DEVELOPMENT OF COURTESY BUS SCHEDULING SYSTEM FOR NURSING CARE FOR THE ELDERLY

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Abstract: This study aims to develop a courtesy bus scheduling system for nursing care for the elderly especially in built-up areas. The essence of the problem discussed here is a shortest route problem. However, there are many constraints that are characteristic to nursing-care service and densely built-up areas such as in Tokyo. The problem is formulated as an optimality problem with some constraints. The system is developed based on Geographic Information System (GIS). Some constraints and variables related to geographical attributes are dealt with GIS efficiently. Finally the result generated by the system is demonstrated.

Key words: courtesy bus, Geographic Information System, combinational optimization problem, Vehicle Routing Problem

1. INTRODUCTION

Many developed countries face a major health and long-term care challenge as the population ages and people live longer lives. In April 2000, a new social service system was started in Japan. The program is called "Kaigo Hoken" in Japanese, which can be translated as "social care insurance", "long term care insurance", or "nursing care insurance system" in English. The introduction of this care insurance system has encouraged diverse private-sector businesses to enter this market so as to respond to the rapidly increasing demand for care services such as home-visiting service, day care service, short-term residential care service, and long-term care at special nursing homes or health facilities for the elderly. In order to supply care service at health facilities, the courtesy bus is required.

This paper aims to develop a courtesy bus scheduling system for nursing care of the elderly. The paper is organized as follows: In the next chapter, following a brief review of care insurance system and the characteristics of the care services for the elderly, problems in developing a courtesy bus scheduling system for nursing care of the elderly especially in built-up areas are discussed. Then, Chapter 3 gives the framework for solving the problem and the scheme of scheduling system based on Geographic Information System (GIS). In Chapter 4, the system is applied to an existing data set and the feasibility is examined.

2. THE CHARACTERISTICS OF NURSING CARE SERVICES OF THE ELDERLY

2.1 Nursing Care Services in Japan

The ratio of the elderly, namely aged 65 and older, in Japan reach the highest level in the world. Japan's Ministry of Labor and Welfare is prompting a New Ten-Year Strategy to Promote Health Care and Welfare for the Elderly, which is called "The New Golden Plan." This plan is the compilation of health and welfare plans for the elderly formulated by all local governments in Japan (Ministry of Health and Welfare (1999)). It indicates the urgent development of the infrastructure for long-term care service for the elderly.

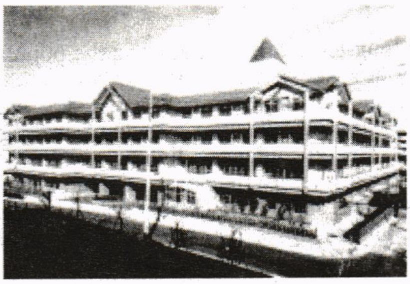
For that purpose, long-term care insurance system was established in April 2000. Everyone aged 40 and over is required to join the system and pay premiums. Alternatively, people who are 65 years old or over and need nursing care can receive support from municipalities according to the degree of their disability.

It becomes more important to provide long-term care services through a variety of business entities to respond to the increasing demand and to ensure service users opportunities to select services. Actually, some municipalities contract with private-sector companies for such as commuting care service facilities (day services).

There are several types of services, such as home-visiting service, day care service, short-term residential care service, and long-term care at special nursing homes or health facilities for the elderly. Hereafter, this paper focuses on so called "Day Care Service."

Day Care Service is for the elderly who need not stay in a hospital but have some difficulty in their activities by themselves. The service is provided in "Day Service Center"(health facility) or "Home for Elder People". Throughout the paper, let's call them "Service Center" for brevity. The service aims at recovering their health or keeping their good health of both body and mind with rehabilitation and other activities. Figures 1-(a) to (d) show the appearance of the day care service.

Since care services are people-intensive ones and the contents of the services should be customized to each user, it seems difficult to make them efficient. However, there still exists some room for improving the current situation.



(a) Day Service Center

(c) Lunch Service

(b) Visit to the Facility by Courtesy Bus

(d) Recreation

Figure 1. Sketch of Day Care Service

As shown in table 1, a typical day care service stars from picking up the users at their homes and bring them to the service center by courtesy bus except for a few users who can go to the center by walk. According to what we heard from the staffs of a day service center, they have trouble in deciding the route and the scheduling of courtesy bus. They plot the position and attribute data of the users on a paper made map, and draw lines by trial and error. Then they decide a route and drive the courtesy bus to examine whether the bus can run and time the travel. If they find a problem, they draw lines and examine them again. Hence, introduction of computer aided system for deciding the route and the scheduling of courtesy bus would make a great contribution to increasing efficiency of the work.

For that purpose, this study aims to develop a courtesy bus scheduling system for nursing care for the elderly.

Table 1. An example of Timetable for Day Care Service

9:00 – 10:00	Picking up the users near their homes
10:00 – 11:00	Break and health check-up
11:00 – 12:00	Recreation (*e.g.* painting, ceramic arts and karaoke.)
12:00 – 13:00	Lunch
13:00 – 14:00	Recreation
14:00 – 15:00	Afternoon Tea
15:00 – 16:00	Dropping the users near their homes

2.2 Problems in Taking the Elderly to and from Service Center by Courtesy Bus

It seems to be easy to obtain a solution of the problem based on an off-the-shelf GIS. However, there are many factors which we should consider in case of nursing care for the elderly. To describe the characteristics of the problems, let us illustrate an actual example.

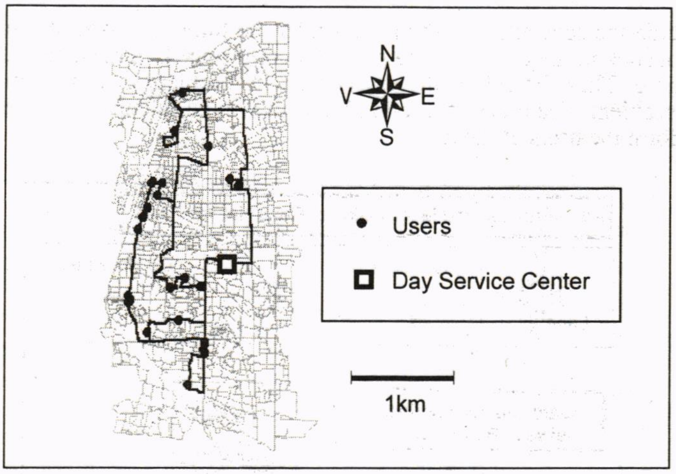


Figure 2. Outline of the Positions of Users and Day Service Center (Rokugatsu, Seifu-Kai, Social Welfare Corporation, Adachi Ward, Tokyo).

Figure 2 shows spatial distribution of the users of Day Service Center "Rokugatsu", which is managed by social welfare corporation "Seifu-Kai" in Adachi Ward, Tokyo, Japan. A typical user visits the facility two days of the week. He/she goes there by courtesy bus, stays there and does some hobbies or rehabilitation for several hours, then goes back to his/her home by the bus. The users plotted in the map belong to two groups on the same day of the week. This area is densely built-up, where some of the roads are too narrow for the bus to go through or to stop for picking up the users. Some others are one-way or cul-de-sac. Besides, some of the users are handicapped, who may not be able to cross the road, may have to be wheeled around, or may not be able to be seated in the bus for a long time. Furthermore, the capacity for the wheelchairs is limited (Figure 3). Consequently, it takes dozens of hours even for an experienced driver to schedule them because it is still being done manually at present.

Under such conditions, the care agency should group the users and decide the schedule for service and the routes of courtesy buses simultaneously considering cost saving.

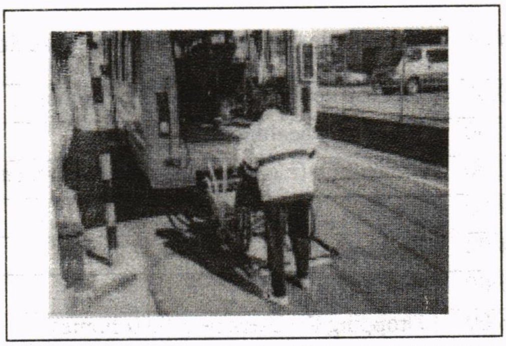


Figure 3. An Example of the Characteristic Factors: User in Wheelchairs.

3. DEVELOPMENT OF COURTESY BUS SCHEDULING SYSTEM FOR NURSING CARE FOR THE ELDERLY

3.1 Basic Idea for Development of the System

In order to decide the schedule, we should consider the time of arrival of the bus. However, the users do not stick to the time of being picked up or dropped. In most cases, they only want to know the time. Thus, hereafter, the essence of the problem discussed in the paper is a shortest route problem. The times of arrival of the bus will be calculated by the system and the agency will inform the users of them.

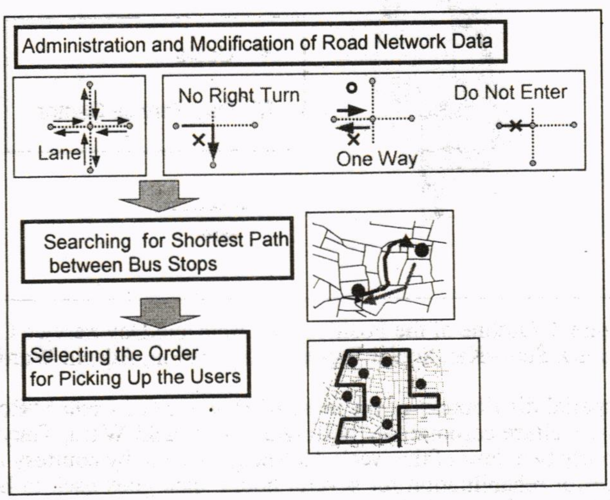


Figure 4. Outline of the Scheduling System Implementation

Although it seems to be easy to decide the route based on an off-the-shelf GIS, it cannot support solving the problem. Since there are many constraints to be considered as mentioned in Chapter 2. Thus, in this chapter, we develop a system to support deciding the route. As illustrated in Figure 4, the outline of the procedure by the system we develop consists of three steps. We constructed the data on Arc View 3.2, which is the GIS software produced by ESRI.

First, we build up the data of road network and users. Data of the users contain following attributes: age, day of the week when he/she comes, contents of the service, wheelchair users or not, ability to walk alone, handicapped level and so on. Although road network data are provided by municipalities, they are not available as they are in densely built-up areas because of the reason mentioned in Chapter 2. Thus, we modify the road network data to consider whether it is a highway or a back road and consider the conditions such as no right return and one way. We also decide the bus stop for each user and plot it with GIS.

Secondly, we search the shortest path among each bus stop and estimate the travel time/cost. For this purpose, each link has the data of time required, which may change according to time of the day.

Thirdly, after having obtained the cost/time among bus stops, we select the order in which the courtesy bus picks up the users to the center and drops them on the way home.

3.2 Searching the Shortest Paths among Bus Stops

Road network data which are used for supporting regional analysis or city planning are not available as they are especially in densely built-up areas. There, some of the roads are too narrow for the courtesy bus to go through or to stop for picking up the users, some others are one-way or cul-de-sac. Thus, detailed link and node data are required. Besides, some of the users are handicapped, who may not be able to cross the road. Hence, the links are divided into lanes. At intersections, to consider such as "No Right Turn", some node are added.

Hereafter, let us identify the bus stop with the user and let i (i=1,2,···, ··· $\bar{I}$) denote each user or bus stop. $\bar{I}$ equals the number of the users. Suppose that the bus stops can have the same place. It is not necessary for the bus to stop in front on each user's home. Since some users can walk by themselves or the road in front of their homes may be too narrow. If some of them live in the neighborhood, the agency can ask them to use the same bus stop from the viewpoint of efficiency. Thus, we should decide the bus stop referring to their attributes.

Algorithms for the shortest paths problem have been studied for a long time and advances in the theory are still being made. Among them, Ford algorithm (Ford *et al.* (1962)), Bellman algorithm (Bellman *et al.* (1958)) and Dijkstra algorithm (Dijkstra (1959)) are especially well known. A good description of their performances appears in Cherkassky *et al.* (1996). Since we do not dwell on or attempt a detailed study of efficiency, we choose Dijkstra algorithm, which is the most widely known one and is said to be efficient.

3.3 Deciding the Schedule and Route

The cost/time between two bus stops have been completely prepared. Thus, it is natural to consider the problem to select the order in which the courtesy bus picks up the users so that the total of the cost, specifically distance, time or generalized cost, spent in the tour is as small as possible. The problem is the well-known vehicle routing problem (VRP), a special case of which is the traveling salesman problem (TSP).

Let x_{ij} be a binary variable ($x_{ij} \in \{1,0\}$ $(\forall i, \forall j \in S)$), which indicates whether or not the courtesy bus goes directly from bus stop i to j, that is,

$$x_{ij} = \begin{cases} 1 & \text{: If the courtesy bus goes directly from } i \text{ to } j, \\ 0 & \text{: Otherwise.} \end{cases}$$

$S=\{0,1,2,\cdots,\cdots\bar{I}\}$ denotes the union of the set of bus stop, $\{1,2,\cdots,\cdots\bar{I}\}$, and the set of facility, $\{0\}$.Let c_{ij} be the corresponding cost (, time or distance). The total cost of the tour is then

$$C=\sum_{i\in S}\sum_{j\in S-\{i\}}c_{ij}x_{ij} \quad . \tag{1}$$

Clearly, since a unique bus stop is visited after each bus stop

$$\sum_{i\in S-\{j\}}x_{ij}=1 \quad (\forall j\in S-\{0\}), \tag{2}$$

$$\sum_{i\in S-\{0\}}x_{i1}=\bar{K}, \tag{3}$$

$$\sum_{j\in S-\{i\}}x_{ij}=1 \quad (\forall i\in S-\{0\}), \tag{4}$$

$$\sum_{j\in S-\{0\}}x_{1j}=\bar{K}, \tag{5}$$

where $\bar{K}$ denotes the number of subtours (closed loops), namely the number of the group of users. In order not to allow sub-subtours in each subtour, following condition should be added:

$$\sum_{i\in U}\sum_{j\in T_k-U}x_{ij}\geq 1 \qquad (\forall U(\neq\phi)\subset T_k\subset S,\forall k), \tag{6}$$

where ϕ denotes empty set, T_k denotes a subset of S corresponding to a subtour and satisfying the following equations:

$$\bigcup_{k=1}^{\bar{K}}T_k=S, \tag{7}$$

$$T_k\cap T_{k'}=\{0\}\ (\forall k,k'(k\neq k')) \ . \tag{8}$$

(7) and (8) yield

$$\sum_{\forall k}|T_k|-\bar{K}+1=|S|=\bar{I}+1, \tag{9}$$

where $|\cdot|$ denotes cardinality.

Needless to say, we should consider not only the cost for the service agency but the torment of the users. In that case, the objective function itself should be modified. We also would like to mention that long moderate journey does not cause torment to the elderly, since they may enjoy talking in the bus. These aspects will be discussed in the final chapter.

First, we should consider the number of seats for the users:

$$|T_k|-1\leq\bar{T} \quad (\forall k), \tag{10}$$

where $\bar{T}$ is the capacity of the bus.

Secondly, we should consider the capacity for such as wheelchairs, which is given by

$$\sum_{i\in T_k-\{0\}}y_{li}\leq\bar{y}_l \quad (\forall k,\forall l), \tag{11}$$

where y_{li} is a 0-1 variable which indicates the attributes related to capacity $\bar{y}_l$. Suppose y_{1i} denotes whether or not the user uses wheelchairs:

$$y_{1i}=\begin{cases}1 & \text{: User in wheelchairs,}\\ 0 & \text{: Otherwise.}\end{cases}$$

The agency might aspire to distribute some users according to their attributes. For instance, since to nurse a person suffering for senile dementia requires much manpower, distributing such persons contribute to not only driving the labor costs down but providing better-kept service. In that case, the constrain is given as follows:

$$y_{l\min} \le \sum_{i\in T_k-\{0\}} y_{li} \le y_{l\max} \quad (\forall k, \forall l) \ , \tag{11'}$$

where $y_{l\min}$ and $y_{l\max}$ are the minimal and maximal number that the agency requests. Because of a similar reason, if the agency wants to smooth the number of users, we can add the following constraint:

$$T_{\min} \le |T_k| - 1 \le T_{\max} \qquad (\forall k), \tag{12}$$

where $T_{\min}$ and $T_{\max}$ are also the minimal and maximal number.

Herewith, the problem of deciding the schedule and route is formulated as follows.

$$\min_{x_{ij}}. \quad C = \sum_{i\in S}\sum_{j\in S-\{i\}} c_{ij} x_{ij} \tag{13}$$

subject to (2)–(8), (10)–(12).

Needless to say, the solution does not say anything about the priority among $\overline{K}$ subtours.

One can add many other constraints to the problem. User sometimes prefers to belong to the same group of his/her friends. The condition to make user m and user n belong to the same group can be formulated as follows:

$$\Pi_{\forall k}\left[\sum_{i\in T_k-\{m\}} x_{im} + \sum_{i\in T_k-\{n\}} x_{in} - 1\right] = (-1)^{\overline{K}-1} \ . \tag{14}$$

Since, if they belong to different groups, left side of the equation above becomes zero.

On the other hand, long journey may give the elderly a lot of stress. We can set the limit on the time required in a tour:

$$\sum_{i\in T_k}\sum_{j\in T_k-\{i\}} c_{ij} x_{ij} \le \overline{C} \ (\forall k) \ . \tag{15}$$

Alternatively, replacing (13) with the following objective function, we can make the times required in a tour vary in a small compass.

$$\min_{x_{ij}}. \quad C = \sum_{i\in S}\sum_{j\in S-\{i\}} c_{ij} x_{ij}$$

$$+\alpha\left\{\sum_{\forall k}\left(\sum_{i\in T_k}\sum_{j\in T_k-\{i\}} c_{ij}x_{ij} - \frac{1}{\overline{K}}\cdot\sum_{i\in S}\sum_{j\in S-\{i\}} c_{ij}x_{ij}\right)^2\right\}^{\frac{1}{2}}, \tag{16}$$

where α is a parameter.

Algorithms for the VRP/TSP have been also studied and amazing advances are still being made. We would like to note that many of them are developed for symmetric VRP/TSP where $c_{ij} = c_{ji}$ $(i \neq j)$, and the problem we have formulated is asymmetric VRP/TSP where $c_{ij} \neq c_{ji}$. In general, the latter is more difficult to solve than the former.

The number of the users that the bus should pick up and drop in a tour is usually less than 20. Besides, we need not to dwell the optimal solution for the problem. In other words, even if it is classified into local search method, operational algorithm is better than the one which is theoretically sophisticated but difficult to handle. Because what we aim at here is not efficient solution but efficient operating or working. The optimal value that we would obtain by solving the problem above shown is only a benchmark. Consequently, we choose the 2-opt procedure (Lin (1965)) and Or-opt procedure. For detail refer to *e.g.* Golden *et al.* (1985).

4. CASE STUDY

The case study is on the day care center which were introduced in Chapter 2. The number of the users is about a hundred. The users are roughly grouped by day of the week. The first group goes to the facility on Monday and Thursday. The second one goes on Tuesday and Friday, and the third one on Wednesday and Saturday. Each group is divided into two sub-groups by time of the day, that is, 9:00 and 10:00 for starting. Consequently, there are six groups and each of them has fifteen to twenty users.

As an opening gambit, we chose two groups which belong to the same day of the week. The total number of the users is 31. The number of the seat of the courtesy bus is 18. In addition, the bus can bring two persons in wheelchairs.

We illustrate the results by hands and the developed system in Figure 5. In this study area, the number of nodes is about 2,800 and the number of links is about 3,900.

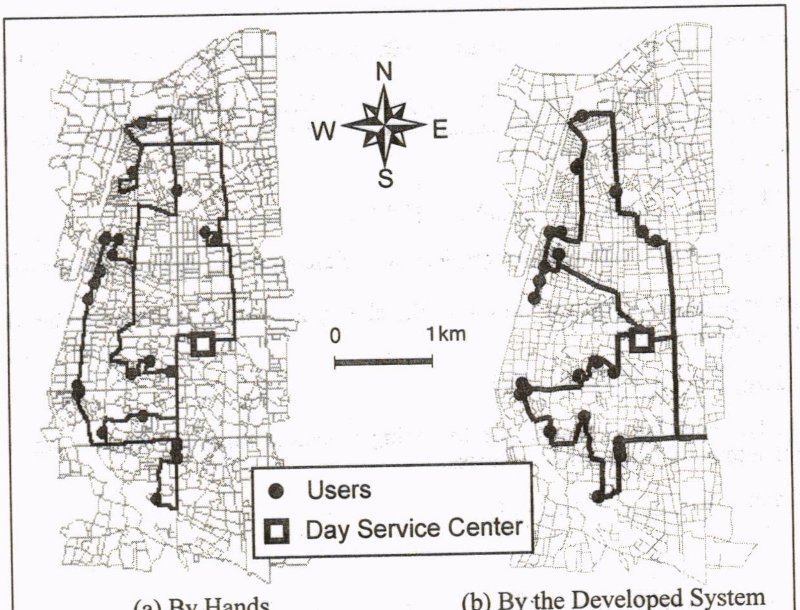


Figure 5. Comparison between the Results

While the total time for two tours based on the route designed by hands was 70 minutes (= 39 min. + 31 min.), the total time based on the route designed by the system and shown in Figure 5 was 52 minutes. And that, in the latter, the time required for each tour was 26 minutes, namely the same. After we prepared the data set, it required only 30 minutes to calculate the shortest path among users and the courtesy route. Besides, the latter results is more convenient for the users because none of the users need cross the trunk lines and the total distance they walk from home to bus stop is less than that of the former. Comparing the results, we still continue to examine whether some important factors are not considered in the system

Since 2-opt/Or-opt algorithm belongs to local search method, the results depend on the initial value set. The results also depend on the parameter α. However, after being obtained the shortest path among users, it took only 5 minutes to reach the stable state in the calculation of TSP when we use a computer whose CPU operates at 600 MHz. Thus, we could try more than several times and select the best solution among them with ease.

5. CONCLUSIONS

The demands for care services for the elderly in developed countries are rapidly increasing. Although care services are people-intensive ones there still exists some room for making them more efficient especially by using GIS.

In this paper, we have focused on the so-called day care service, especially the problem of courtesy bus scheduling. According to the preliminary survey, many important factors to be considered were abstracted. This implied that an off-the-shelf GIS could not support solving the problem. Thus, we developed a new system based on GIS. A scheme to support the task was shown. Then, the problem was formulated as an optimality problem with some constraints that are characteristic to nursing-care service and densely built-up areas. It was also shown that some of the constraints and variables related to geographical attributes could be dealt with GIS efficiently. Finally the system was applied to actual data set and its potential was examined.

This study is the first step for the application of GIS to care services. As for the courtesy bus, we try to deal with the data of whole users simultaneously. There remain many tasks to attack. Hence, we try to consider other systems such as to decide the number of courtesy bus, to allocate the time for service, to consider the utility level of the user and so on. They should include the system developed here as a subsystem.

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