, however, they are desirable conditions rather than rigid rules strictly applied to school location plan. They can be relaxed if it permits a better relocation planning.

We thus finally discuss several options that go beyond the given conditions. A focus is on the schools of low occupancy rate, because they are not only economically inefficient but also undesirable as an educational environment.

Many indispensable schools are low in occupancy rate. Typical examples include W-16, W-17, W-18, W-19 and W-20 that cannot be closed due to the accessibility condition. To integrate these schools, it is effective to relax the accessibility condition and to permit pupils to go to schools by bicycle. School bus system should also be considered because its cost is lower than that of keeping four schools.

Schools W-2 and W-3 are both low in occupancy rate. The rate is still low even if they are integrated into a single school. In such a case, expansion of their neighboring school is worth discussing. They can be integrated into W-1 if temporary classrooms are built in W-1. School expansion is effective especially in urban and suburban areas where accessibility demand is not critical.

In Japan, pupils are not permitted to attend schools in neighboring wards. However, if this rule is relaxed, schools I-5, I-6, W-2, and W-3 can be integrated into a single school. This also applies to I-15 and W-3, though temporary classrooms are necessary in I-15. Attendance to schools in neighboring wards should be permitted at least around ward boundaries in urban areas.

4. Conclusion

This paper has developed a new decision support method for school relocation planning. It aims to assist the understanding and discussion of the properties of school relocation problem rather than to propose directly the candidates for the final decision. Numerical measures are effective for analyzing the present status of school location, especially the effect of desirable conditions on school location. School grouping makes it easier to devise a school relocation plan. The method was applied to school relocation planning in Chiba City, Japan. The result provided useful empirical findings as well as illustrated the utilization of the method in concrete planning process.

We finally discuss some limitations and extensions of the paper for future research.

First, this paper takes only the school size and accessibility as desirable conditions. In actual school relocation planning, however, it is necessary to discuss a wide variety of conditions other than school size and accessibility. The method should incorporate further conditions for more practical school relocation planning.

Second, this paper does not consider the opening of new schools. However, even if children are decreasing, integration of existing schools into a new school is often effective in school relocation. The method should be extended to treat both the opening and closure of schools.

Third, application of the proposed method requires the basic knowledge of mathematical programming and statistics. Unfortunately, participants of school relocation planning do not necessarily have much experience in these fields.

Implementation of the method in the computer environment is clearly desirable. One possible option is to incorporate the method into a collaborative decision support system (Hultz *et al*., 1981; Bohnenberger, 2005). It works more effectively if it is combined with GIS and connected to the Internet (Yeh and Chow, 1999; Church, 2002; Higgs, 2006; Nejad *et al*., 2009). Computer implementation will greatly help collaborative school relocation planning.

Acknowledgement

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