Urban Bus Network Design Using Genetic Algorithm and Map Information

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Abstract: Within local areas, buses plays an important role, therefore the bus network design is important. Bus network design problem consists of the bus stop number decision problem and the bus stop location decision problem. In this paper, the bus stop number decision problem is determined based on map information. The bus stop location decision problem is determined by a genetic algorithm. Genetic algorithms are optimization techniques which operate on the principle of the chromosome. We show a genetic algorithm is an effective way to solve bus stop location. We aim to solve the bus network design for the students commuting to Kanazawa Institute of Technology. As compared with the conventional bus stop, the total travel distance from dormitory to the bus stop was shortened by 2,551.18 m. Maximum distance from the bus stop to dormitory was shortened by 702.69 m. The number of bus stops decreased by 27.

Keywords: Urban bus network design, Bus stop number decision problem, Bus stop location decision problem, Genetic algorithms

1. INTRODUCTION

Buses are indispensable to people's lives as general public transportation. When designing a bus system, one important issue is to properly position the bus stop. Bus stop placement is important so that the bus stop is in a position that is easy to use for the bus and the user. If the bus user is assumed to be at home, the bus user must walk from their house to the bus stop. It is necessary to place the bus stop as near as possible to the user's home. Also, the stop times of the bus stops is increased when the number of bus stops is increased. The bus ride time of the user becomes longer. Thus, while shortening the distance to the bus stop from bus users home, it is necessary to place the bus stops so that bus stop times of the bus is reduced.

In general, the bus stop location decision problem is to select a subset of the bus stops to provide the best service at the lowest cost. This problem is an optimization problem and belongs to facility location problem. The facility location problem is known to be belonging to NP-hard, and is classified as a difficult problem to solve in an effective processing time (Davis et. al., 1994; Okabe and Suzuki, 1992).

Kanazawa Institute of Technology (hereinafter referred to as the KIT) is located in Nonoichi and is the hub of transportation. This makes KIT a very convenient place. Nonoichi is located in a city of 51,127 inhabitants (City of Nonoichi, 2015). Student of KIT account for 14% of the population of Nonoichi. In addition, Ishikawa Prefecture has about 165 rainy days in a year, making it the wettest city in Japan. Therefore, students have to use the public transport such as rail and bus. Nonoichi operates the community bus called Notty. The bus stop and the bus route of the current Notty is shown in Figure 1. The Notty service has 4 routes, northern route, western route, southern route, central route. These pathways have a total number of 120 bus stops throughout Nonoichi. Notty covers the all area of Nonoichi, but bus route hasn't been created for the utilization purpose of the citizen.

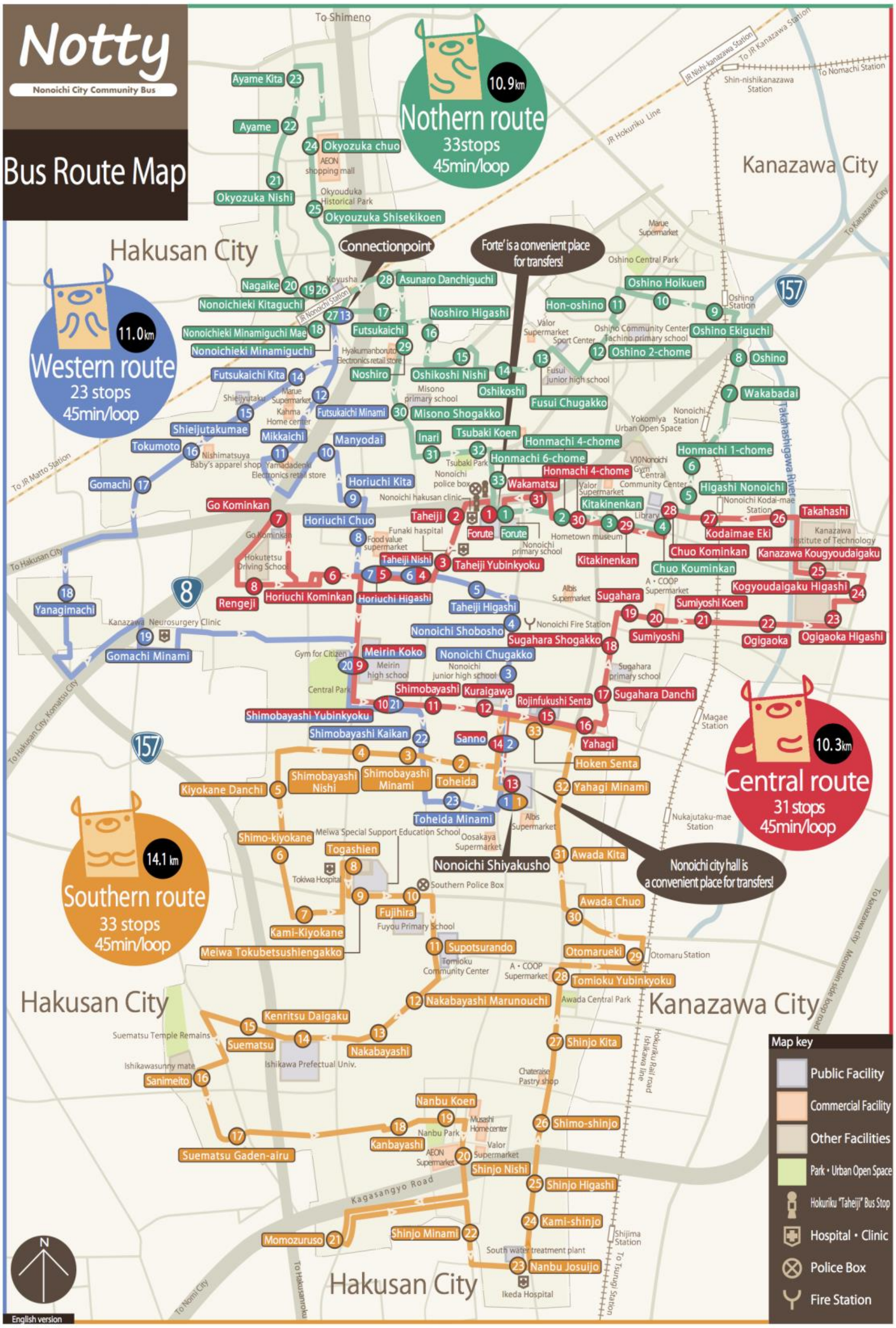

Figure 1. Bus stop and the bus route of the Notty (Notty Route Map, 2015)

For these reasons, in this paper, students of KIT dormitories are targeted. The purpose of this paper is to solve the bus network design which minimizes walking distances to the Notty bus stop for KIT students. Therefore this paper is not assuming the transfer of the bus because the transfer of the bus is a waste of time and money.

The main contribution of the study, is to propose a solution of the bus stop location decision problems for the students of KIT. In addition, show that a technique that uses a genetic algorithm (Gen et. al., 1997; Winter, 1995; S. Babaie-Kafaki et. al., 2008) is valid to solve bus network design. Genetic algorithm can search for solutions in a wider are, insert constraint functions easier, and acquire better solutions. We show the effectiveness of the proposed method by indicating that the new bus stop will be better than the existing bus stop by minimizing total walking distance and the number of bus stops.

The format of this paper is as follows. In Section 2, we show the formulation of the problem. In Section 3, we show the algorithm of a problem for the optimization model. In Section 4, we show the computer execution results. In Section 5, we show a summary and outlook.

2. FORMULATION OF THE PROBLEM

The bus stop location determination algorithm uses the genetic algorithm to select the best bus stop according to the evaluation function from the bus station candidate points. First, we explain how to calculate the distance (d_{ij}) between dormitory i and bus stop j. The Hubeny equation (Bowring, 1996; Kawakami et. al., 2012) is known as an effective method of obtaining the exact distance. Therefore the distance between dormitory i and bus stop j is calculated by using the Hubeny equation, shown below. The definition of d_{ij} is shown as follows equation (1). Where let x_i be latitude of KIT dormitory i or bus stop i. Let y_j be longitude of KIT dormitory j or bus stop j. Let $d_{x'}$ be difference of longitude between KIT dormitory i and bus stop j. Let $d_{y'}$ be difference of latitude between KIT dormitory i and bus stop j. Let $\mu_{y'}$ be average value of altitude between KIT dormitory i and bus stop j. Let M be the meridian radius of curvature between KIT dormitory i and bus stop j. Let N be the prime vertical radius of curvature. Let W be the meridian and prime vertical radius of curvature of the denominator. Let e be major eccentricity. Let a be the semi-major axis. Let b be the semi-minor axis.

$$d_{ij} = \sqrt{\left(\mathrm{d}_{y'}M\right)^2 + \left(d_{x'}N\cos\mu_{y'}\right)^2} \tag{1}$$

where,

x_i	: Latitude of KIT dormitory i or bus stop i.
y_j	: Longitude of KIT dormitory j or bus stop j.
$d_{x'} = x_i - x_j$	: Difference of longitude
$d_{y'} = y_i - y_j$	: Difference of latitude
$\mu_{y'} = \frac{y_i - y_j}{2}$	: The average value of the latitude
$M = \frac{a(1-e^2)}{W^3}$	: Meridian radius of curvature
$N = \frac{a}{W}$	: Prime vertical radius of curvature

$W = \sqrt{1 - e^2 \sin^2 \mu_y}$: Meridian and prime vertical radius of curvature of the denominator

$e = \sqrt{\frac{a^2 - b^2}{a^2}}$: Major eccentricity

a : Semi-major axis

b : Semi-minor axis

We prepare the bus stop candidate points which can become the bus stops. And we select the bus stop from the bus stop candidate points. The bus stop location decision problem is defined as a problem of selecting the bus stop set which has the smallest total cost. The cost is defined as the sum of the distance from KIT dormitories to the nearest bus stop. The bus stop location decision problem is formulated as follows equation (2). Where let m be the number of KIT dormitories. Let n be the number of candidate points of bus stops. Let p be the number of bus stops to be installed. Let X_{ij} be set at 1 if the bus stop i is the shortest distance from dormitory j, otherwise 0. Let Y_j be set at 1 if the bus stop is installed at bus stop candidate point j, otherwise 0.

$$\min \sum_{i=1}^{m} \sum_{J=1}^{n} d_{ij} \cdot X_{ij} \tag{2}$$

$$\text{s.t.} \quad \sum_{j=1}^{n} X_{ij} = 1 \ \forall \ i$$

$$X_{ij} \leq Y_j \quad \forall \quad i, \quad j \mid i \neq j$$

$$\sum_{j=1}^{n} Y_j = p$$

where,

m : Number of KIT dormitories

n : Number of Candidate points of bus stops

p : Number of bus stops to be installed

$X_{ij} \in \{0, 1\}$: If the bus stop i is the shortest the distance from dormitory j, X_{ij} is 1. Otherwise X_{ij} is 0.

$Y_j \in \{0、1\}$: If the bus stop is installed at bus stop candidate point j, Y_j is 1. Otherwise Y_j is 0.

3. ALGORITHM DESIGN

3.1 Generation of Gene Code

A gene is a part of a chromosome. The chromosome is composed of multiple genes. We explain a method of creating a genetic code of chromosomes. In areas where there is a KIT dormitory, the area is divided into four horizontal and four vertical areas. Figure 2 is the results of the division. KIT dormitories are located in nine out of 16 areas. Therefore, we decided to place the bus stops to KIT in the nine regions which have the KIT dormitories. We create four candidate points of bus stops in each area. The bus stop candidate points are placed on the main road where it is possible to put bus stops. We then select one point for the bus stop from the candidate points in each area. We use the latitude and longitude information of candidate points, bus stop and KIT dormitories when we execute the proposed bus stop location algorithm. The bus stop location algorithm selects the best bus stop from among the candidate points of bus stops using a genetic algorithm.

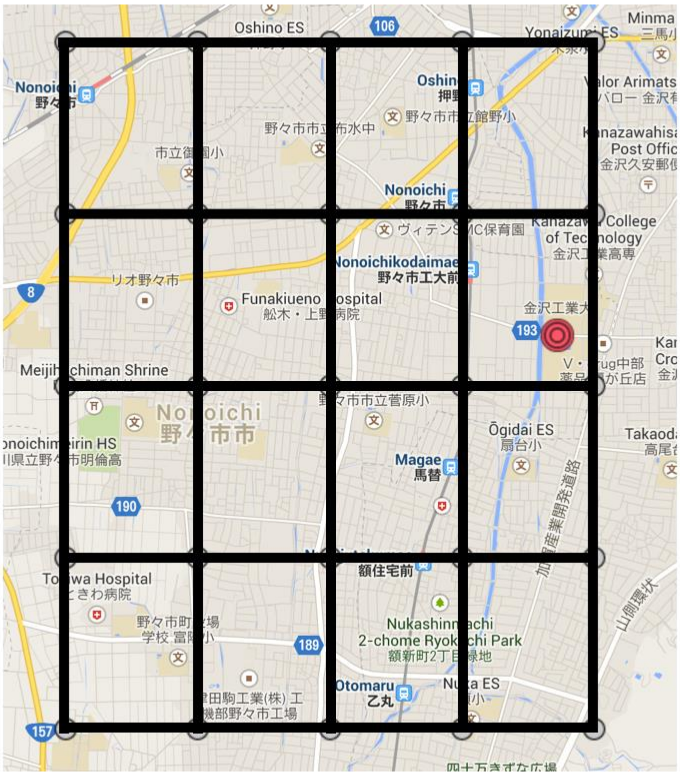

Figure 2. Area where there is a KIT dormitory

Since one point is selected from four candidate points, we express the four candidate points in binary two bits.

00, 01, 10, 11 show first, second, third and fourth bus stop candidate points. Since there are nine areas, the chromosome is made by concatenating the nine genes which represent the candidate points (Figure 3).

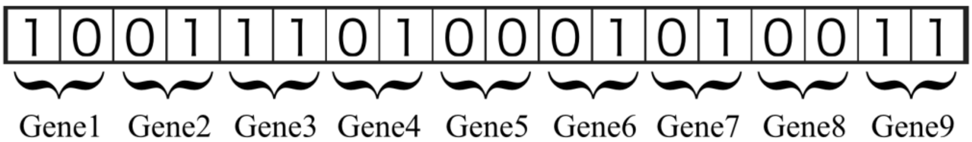

Figure3. Example of bus stop location chromosome

3.2 Creation of First Generation

The first generation will be created using random numbers. Each gene is represented as 2 bits and assigned a value obtained by generating random numbers from 0 to 3 in decimal (a binary number 4 types of 00, 01, 10, 11). One chromosome is made by combining the value which shows candidate points in the area. Ten chromosomes are created in the first generation figure 4.

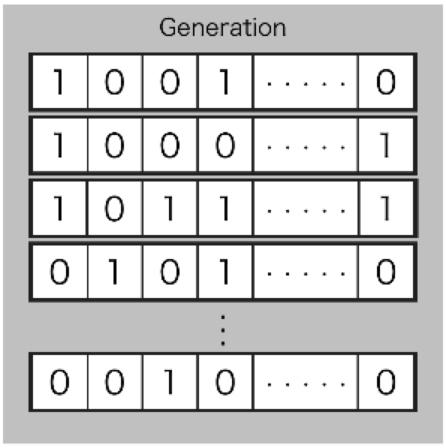

Figure 4. Example of Generation of model

3.3 Evaluation of Fitness value

An evaluation function is calculated using the information of KIT dormitories latitude and longitude. The evaluation function is defined as the value which is obtained by subtracting MAX from distance of the nearest bus stop from KIT dormitories. Here, MAX is defined as a number greater than the value of the largest distance between all the bus stops and all the dormitories. We defined the distance between dormitory i and bus stop j from using the Hubeny equation, shown section 2 equation (1).

Fitness value of dormitory i is defined as follows equation (3).

$$\text{Fitness Value } i = \left| \min_{0<j<p} \sqrt{\left(d_{y'} M\right)^2 + \left(d_{x'} N \cos \mu_y\right)^2} - \text{MAX} \right| \tag{3}$$

Therefore we define the fitness value sum of the chromosome as follows equation (4).

$$\text{Fitness Value } sum = \sum_{i=0}^{m} \text{Fitness Value } i \tag{4}$$

3.4 Rank Selection

According to Darwin's evolution theory, in order for the best individuals to survive, there is a need to create new offspring. A genetic algorithm keeps or deletes chromosomes, depending on fitness values. Methods of selecting high fitness chromosomes include, but are not limited to, rank selection, roulette wheel selection, tournament selection, and boltzmann selection. In this paper because there is a very large difference in the fitness values, the rank selection is used. In rank selection, each chromosome is ranked according to fitness values. Selections that are kept or deleted are decided using predetermined probability for each ranked chromosome. Ranked chromosomes are taken over to the next generation using the following probabilities 100%, 50%, 40%, 40%, 40%, 40%, 40%, 40%, 30% and 30%. Chromosomes which have high fitness are kept at a high probability.

3.5 Crossover and Mutation

To explore the chromosomes of higher fitness, it is necessary to introduce a new chromosome. The selection algorithm operations are done to replace a part of the chromosome genes. This process is the most important parts of the genetic algorithm. The operation of replacing a portion of the gene is carried out using crossover and mutation. Crossover makes two new chromosomes by combining two chromosomes. We use one-point crossover and two-point crossover. The image of one-point crossover is shown in figure 5. There are two chromosomes, one crossover point is shown. The left side of the first chromosome and the right side of the second chromosome are combined, and a new chromosome is created. In a similar way, the left side of second chromosome and right side of first chromosome are combined, and a new chromosome is created. The image of two-point crossover is shown in figure 6. There are two chromosomes, two crossover points are shown. The left side of the first chromosome, the middle portion of the second chromosome and right side of the first chromosome are combined, and a new chromosome is created. In a similar way, the left side of the second chromosome, the middle portion of the first chromosome and right side of the second chromosome are combined, and a new chromosome is created. For both one-point and two-point crossover, the position of the crossing points are decided randomly.

Mutation is to change the value of the gene to a different value. We are dealing with gene bit strings, and mutation is done by replacing the 0 and 1. By mutating, the possibility of finding a local optimal solution is prevented.

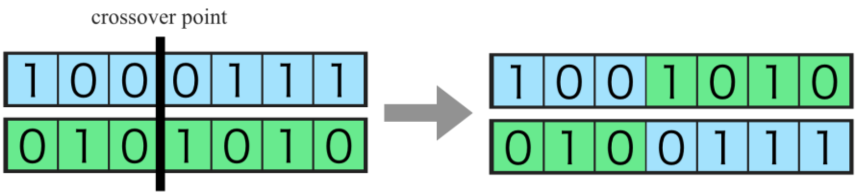

Figure 5. Image of one-point crossover

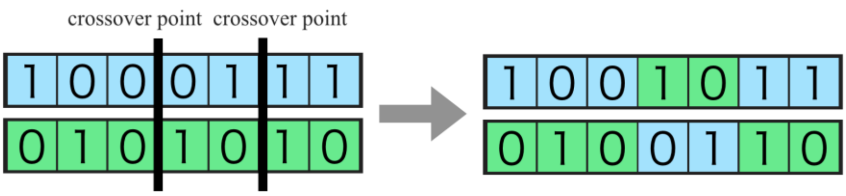

Figure 6. Image of two-point crossover

3.6 Description of Flow

Figure 7 shows the flow description used in resolving the bus stop location decision problem. This flow is made in reference to genetic algorithm.

At the beginning, information of latitude and longitude of KIT dormitory and latitude and longitude of the candidate points of bus stop are obtained. This information will be used to evaluate the chromosomes. Then, 10 sets of chromosome from the first generation is created. The generation of chromosomes is shown in Section 3.2. Random numbers from 0 to 3 are created and matched against the corresponding 2 bit gene, to create a chromosome. As there are nine regions for the candidate points of bus stops, using random numbers to create chromosomes is repeated nine times. The first generation for each chromosome is created by repeating the chromosome creation process 10 times.

After the first generation of chromosomes, a fitness evaluation is conducted for each chromosome. Fitness is determined by a formula shown in Section 3.3. Higher fitness implies better chromosomes. Then, chromosomes will be sorted in descending order by fitness value.

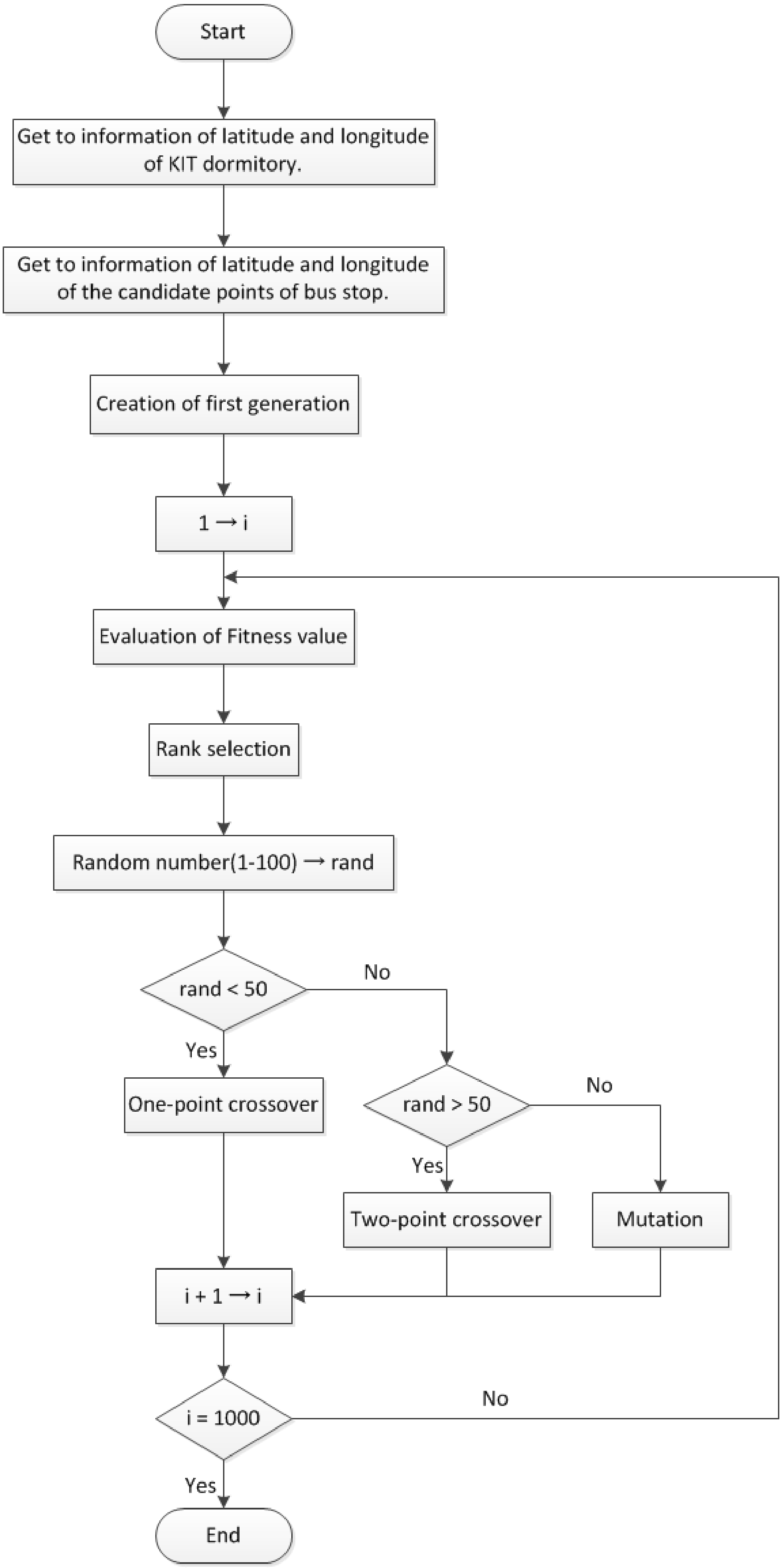

Figure 7. Outline of the proposed bus stop location algorithm

After this, the next generation is created. The method for generating the next generation consists of two steps. The first step is to select chromosomes of the current generation to take over the next generation of chromosome, using the rank selection shown in Section 3.4. The second step is to perform a one-point crossover, two-point crossover, or mutation using the chromosomes selected by rank selection. A chromosome that has been created by this process will be the next generation of chromosomes. In this case, random numbers from 1-100 are created, and when the value of the random number is less than 50, one-point crossover is carried out performed. When the value of the random number is larger than 50, a two-point crossover is carried out. When the value of the random number is 50, a mutation is carried out. These two steps are conducted until a total of 10 chromosomes are created.

Then, the process of rank selection, one-point crossover, two-point crossover and mutation is repeated. The chromosome set of highest fitness is carried over to the next generation.

4. COMPUTER EXPERIMENT RESULTS

We have applied the proposed method to the case to commute from KIT dormitory to KIT. First we decided the candidate points of the bus stops by using the map information. We have divided the area around KIT dormitories into 16 area. In the divided areas, we created four candidate points for the bus stop on the main road. The results of the candidate points of bus stop are shown in figure 8.

The number of generations was defined as 1000 generations and then we executed the proposed method. The execution results are shown in Table 1. The total distance is the sum of the distances from KIT dormitory to the bus stop. The current bus stop is the evaluation result which is on the current Notty central bus route. The new bus stop is the evaluation result calculated by the algorithm. For the current bus stop, total distance from KIT dormitory to the bus stop is 34,089.04 m. On the other hand, the distance to the new bus stop got a value of 31,537.86 m. Using the algorithm that we propose, it was possible to shorten the distance by 2,551.18 m. In addition, the maximum distance from a KIT dormitory to the bus stop is shown. Currently the maximum distance between a KIT dormitory and the bus stop is 1,346.05 m. On the other hand the new bus stop is located 643.36 m from the KIT dormitory. Using the algorithm that we propose, it was possible to be 702.69 m shorter. Also, Also, The nine bus stops were selected by the proposed method and the one bus stop was placed at KIT. The number of required bus stop was reduced from 37 to 10. The current bus can travel a lap in 45 minutes when it is proposed method could be two laps in 45 minutes.

Position of the current bus stops and the new bus stops is shown in figure 9. Only the current position of the bus stop and the new bus stop are shown. Current bus stops are yellow and the new bus stops, which have been calculated in our algorithm, are shown in blue.

Figure 10 shows the position of KIT dormitories in addition to new bus stop and current bus stop. KIT dormitories are green. There are not many KIT dormitories in the area of B, so the number of bus stops has been reduced. In contrast, there are a lot of KIT dormitories in area A, hence this area has several bus stops. In addition, areas C and D are the most distant KIT dormitories however they also have a bus stop.

The transition graph of the distance value is shown in figure 11. The distance values become lower whenever the algorithm repeats a generation. We conducted the experiments with the use of 2.6GHz computer which has an intel core i5. Run time of the proposed method was about 56957.044ms.

Figure 8. Candidate points of bus stop

Table 1. Execution result

	Current bus stop	New bus stop	Difference
Total distance from KIT dormitory to bus stop (m)	34,089.04	31,537.86	-2,551.18
Longest distance from KIT dormitory to bus stop (m)	1,346.05	643.36	-702.69
Number of bus stops	37	10	-27

Figure 9. Current bus stop and the new bus stop

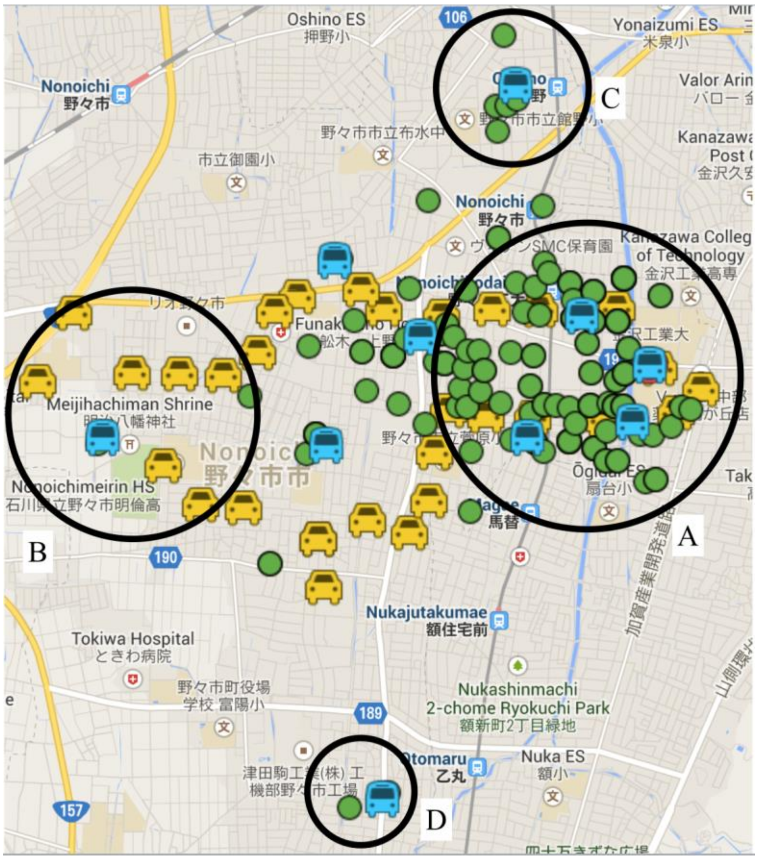

Figure 10. Region classified by the characteristic

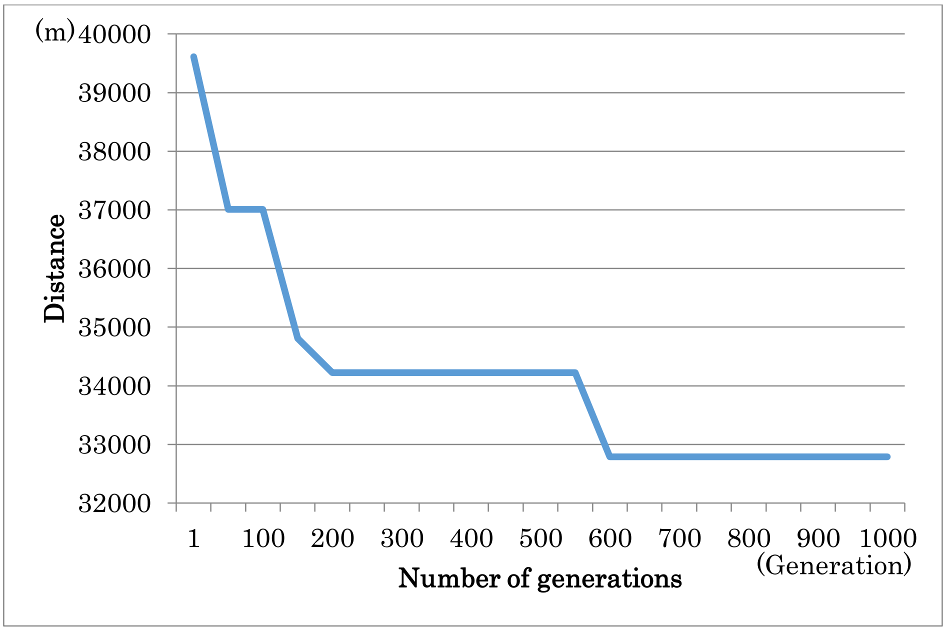

Figure 11. Transition graph of the distance value

5. CONCLUSION

Public transport plays an important role in the city. Within local areas buses plays an important role, therefore the bus network design is important. The design must determine the location of the bus stops and bus stop number which is generally difficult to solve.

In this paper, the bus stop number decision problem is determined based on map information. The bus stop location decision problem is determined by a genetic algorithm.

Genetic algorithms are optimization techniques which operate on the principle of the chromosome. We show a genetic algorithm is an effective way to solve bus stop location in this paper.

In this research, we aim to solve the bus network design for the students commuting to KIT. We set a plurality of bus stop candidate points, and determined the optimal bus stop points by using a genetic algorithm.

Using the results of computer experiments, we have succeeded in placing ten bus stop. As compared with the conventional bus stop, the total travel distance from KIT dormitory to the bus stop was shortened by 2,551.18 m. Maximum distance from the bus stop to KIT dormitory was shortened by 702.69 m. The number of bus stops decreased by 27. The bus is now able to travel 2 laps in 45 minutes instead of 1, greatly increasing the convenience of riding the bus.

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