AN EVALUATION MODEL OF THE LEVEL OF EMERGENCY MEDICAL SERVICE IN SPARSELY POPULATED AREAS

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In rural areas, services to support daily life are generally short and a large disparity exists from place to place. This study proposes an index to measure the level of emergency medical service, a minimum service to support daily life, at given locations. The required characteristics of the level of service index are firstly discussed, and then an accessibility type index is proposed with holding the characteristics pointed out in the discussion. By using this index, we develop a systematic method to find the sub-system of that improvement that contributes the most to raising the level of service. This method gives us the order of improvement over sub-systems under the restrictions of budget, time, and other resources. The usefulness of the methodology is examined through a case study.

Key Words: Performance based design, Emergency medical service, Level-of-service, Rural areas, Network analysis

1. INTRODUCTION

Services to support daily life are generally few and a large disparity exists from place to place in rural areas. Under the situation wih a high percentage of elderly people in rural areas, emergency medical services are one of the most important services for daily life. The role of infrastructure development is important in order to raise the level of services and reduce the disparity.

Evaluation of infrastructure development has been done mainly from the viewpoint of the supply side. However an evaluation from the user side, in other words “performance evaluation”, is more essential. For the supply side evaluation, indices of output such as total distance of road improvement and the number of community libraries are used, for example. For the user side evaluation, indices of outcome should be used, such as saved travel time due to road improvement and the number of visitors or the number of books loaned.

This study proposes an index to measure the level of emergency medical services, a minimum service to support daily life, at given places, and develops a systematic method to find a sub-system which can most efficiently raise the service level, or find the order of improvement over sub-systems under the restrictions of budget, time, and other resources. In chapter 2, the required characteristics of the level of service index are discussed firstly. Then, an accessibility type index is proposed whose characteristics are pointed out in the above discussion. In chapter 3, following the clarification the relationship between the contents of improvement in the sub-system level and the survival rate as an evaluation index of the total system, we develop a method to find the sub-system whose improvement contributes the most to raising the level of service. The usefulness of the methodology is examined through a case study in chapter 4. Chapter 5 concludes this study.

2. PROPOSED INDEX TO EXPRESS THE LEVEL OF EMERGENCY MEDICAL SERVICE

2.1 Study review

The aim of emergency medical services is to save lives. The survival rate on a point basis is therefore selected as the index to express the supply level of emergency medical services.

Currently used indices are divided into three groups. The first one uses characteristics of a system component to measure the level of service.

Emergency medical services have the following two characteristics, (1) providing immediate medical care when needed, (2) the place for medical care is usually different from the scene. As a result of these characteristics, accessibility to a hospital becomes an important factor which influences the level of service. Accordingly, how the accessibility relates to the survival rate is essential in evaluating an emergency medical system. This in turn implies the necessity to quantify the accessibility. The indices in the second group are to measure physical level of accessibility expressed by distance or response time[1, 2].

In the emergency medical service, however, the time lag from time of the incident occurrence to the time of arrival at a hospital is not linearly related to the survival rate. Eisenbelg *et. al*[3] found a statistically significant relationship between these two by examining data from more than 600 cardiac arrests in the U.K. and arranging the data as a survival rate curve. These types of indices are those in the third group. However, these indices are related to the supply side, so that the conditions of medical facilities, which vary in time, are not be taken into consideration. In addition, they assume only one level of emergency medical care is given to a patient/injury before arriving at a hospital.

Swersey[4] reviews a wide variety of past studies about the deployment of emergency service units including emergency medical services.

2.2 Basic idea of this study

There exists three necessary conditions that the level-of-service index should hold. The first condition is that the index can evaluate the level-of-service directly. The supply level of emergency medical service has been expressed by such indices as “the number of ambulances deployed per km^2” or “the number of doctors per ten thousand residents”[5]. The numbers of facilities and personnel for emergency medical services partly contribute to the level of service, but are not a measure of the level of service itself.

There is a problem in comparing the situations under the different conditions by “unit area” or “unit number of population”. These problems originate from looking not to the essence of the service, but to a components of the supply system. Hence, such confusion could be avoided if there is an index that expresses the level of service itself. From this point of view, an index of the level of service should be defined relating to the essence of the service.

The second condition is that the index should be a point base index. Generally in mountainous areas, the distance between hamlets is long because the hamlets are located linearly along valleys, so the level of emergency medical service differs greatly from hamlet to hamlet. The arrival time of an ambulance to the scene varies from a couple of minutes to a couple of hours[6]. Clearly therefore, the level of emergency medical service is highly dependent upon the location.

There is a question in using an average type index for expressing the level of service with a big variance. This is because the index must evaluate the level of service not on an area basis but on a point basis because of the existence of locational disparity. A major interest of a current or a future resident is placed on the disaggregate level of service at his/her residential location.

The third condition is that the index must be sensitive in improvement. The level of service at a reference point is a function of both the accessibility from the reference point to the surrounding service points, and the quality of service at the service point. The level of service can be raised by improving the transportation system for easier access to/from the reference point to the service point and/or upgrading the service facility to supply a higher quality of service, for example. In addition, there is an attempt that the supply side of the service also approaches the consumers. A mobile library, doctor’s house call, and mail order with delivery service are good examples.

In the emergency medical service, faster conveyance of the patient by ambulance, upgrading the level of medical care at medical facilities, and giving a higher level of pre-hospital care during transportation to the hospital are effective improvements for raising the level of service. The level of service index must be sensitive enough to the differentiate between alternative improvements and must reflect the change of “quality of life” which is carried by the system improvements.

The index proposed in this study is formed of two parts: estimated pre-hospital time after an incident occurrence taking the hospital choice into consideration, and estimated survival rate taking into account the existence of some different levels of emergency medical care before arriving at a hospital. It means that this index evaluates an emergency medical system, as being a comprehensive system including both medical care and patient conveying, from the view point of accessibility.

2.3 Estimation model of arrival and conveyance times

Patients/injuries who need emergency medical service are usually conveyed by ambulance. The arrival time at the scene and conveyance time to a hospital depend on the running speed of the ambulance, the distance from the ambulance station to the scene, and the distance from the scene to the hospital. In spite of the expectation that running speed depends on traffic and road conditions, for example, road width, curvature, and traffic congestion can be considered as constant regardless of these conditions, from the result of regression analysis using action data. The running distance can be understood to be equal to the road distance from the closest ambulance station to the scene.

The conveyance distance varies depending on the location of the chosen hospital. Though many factors influence hospital choice, the dominant factors are the severity of the incident, the type of incident, and the time of occurrence. Figure 1 shows a tree to estimate a chosen hospital by considering these influencing factors. In this figure, “Severe Case” means an injury or disease that needs hospitalization for more than three weeks, “Minor Case” means an injury or disease that does not need hospitalization, and “Intermediate Case” means those excluded from the above two types.

Based on this result, arrival time at a scene, t_s, and conveying time, t_c, can be estimated as,

$$t_s = d_s / v_o \quad (1)$$

$$t_c = d_c / v_o + t_o \quad (2)$$

where, d_s is the road distance between a scene and the closest ambulance station, d_c is the road distance between the scene and the hospital given by the hospital choice tree in Figure 1, v_o is the average speed of the ambulance, and t_o is the average treatment time at the scene.

The estimated times show a good fit to those observed, and hence the proposed estimation model can be taken to have a good replication capability.

2.4 Estimation model of the beginning time of emergency medical care

Patients are usually conveyed to a hospital while receiving so called pre-hospital care from a basic life support unit (BLS), advanced life support unit (ALS), and/or doctor(s). The available treatment of care restricted by law varies in the above listed care levels, Figure 2 shows an image of the relationship between the time length of stages, time length under a certain care level, and the care beginning time of each care level, “Care level” means a stage at which a medical unit of a certain care level provides medical care to a patient, “Stage” means an action component which composes a stage such as ambulance running from a scene to a hospital. In this example, time shortening of any stage will contribute to the beginning time of doctor’s care because the stages are connected in series. The beginning time of care level, m, can be obtained by summing up the time length of preceding care levels, 1, ..., m-1, as follows,

$$\begin{aligned} t_k &= t_{k-2} + \textstyle\sum_m t_{k-1,m} \\ t_{k-1,m} &= \max_n \left[t_{k-1,m,n}(s) \right] \end{aligned} \quad (3)$$

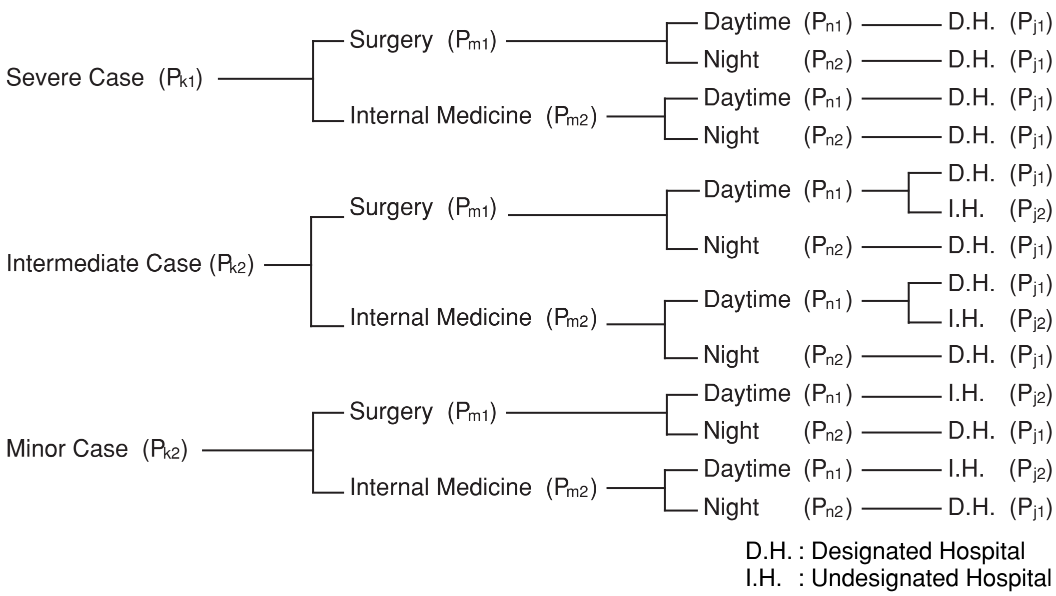


Fig. 1 Tree of hospital choice

where $t_{k\text{-}1,m}$ means the m th stage in care level k-1. $t_{k\text{-}1,m,n(s)}$ means the n th concerning action, which must be completed by the beginning of the next stage, and the length can be controlled by an improvement of sub-system, S.

2.5 Survival rate corresponding with a certain incident type

This curve relates the survival rate with the beginning time of medical care is called the "survival rate curve". The shape of the survival rate curve varies with incident type. The curves are characterized by the degree of steepness of its middle part and the time delay when survival rate becomes 0. Based on Cara[7], a logistic curve is selected to represent a set of survival rate curves.

$$f_{i,k}(t_k) = 1 - \frac{1}{1+\exp\left[-a_{i,k}\left(t_k - b_{i,k}\right)\right]} \tag{4}$$

where $f_{i,k}(t_k)$ is the survival rate of a patient with incident of type i, the care beginning time (of care level k) is t_k, and $a_{i,k}$ and $b_{i,k}$ are parameters.

Some survival rate curves with different incident types are shown in Figure 2. Attention should be focused on the big difference that exists in the sensitivity of the survival rate to the care beginning time between the curves.

2.6 A point base index of service level

While being conveyed from the scene of the incident to a hospital, patients receive pre-hospital care by several life supporting units that provide different levels of medical treatment. The level of medical treatment is generally higher at later stages. The probability that the life support unit with medical treatment of level k firstly succeeds to save a life, is the probability that the life support units at earlier stages could not succeed in doing so, and that the unit of level k can. The survival rate of a patient, $P_{i,k}$, involved in an incident of type i at the beginning time of care, t_k, is given as,

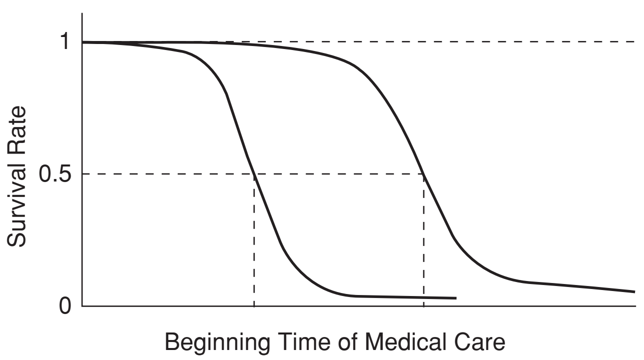


Fig. 2 Survival rate curves

$$P_{i,k} = \begin{cases} f_{i,k}(t_k)\Pi_{k'=1}^{k-1}\left\{1 - f_{i,k'}(t_{k'})\right\} & (k \geq 2) \\ f_{i,1}(t_1) & (k = 1) \end{cases} \tag{5}$$

This probability, $P_{i,k}$, also depends on the time of day of incident occurrence, h, and the place of occurrence. x, so that rewriting the survival rate as $P_{i,h,x,,k}$, the resultant survival rate after receiving the highest medical care of level K, is expressed as,

$$P_{i,x,h}^{total} = \sum_{k=1}^{k} P_{i,h,x,k} \tag{6}$$

The probability of the incident occurring varies with the type of incident and the hospital choice depends on the time of the occurrence. Taking this into account, the point basis index is then defined as,

$$S(x) = \sum_i \sum_h P_i P_h P_{i,h,x}^{total} \tag{7}$$

The index value of an area with more than two reference points, is given by taking the summation of $S(x)$ weighted by the population ratio of the area.

3. NETWORK ANALYSIS FOR SYSTEM IMPROVEMENT

3.1 Stages as a job unit

Similar to other systems, an emergency medical system also consists of sub-systems. Because of budget restrictions or other conditions relating to the system improvement, it is important to find a sub-system to be improved whose improvement will be the most effective in raising the level of emergency medical service in an area. For such a purpose, the relationship between an improvement plan of a sub-system and the effect, resultant change of the level of service, should be made clear.

An emergency medical system, as a total system including the conveyance and medical services, consists of many components such as scene, ambulance stations, hospitals, heliports, ambulances, etc. The service supplied by the emergency medical system can be broken down into several job units such as a request to the fire/police department, dispatching an ambulance to the scene, conveying the patient from the scene to a hospital, and giving appropriate medical treatment to the patient at the hospital. We will call each of the job units a "stage", hereafter. Each stage is supported by several sub-systems to perform its function. The combination of these subsystems such as the location of ambulance deployment, the type of conveyance means, the medical level of a hospital, and the location of the hospital, determine the duration of each stage. By using this time length of each stage, called "stage length" hereafter, we can obtain the cumulative time length before providing a certain level of medical treatment to the patient after the time of incident occurrence.

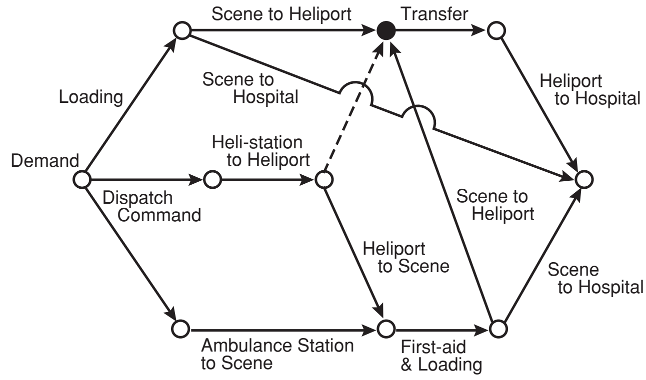


Fig. 3 A network of stages

3.2 Network of stages

What is important in the emergency medical system is how fast the patient can receive adequate medical treatment. Let us focus on shortening the time length of the longer stage which is comparatively easy to shorten. Here, attention should be paid to the fact that the improvement of a stage does not necessarily mean the improvement of the total system. In this case, several stages work simultaneously and the following stage can be started only if all the preceding stages have ended.

Figure 3 outlines a typical process of an emergency medical service. An arrow represents a stage and the direction shows the direction of time passing. The symbol of node "○" denotes the node where the following stage can start if one of the preceding stages has ended. The beginning time of the following stage is, therefore, given as the ending time of the earliest ended preceding stage. The other symbol of node "●" represents the node at which the following stage cannot start if all the stages concentrated at the node have not ended. At a node of this type, the beginning time of the following stage is given as the latest end time of the preceding stage. (In the above mentioned case, several stages work simultaneously.) In such a case, an improvement of a sub-system, which relates only the stages and has no bearing on the beginning time of the following stage, does not carry any improvement to the total system.

3.3 Critical path

A path composed of several consecutive stages, where total stage length directly affects the time length of the total system, is hereafter called the "critical path" in this study. This is a similar concept to those used in the context of PERT, a technique for system optimization. By identifying the critical path, we can find which stage dominates the time length of the total system. The total system can be improved by improving the sub-system which supports the stage on the critical path.

The critical path can be found systematically as follows. The first step is to represent the emergency medical service as a network of the component stages. The nodes are numbered from left to right. A stage is specified by the node numbers at both ends. Denote a stage, $S_{l,m}$ and the stage length, $d_{l,m}$ where l and m are the node numbers of the beginning node and ending node, respectively, and $l<m$. The second step is to calculate the earliest node time of node l, t_l^E , and the latest node time of node m, t_m^E .

The earliest node time of node m, t_m^E, is defined as,

$$\begin{cases} t_0^E = 0 & (m=0) \\ t_m^E = \begin{Bmatrix} \max\limits_{S_{l,m}\in S} \left[t_l^E + d_{l,m} \right] & (for\ \delta = 1) \\ \min\limits_{S_{l,m}\in S} \left[t_l^E + d_{l,m} \right] & (for\ \delta = 2) \end{Bmatrix} & (m \geq 1) \end{cases} \quad (8)$$
$$(m = 0,1,\cdots,n),\ l<m$$

where $S_{l,m} \in \boldsymbol{S}$ shows that the stage $S_{l,m}$ is a member of the system $\boldsymbol{S}$, and t_l^E is the starting time of the stage which precedes the stage starting at t_m^E. δ = 1 corresponds to the node "●" and δ = 2 corresponds to the node "○". The earliest node time at the last node n, t_n^E , becomes the ending time of the last stage, λ. The latest node time of node l is defined as,

$$\begin{cases} t_n^L = \lambda & (l=n) \\ t_l^L = \min\limits_{S_{l,m}\in S} \left[t_m^L + d_{l,m} \right] & (l \leq n-1) \end{cases} \quad (9)$$
$$(l = n, n-1,\cdots,0),\ l<m$$

where t_m^L is the starting time of the stage which follows the stage starting at t_l^L.

These two node times are equal for some nodes and are not equal for remaining nodes. A critical path can be defined as the path formed by the consecutive stages while having the following relationship between the beginning and the ending nodes,

$$t_l^E + d_{l,m} = t_m^L \tag{10}$$

The stage length of a stage on the critical path is denoted as $\tau_{l,m}$, hereafter.

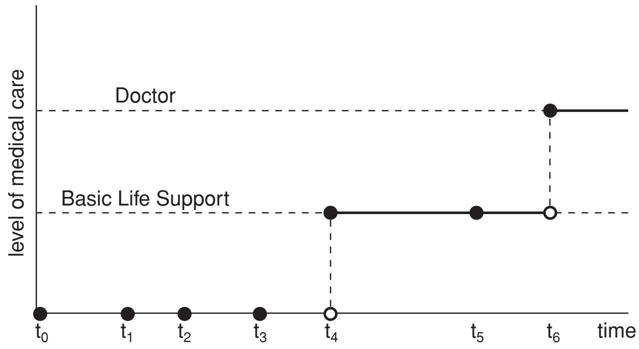
3.4 The stage to be improved

What should be done next to the critical path identification is to select the stage to be improved among the stages which compose the critical path. For this purpose, some evaluation indices are introduced. As stated earlier in this study, the index for selecting a stage to be improved must strongly reflect the level of emergency medical service as essential. The author proposed the survival rate of a patient as the essential index of the level of service[8]. The survival rates will also be used in this study as the index of the level of emergency medical service. Indices which measure the efficiency of system improvement will be formed by taking this index of survival rate and relating factors into consideration. The efficiency indices will be based on the degree of influence resulting from an improvement of a stage on the survival rate. We shall look back at the estimation process of the survival rate in the next section.

3.5 The survival rate of a patient

Usually, patients are conveyed to the closest hospital with a sufficient level of care while receiving the pre-hospital care by medical staff. The medical care staff are classified into several classes based on their care level, e.g. basic life support unit (BLS), advanced life support unit (ALS), and doctor(s). The level of available treatment is restricted by law to staff with the care levels mentioned above. Figure 4 illustrates an example of the relationship among the stage periods, beginning time of care of a certain care level. An emergency medical service consists of several stages from the occurrence of an incident to the beginning of medical care by doctors. On Figure 4, reduction of stage length of any stage contributes to shortening the time before they receive care from doctors. This means that all the stages shown here exist on the critical path, in this case.

The point base index at x, $S(x)$, is given by taking the survival rate of a patient, $P_{i,h,x}^{total}$ formulated by,



t_0: incident occurrence
t_1: report
t_2: turning out of ambulance
t_3: arrival at the scene
t_4: beginning of pre-hospital care
t_5: arrival at a hospital
t_6: beginning of doctor's case

Fig. 4 Stages and the care levels

$$S(x) = \sum \sum P_i P_h P_{i,h,x}^{total} \tag{11}$$

Kita[8], while taking into account the type of incident, i , and the time of incident occurrence, h, which affects the hospital choice.

3.6 Efficiency indices for system improvement

For selecting a stage to be improved from the stages composing the critical path, introducing some criteria will be useful. There exists many factors which should be taken into consideration for system improvement, e.g. the reduced time of stage period, the increase of survival rate, improvement cost, technology, environmental impact, public acceptance, etc. For simplicity, we take only the following three factors into consideration, i.e. (1) increase of survival rate, (2) reduced time length before providing a medical treatment, and (3) improvement cost.

Two indices, *SD* and *SC*, are introduced which are defined as,

$$SD = \frac{\Delta S(x)}{\Delta \tau_{l,m}} \tag{12}$$

$$SC = \frac{\Delta S(x)}{C_{l,m}} \tag{13}$$

SD measures the sensitivity of reduced time length on the survival rate, and *SC* measures the sensitvity of improvement cost on the survival time. $\Delta S(x)$ is the increase of the survival rate at point x, $S(x)$, $\Delta\tau_{l,m}$ is the reduced stage length of the stage, $s_{l,m}$, on the critical path, and $C_{l,m}$ is the improvement cost due to the improvement

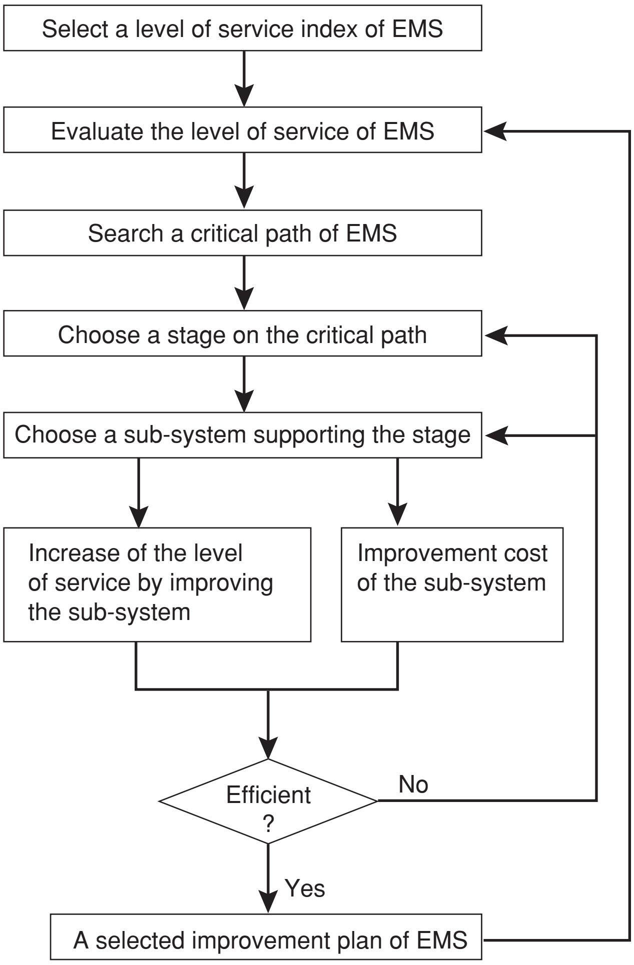


Fig. 5 The planning process

Fig. 6 Eastern Tottori region

of the sub-system corresponding with the stage $s_{l,m}$. The purpose of this approach is to find the stage which contributes the most to raising the level of service index, $S(x)$, and to make an improvement plan for the sub-system supporting the extracted stage. Figure 5 shows the process of this approach.

4. CASE STUDY

4.1 Study area and the setting conditions

The region selected for this case study is the southern part of Eastern Tottori region (Figure 6), which consists of eight towns and villages. Low mountains prevail on the most part. The major roads are Route 53, running from the north to the south, and Route 29 from north to southeast. Five hospitals, one is in Chizu town and the remaining four are in Tottori City, are designated as emergency hospitals. One hospital, with an emergency medical center, located in Tottori city can provide a higher level of emergency medical care for patients/injuries with more severe conditions than the others. The Eastern Tottori Department of Fire Defence supplies the ambulance service. Four ambulance stations exist in the study area, and another ambulance station close to the area, which covers a part of the area. The speed of an ambulance is assumed to be 60 km/h.

For simplicity, three kinds of incidents, i=1, 2, and 3, are taken into consideration which correspond to "cardiac arrest", "cease breathing", and "excessive bleeding", respectively, for simplicity. Three levels of emergency medical care, k=1, 2, and 3 are also considered in this study, which correspond to basic life support (BLS), advanced life support (ALS), and doctor support, respectively. Hence, nine types of survival rate curve are used in total.

The parameters of survival curves, $a_{i,k}$ and $b_{i,k}$, are fixed based on Cara[7] as shown in Table 1. The incident occurrence probability for each kind of incident, P1, P2 and P3, are assumed to be equivalent to the occurrence probability of these diseases, and estimated as 0.187, 0.187, and 0.088, respectively[9]. Estimation of system improvement cost is based on the cost data shown in Yano[10] and Yonekura[11].

Table 1 Parameters of survival curve

	$a_{j,k}$			$b_{j,k}$		
	k=1	k=2	k=3	k=1	k=2	k=3
i=1	2.76	3.45	4.61	5.0	4.0	3.0
i=2	0.92	1.15	1.38	15.0	12.0	10.0
i=3	0.46	0.55	0.69	30.0	25.0	20.0

The data analysis is carried out on a hamlet basis called "koaza". The number of reference points is 220 in total in this area. If needed, the value of the level-of-service index at each point can be aggregated by taking their average on a municipality basis.

4.2 Point base level of emergency medical service and its disparity

Figure 7 shows the spatial distribution of the service level for the incident of type, k=2. It can be found that a rather big disparity in the level of service exists between reference points even though they are in the same municipality. This stems from the geographical characteristics of mountainous sparsely populated areas where hamlets are located linearly along the valley. The importance of a point basis measurement can be understood from this fact. People who are involved in this kind of incident, cease breathing, at a place of high service level denoted by the symbol ● denoted by ◆. It can be said that these places are not safe for people with a high possibility of having ceased breathing such as an asthmatic.

4.3 System improvement 1

The solid line on Figure 8 shows the present level of emergency medical service in each municipality. In finding a sub-system to be improved, the time length of the stages, namely the arrival time at the scene, and the conveyance time to the hospital as estimated by the choice tree, were retrieved. From the result of the comparison, it can be found that the conveyance time is longer than the arrival time in most cases (Figure 9). To reduce the conveyance time, there exists several planning alternatives such as setting up new medical facilities, road improvement, introduction of a helicopter, and so on. A helicopter supported conveyance system is examined in this study. The helicopter station is assumed to be located at the emergency medical center in Tottori city. By changing the conveyance means from ambulance to helicopter, the conveyance time was reduced (Figure 9) and the value of the index went up in every municipality (Figure 8).

For the improvement of this helicopter supported conveying system in raising the value of index, a key is to make the departure time from the closest heliport to the scene earlier. This departure time from the heliport depends on both the arrival time of the helicopter (to the heliport) as well as the arrival time of the patient (to the

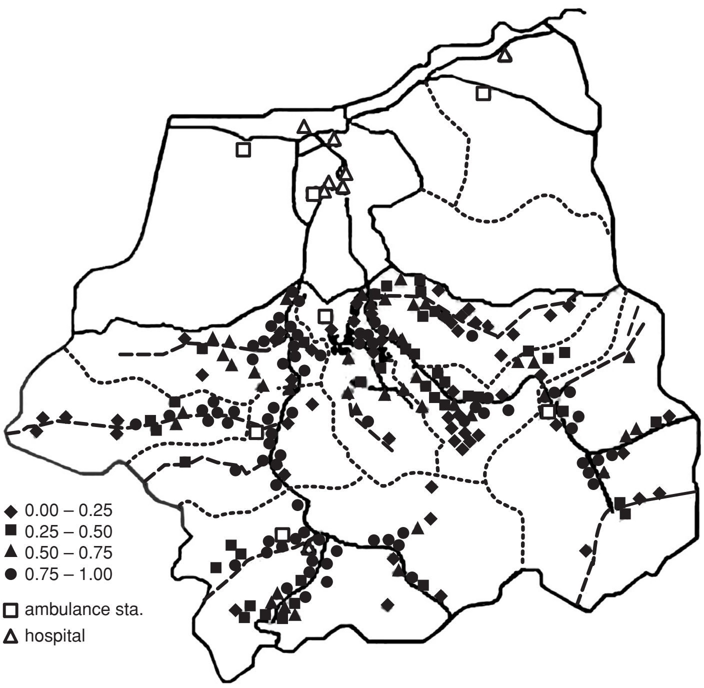


Fig. 7 Spatial distribution of the service level

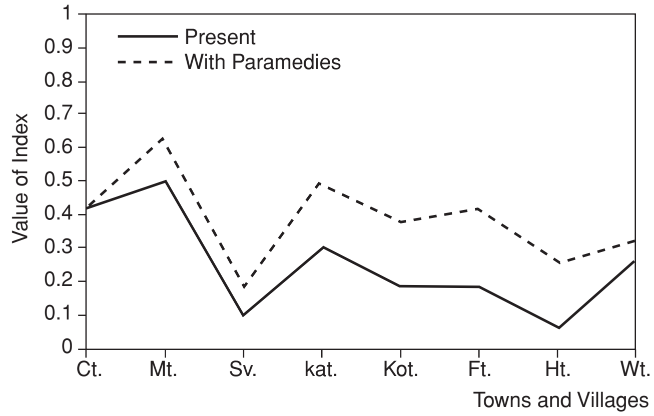


Fig. 8 Supply level of emergency medical service

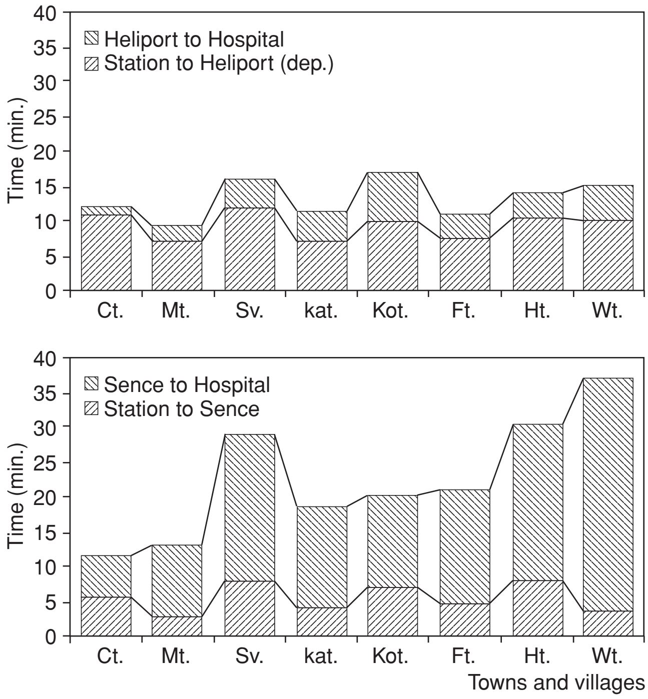


Fig. 9 The time of stages

heliport) from the scene. The result of examinations, which consider relocation of the helicopter station to the former and road improvement for the latter, show that the road improvement from the scene to the heliport can reduce the time more and carries higher level of service than relocation of the helicopter station. This can be interpreted because there are many reference points far from the closest heliport in this area, a fact which highly affects the result. Even though it was not examined in this study, developing new heliports may therefore also be effective.

4.4 System improvement 2

"Increase in the number of ambulance stations", "Increase in the number of medical facilities", "road improvement", "introducing a helicopter", etc. are listed as countermeasures to shorten the stage period of these stages. Among them, the following three alternatives are selected for analysis,

S_1 : road improvement between the closest ambulance station and the scene;

S_2 : road improvement between the scene and the closest hospital;

S_3 : introducing a helicopter for emergency medical service.

Road improvement can increase the traveling speed of an ambulance. Introducing a helicopter can raise the conveyance speed. It can be expected to shorten the stage period of the stage "conveyance from the scene to the hospital" which is a component of the critical path.

The values of point base index $S(x_a)$ and $S(x_b)$ at the points A and B are evaluated as 0.148 and 0.110, respectively, shown in Figure 10. Among the stage period of each stages, the stage period of the stages "from ambulance station to the scene" and "from the scene to the hospital", which exist on the critical path, are longer than the others.

Table 2 shows the estimation value of indices under the condition of the sub-systems being improved. In Table 2, the alternative S_1 carries the biggest improvement on the level of service index $S(x_a)$ at point A, and the alternative S_3 carries the biggest one at point B. This result shows that the same alternative does not necessarily carry the same effect. This difference showed that the degree of effect varies at points since it highly depends on the geographical conditions. In the Mountainous area

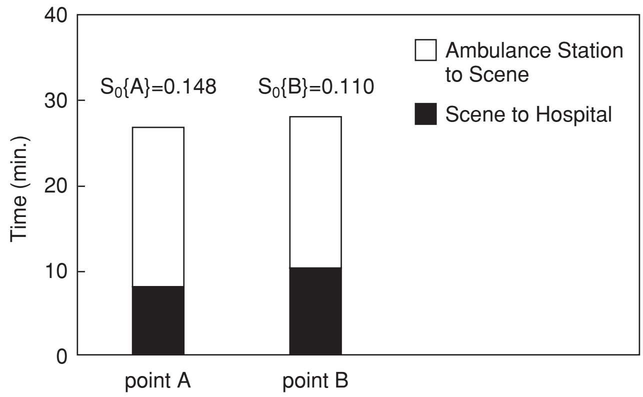


Fig. 10 Stage length

Table 2 Estimating value of indices

(point A)

System	S_1	S_2	S_3
$\Delta S(x)$ ($\times 10^{-2}$)	3.65	0.06	2.27
$\Delta\tau_{l,m}$	1.14	2.93	13.55
$C_{l,m}$ ($\times 10^{2}$ yen)	1.83	4.72	2.22
SD ($\times 10^{-2}$/min)	3.20	0.02	0.17
SD ($\times 10^{-10}$/yen)	1.99	0.01	1.02

(point B)

System	S_1	S_2	S_3
$\Delta S(x)$ ($\times 10^{-2}$)	3.11	0.09	5.72
$\Delta\tau_{l,m}$	1.37	2.74	15.83
$C_{l,m}$ ($\times 10^{2}$ yen)	2.20	4.41	2.22
SD ($\times 10^{-2}$/min)	2.27	0.03	0.36
SD ($\times 10^{-10}$/yen)	1.41	0.02	2.58

dealt with in this case study, a rather big disparity in geographical conditions exists from point to point, e.g. the distance to the central place of the area and the terrain along the road connecting them. This is the reason why the orders of alternatives in their effects are in reverse at the points A and B.

$\Delta\tau_{l,m}$ in Table 2 shows the amount of time by which the stage length has been reduced. Since these stages are on the critical path, the reduced time length directly affects the total reduced time. The values corresponding to the alternatives differ from each other. The increase of $S(x)$ per unit reduced time *SD*, also shows the existence of a difference. Attention should be given to the result that an alternative with a bigger value of $\Delta\tau_{l,m}$ is not necessarily an alternative with a bigger value of *SD*. The reason why the value of *SD* for the alternative S_1 is bigger than those for S_2 is because of the existence of non-linearity in the survival rate curve. The shape of the survival rate curve varies according to the types of incident and the level of medical care. The effect of an alternative is high if the range of reduced time is in the part of the survival rate curve with high sensitivity, and is low if it is in the part with low sensitivity. The time reduced by an alternative is in the highly sensitive part in one case, the time reduced by the same alternative is in the low sensitive part in another case, depending on the point and the type of incident. The improvement effect increases if the range of reduced time overlaps more into the highly sensitive part of the survival rate curve. As seen from Table 2, the improvement effects differ from each other including the reverse order of alternatives in $\Delta\tau_{l,m}$ and $\Delta S(x)$.

Comparison of S_1 and S_3 shows an example. S_3 gives a bigger improvement than S_1 in time reduction at both points of A and B. However, the improvement effect by S_3 measured in the increase of the level of service is smaller than that by S_1 at point A, and bigger at point B. This is because the sensitive part of the survival rate curve corresponding to the doctor level in the medical care and type 2 in the type of patient overlaps the range of reduced time by S_1 at point A, while it does not overlap the range at point B. Similarly, in the comparison of S_1 and S, the reason, why the improvement effect of S_1 is bigger than S, is because the time reduction by S greatly overlaps the range where sensitivity of the time before commencing medical care on the survival rate is high, while the sensitivity is low in the range of time reduction by S_2 .

In comparison to the average of *SD* at each point, over all the reference points in the case area, the biggest ones are due to S_1. The reason can be understood because the contribution of S_1 on the improvement of the earlier stage is bigger than those of S_2 and S_3, and thus, the earlier medical care given to patients is effective. This result underlines the importance of medical care given at the earlier stages.

From the view point of index $S(x)$, S_1 should be selected as the best plan for system improvement for hamlet A, and S_3 for hamlet B. However these plans need an improvement cost, $C_{l,m}$, so that the cost should be taken into consideration in the selection of planning alternatives.

By focusing on the increase of the level of service per unit cost, *SC*, the alternative S_1 for hamlet A and S_3 for hamlet B show the biggest value, respectively. If the budgets for hamlets A and B are restricted to a certain amount, S_1 should be selected for hamlet A and S_3 for hamlet B, respectively. In this case, the selected plans for hamlets A and B from the view point of maximization of the level of service, $S(x)$, are the same as those from the view point of cost-effectiveness. This is, however, a result under the assumption that the effects of the alternative plans are independent from each other. In actuality, there often exists an "economy of scale" and/or "economy of scope" in an alternative such as the introduction of a helicopter system for raising the level of service at hamlet B and hamlet A.

5. CONCLUSIONS

This study discussed the measurement of a level of emergency medical service as a basic service for supporting life, and then proposed an index based on the survival rate. The usefulness of the proposed index, the ability to indicate the level of service on a point basis and the sensitivity enough to evaluate alternatives for system improvement, etc., are demonstrated through the case study. This index may be useful for cost-effectiveness analysis by taking the cost needed for improvement into consideration, and also be applicable in evaluating investment for enlargement of the service area of a hospital, for example.

By using this index, a methodology was developed for choosing an improvement plan to raise the level of emergency medical service as a basic life support service. To sustain a certain level of life support service is essential to establishing sustainable communities in sparsely populated areas. Several alternative plans exist from different fields of administration, such as construction, health, transport, etc., for raising the level of service. The execution of these plans tends to be done by different sections of government in parallel without enough coordination. Given a restricted budget in infrastructure development, selection of a more effective alternative should be considered not within one section but across many sections.

A comprehensive evaluation of the emergency medical system on a point basis has been made possible by using the proposed index. An opportunity was given to select the most effective plan for system improvement under budget restrictions, by taking into consideration both the increase of survival rate and the costs resulting from the improvements of subsystems. Some useful results were found through the case study, e.g. shortening the stage period of an earlier stage is effective for raising the level of service, and an effective improvement plan differs from point to point. The usefulness of the proposed methodology based on the stage periods is demonstrated for a detailed investigation that considers the location-specific conditions.

However, this study does not touch on how to establish priority of improvement to each hamlet. A question of this sort, which cannot avoid the discussion about efficiency and equity, is for further study. A minimum level of service to be supplied should be discussed in discussing sustainability of peripheral areas. This issue will also be left for further studies.

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