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A Proposal on Road Evaluation Method Considering the Effect of Shortening Emergency Medical Service Transportation Time and the Rate of Aging in Japan in the Future

by

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Abstract

This paper proposes to introduce the estimate of the increase in survivors of critical care patients as a new factor beyond conventional factors to evaluate the effect of building new roads. The estimation is based on the relationships "between the life-saving rate and the EMS (Emergency Medical Service) transportation time" and "between the over-65 ratio and the number of critical care patients per 10,000," derived from the statistics of emergency medical care records and emergency transportation records. The research could open the door to solve the struggle that some significant determinants of the road evaluation are deliberately ignored.

Keywords: Emergency Medical Service, Transportation Time, Survival Rates, Aging

1. Introduction

Reflecting on the original purpose of public works, it ought to be essential for them to be designed to promote the public welfare. This study suggests the public to evaluate the construction of roads based on this fundamental philosophy, specifically focusing on the data from the emergency services. Currently, three criteria are taken into account in order to determine the merit of new roads, i.e., travel time and travel cost savings and the reduction of car accidents. New road constructions are planned only based on whether they make sense economically because these are the criteria to be examined, and other important factors are disregarded despite their contributions to the public welfare only because of the relative difficulty to quantify their economical benefits.

The research is dedicated to introduce a new standpoint which concerns the human life to the road evaluation, which is currently heavily reliant on the economic effect. It is observed that for several diseases the higher survival rates can be expected by lessening the EMS transportation time. In addition to this finding, a significantly positive correlation between the number of critical care

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patients per 10,000 and the over-65 ratio has been discovered. The number of critical care patients who can be saved by virtue of new roads can be estmated using these two findings and the list of future population.

2. The Relationship between the EMS Transportation Time and the Survival Rates of Critical Care Patients

The data of acute and lethal internal diseases, i.e., acute myocardial infarction (AMI), subarachnoid hemorrhage (SAH), cerebral infarction (CI), cerebral hemorrhage (CH) and aortic dissection (AD), and multiple trauma (MT) are collected so as to investigate the relations "between the life-saving rate and the EMS (Emergency Medical Service) transportation time." These diseases are chosen due to their relatively sufficient outbreaks, which are needed to implement the statistical analyses. These data are based on the medical records of transported patients in 2004 and 2005 at nine major local hospitals in Kyushu (**Table 1**). 1,310 patient-samples directly carried to the hospitals (**Table 2**), in which transportation time (between the 119 call and arrival at hospitals), transfer condition (dead or alive and hospitalized or discharged) and status of diseases (Mild, Moderate and Severe) are known, are selected from 4,285 samples.

Table 1 The hospitals.

Iizuka Hospital
St.Mary`s Hospital
Saga Prefectural Hospital Koseikan
National Hospital Organization Nagasaki Medical Center
Saiseikai Kumamoto Hospital
Japanese Red Cross Kumamoto Hospital
Shinbeppu Hospital
Kagoshima Medical Association Hospital
Okinawa Prefectural Chubu Hospital

D.C.: the data on critical care patients who are directly carried to the nine hospitals

Table 2 The data of outbreaks for each disease.

Disease	# of Data	D.C.
AMI	971	197
SAH	426	131
CI	1269	360
CH	1085	416
AD	282	75
MT	252	131
Total	4285	1310

There are negative correlations between the EMS transportation time and the life-saving rates of critical care patients for moderate and severe status of AMI and all conditions of CI, AD and MT. In order to clarify this relationship, the equations between the EMS transportation time (X) and the survival rates of patients with the four diseases (Y) are introduced (**Fig. 1** and **Table 3**), using linear regression analysis.

Table 3 The formulas to show the relationship between EMS transportation time and life-saving rate [3].

Disease	Status	Regression Equation	Coefficient	Degree of Freedom	t-value
AMI	Moderate & Severe	$Y = -0.0160X + 1.1552$	$R^2 = 0.9073$	4	6.257
CI	All conditions	$Y = -0.0048X + 1.0412$	$R^2 = 0.8071$	4	4.091
AD	All conditions	$Y = -0.0112X + 1.0694$	$R^2 = 0.7233$	5	3.61
MT	All conditions	$Y = -0.0119X + 0.9208$	$R^2 = 0.6698$	3	2.467

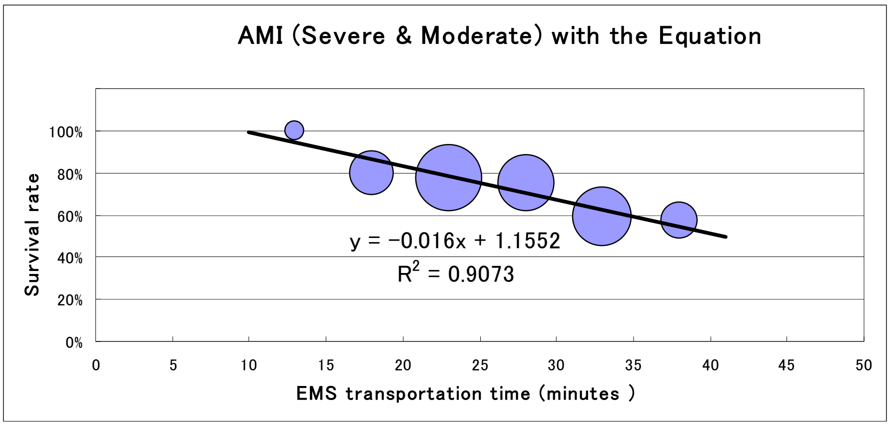


Fig. 1-1 The relationship between EMS transportation time and life-saving rate for AMI.

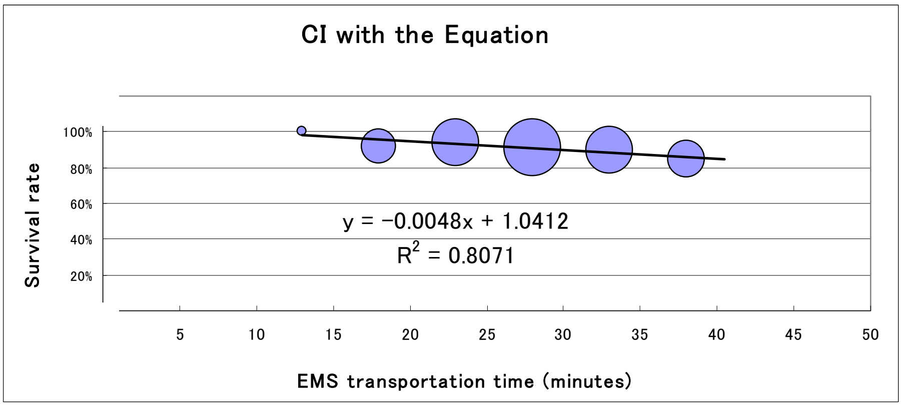


Fig. 1-2 The relationship between EMS transportation time and life-saving rate for CI.

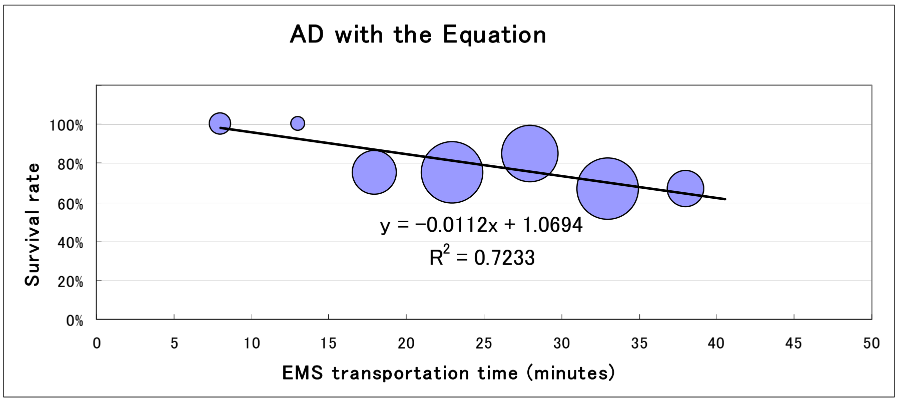


Fig. 1-3 The relationship between EMS transportation time and life-saving rate for AD.

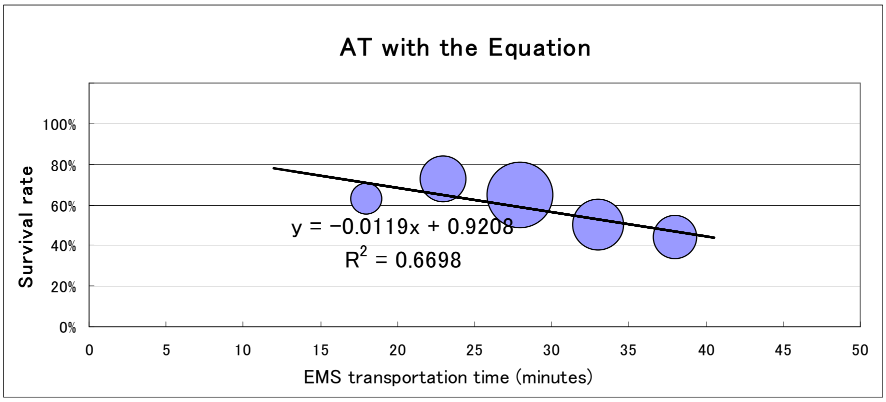


Fig. 1-4 The relationship between EMS transportation time and life-saving rate for MT.

3. The Basic information for the Number of Critical Care Patients and the Over-65 Population

Nagasaki City and Nagasaki Network for Practical Emergency Medicine annually publishes a report based on pre-hospital records in Nagasaki-City area (Nagasaki, Tokitsu and Nagayo) since its foundation in 1997. This report includes the total number of transported critical care patients, the number of transported critical care patients for each disease and the collection rate of pre-hospital records, which is the turnout rate of pre-hospital records. **Table 4** shows the following data of Nagasaki-City area during the previous 11 years.

1. the total population and the over-65 population
2. the ratio of the over-65 population to the total population
3. the collection rate of pre-hospital records
4. the number of transported critical care patients with the four diseases whose life-saving rates exhibit a negative correlation with the EMS transportation time
5. the number of critical care patients with the four diseases
6. the number of critical care patients with the four diseases every 10,000

The total population and the over-65 population are obtained by using the population sorted by age for each city and town on the official website of Nagasaki prefecture. The collection rate of pre-hospital records and the number of transported critical care patients with the four diseases base on annual reports provided by Nagasaki City and Nagasaki Network for Practical Emergency Medicine. The over-65 ratio is calculated, ignoring one percent of the total population whose ages are unknown. The number of critical care patients is given by dividing the number of transported critical care patients with the four diseases by the collection rate of pre-hospital records.

Table 4 The relationship between the over-65 ratio and number of critical care patients.

Year	1998	1999	2000	2001	2002	2003
Population	553,094	551,048	546,606	544,763	542,466	540,849
Over-65 population	97,064	99,936	103,014	106,025	108,782	111,245
Over-65 ratio	17.5%	18.1%	18.8%	19.5%	20.1%	20.6%
Collection rate of pre-hospital records	98.9%	94.5%	83.8%	82.5%	86.2%	91.0%
The number of transported patients with	226	238	224	192	233	271
AMI outbreaks	226	249	265	230	268	295
AMI outbreaks/10,000	4	5	5	4	5	5
The number of transported patients with	551	487	478	538	550	568
CI outbreaks	552	510	565	646	632	618
CI outbreaks/10,000	10	9	10	12	12	11
The number of transported patients with						
AD outbreaks						
AD outbreaks/10,000						
The number of transported patients with	35	16	24	11	9	25
MT outbreaks	35	17	28	13	10	27
MT outbreaks/10,000	1	0	1	0	0	1

Year	2004	2005	2006	2007	2008
Population	538,945	526,988	523,681	520,490	518,066
Over-65 population	113,417	114,062	116,892	119,483	121,267
Over-65 ratio	21.0%	21.6%	22.3%	23.0%	23.4%
Collection rate of pre-hospital records	92.8%	94.5%	82.7%	89.3%	90.3%
The number of transported patients with	329	285	277	264	231
AMI outbreaks	351	299	332	293	253
AMI outbreaks/10,000	7	6	6	6	5
The number of transported patients with	587	620	547	593	610
CI outbreaks	626	650	655	657	669
CI outbreaks/10,000	12	12	13	13	13
The number of transported patients with	98	99	88	107	100
AD outbreaks	105	104	105	119	110
AD outbreaks/10,000	2	2	2	2	2
The number of transported patients with	18	39	24	23	20
MT outbreaks	19	41	29	25	22
MT outbreaks/10,000	0	1	1	0	0

4. The Relation between the Over-65 Ratio and the Number of Critical Care Patients per 10,000

Figure 2 and **Table 5** show the relationship between the over-65 ratio and the number of critical care patients per 10,000 for the four diseases. A positive correlation is apparent. The result of Non-correlation test with t (N-2) distribution indicates that CI is statistically significant on one-side tests at level 1%, AMI and AD are statistically significant on one-side tests at level 5%. A low correlation is observed on MT. **Table 5** shows the linear regression equations, the coefficients, t-values and the results of non-correlation test between the over-65 ratio and the number of critical care patients per 10,000 for the four diseases. In this figure, X represents the over-65 ratio, and Y represents the number of critical care patients per 10,000.

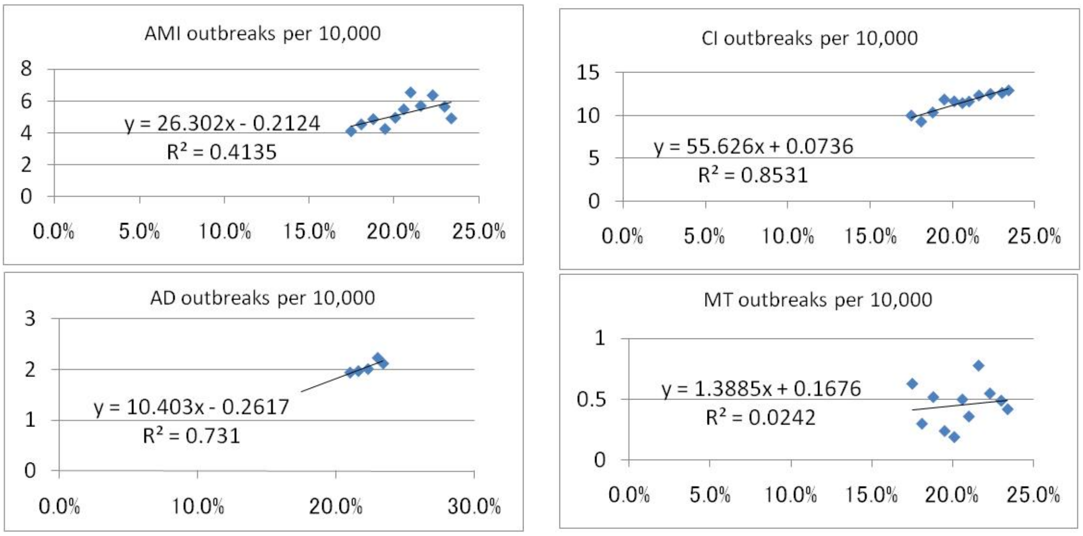


Fig. 2 The relationship between the over-65 ratio and the number of critical care patients per 10,000.

Table 5 The formulas to clarify the relationship between the over-65 ratio and the number of critical care patients per 10,000.

Disease	Regression Equation	Coefficient	Degree of freedom	t-value	Significant Level
AMI	Y=26.302X-0.2124	0.6430	9	2.5190	5.0%
CI	Y=55.626X+0.0736	0.9236	9	7.2295	1.0%
AD	Y=10.403X-0.2617	0.8550	3	2.8552	5.0%
MT	Y=1.3885X+0.1676	0.1556	9	0.4724	—

One-sided test at 1% and 5% of significant level

5. The Estimation of the Future Number of Population, Over-65's and Critical Care Patients in Nagasaki-City Area

National Institute of Population and Social Security Research estimates and publishes the population and over-65 population of every five year to the year 2055, and both of them sorted by city and town until the year of 2035. The population, over-65 population and over-65 ratio of Nagasaki-City are listed in the first three rows of **Table 6**. The number of critical care patients for each disease per 10,000 can be gauged by combining the formulas in **Table 5** and over-65 ratio. Multiplication of the number of critical care patients with one of the four diseases every 10,000 and the population of a particular year in Nagasaki-City area gives the number of critical patients for that disease in the area, taking the progressive over-65 ratio and decline in population into account. The simple average value of the number of critical care patients per 10,000 could be used for MT since there is an insignificant correlation. However, since the number of outbreaks is smaller and the slope is flatter than the other three diseases, the value calculated by the formula is utilized. The results are shown below the third row of **Table 6**.

Table 6 The estimation of the number of critical care patients.

Year		2010	2015	2020	2025	2030	2035
Total population		512166	495318	475308	452695	428390	402751
Over-65 population		124403	140638	151596	153854	152458	149148
Over-65 ratio		24.3%	28.4%	31.9%	34.0%	35.6%	37.0%
AMI	Outbreaks	316	359	389	395	392	384
	Outbreaks/10,000	6.18	7.26	8.18	8.73	9.15	9.53
CI	Outbreaks	688	779	840	852	845	827
	Outbreaks/10,000	13.44	15.72	17.67	18.83	19.72	20.53
AD	Outbreaks	116	133	145	148	147	145
	Outbreaks/10,000	2.27	2.69	3.06	3.27	3.44	3.59
MT	Outbreaks	26	28	29	29	28	27
	Outbreaks/10,000	0.50	0.56	0.61	0.64	0.66	0.68
Excluding MT	Outbreaks	1005	1138	1228	1248	1237	1210
	Outbreaks/10,000	19.61	22.98	25.84	27.56	28.87	30.05
Including MT	Outbreaks	1146	1299	1403	1425	1413	1382
	Outbreaks/10,000	22.38	26.23	29.51	31.47	32.97	34.33

6. The Future of the Number of Critical Care Patients with the Four Diseases

Figure 3 shows the estimation of numbers of critical care patients with the four diseases over time. The lines respectively represent the numbers of critical care patients with MT, AD, AMI and CI from the bottom. In addition, the total number of patients, with AMI, CI and AD that are statistically significant on one-side tests at level 1% or 5%, is also presented. The number peaks in 2025 and then gradually declines. Furthermore, the data of MT is added to the data of the other three diseases in **Fig. 3**. The numbers of patients with the three and four diseases similarly shift due to the small number of critical care patients with MT. The number of critical care patients with the four diseases in 2005 is indexed as 100 as the anchor so that the future number of critical care patients in Nagasaki-City area can be easily grasped. **Table 7** provides the indexed number of critical care patients with the four diseases of every five years starting from 2005. The same process is done at the national scale, and the result is shown.

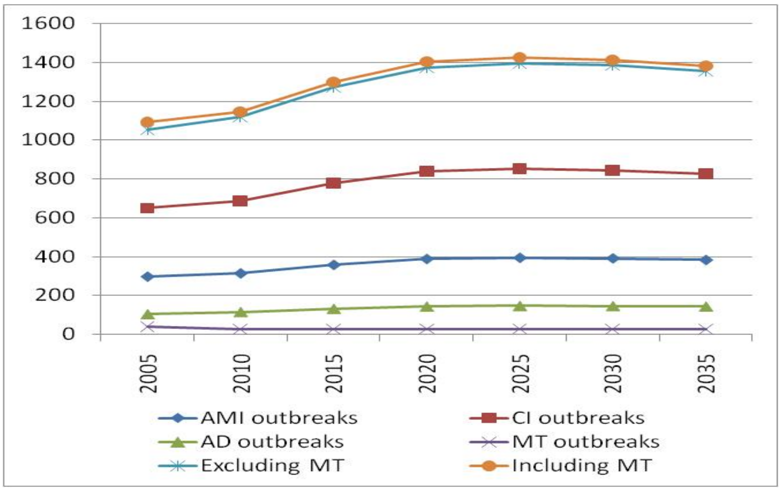


Fig. 3 The shift in the number of critical care patients.

Table 7 The shift in the indexed number of critical care patients with four diseases.

Year	Nagasaki-City area	Japan
2005	100	100
2010	105	114
2015	119	131
2020	128	140
2025	130	142
2030	129	143
2035	126	146
2040		151
2045		150
2050		147
2055		143

The number in 2005 is indexed as 100

7. The Estimation of the Number of Critical care Patients in order to Assess the Effect of Construction of Roads

By the year of 2035, until which the population estimation of every five year is available, the number of critical care patients with the four diseases looks to increase by 26%. After the year 2035, the population estimation sorted by city and town is not available. The number of critical care patients in Nagasaki-City area ought to consequently be gauged by the combination of local policies and the fact that 43% increase in the number of critical care patients at the national scale is expected. In order to assess the impact of building new roads, the life span of them is set as 50 years. As a model, the 50-year period between 2005 and 2055 is chosen. Two simplified possibilities of shift in the indexed number of critical care patients with the four diseases between 2005 and 2055 are exhibited in **Fig. 4** and **Table 8**; the number of critical care patients in 2005 is indexed as 100.

The estimations were derived by the following two extrapolation methods.

1. The value in 2035, 126 (B), does not fluctuate and keeps its value until 2055 (C)
2. The straight decline from the point in 2035, 126 (B), to 100 in 2055 (D), whose value is same as 2005, is hypothesized.

The total number of critical care patients during the 50-year period is 5,000 if the annual number of critical care patients remains the same for 50 years. The two cases (1 and 2) are compared with this anchoring case.

The total number of critical care patients for each case ＝Σ（the average of every 5 years * 5years）

[Case 1]

＝{(100＋105)+(105＋119)＋(119＋128)＋(128＋130)＋(130＋129)＋(129＋126)}＊5／2＋126＊5＊4

＝6,140（123% of 5,000）

[Case 2]

＝{(100＋105)＋(105＋119)＋(119＋128)＋(128＋130)＋(130＋129)＋（129＋126）＋(126＋119.5)＋(119.5＋113)＋(113＋106.5)＋(106.5＋100)}＊5／2

＝5,880（18% increase from 5,000）

The population in Nagasaki-City area shrinks from 526,988 to 402,751, which is 24% decline, from 2005 to 2035. Nevertheless, the number of critical care patients increases by 26%. The number of critical care patients of the two sample cases is almost 120% of that of the anchoring case. The number of critical care patients for each year as well as the total number during 50 years can be obtained.

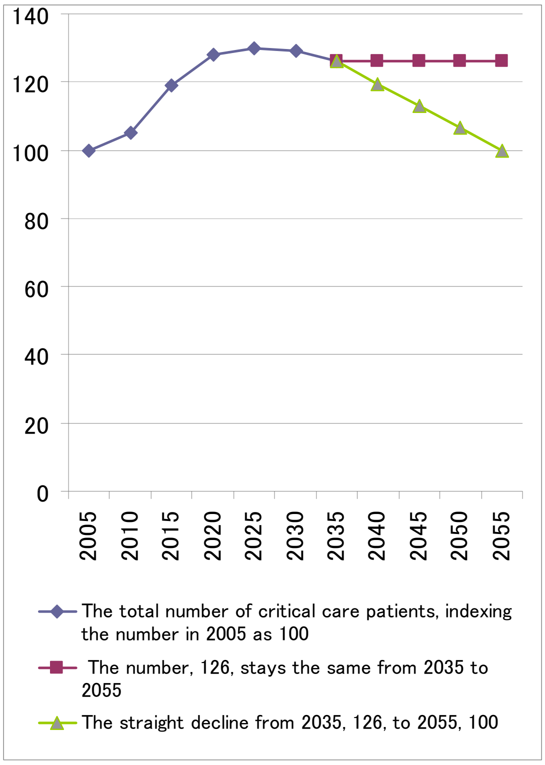


Fig. 4 The shift in the number of critical care patients with 4 diseases, indexing the number in 2005 as 100.

Table 8 The shift in the total number of critical care patients with the 4 diseases after 2035.

Year	126 in 2055	100 in 2055
2035	126	126
2040	126	119.5
2045	126	113
2050	126	106.5
2055	126	100

The number in 2005 is indexed as 100

8. The Estimated Increase in Survivors from the Four Diseases Because of Building New Roads

The combination of estimates by **Table 3** and **Table 5** gauges the survivors by new road constructions. **Figure 5** shows the flow chart. First of all, a major local hospital is set. Then, the areas which rely on that hospital are zoned, and the population in those areas is estimated. A hypothetical sample is shown and explained in **Fig. 6**.

1. Areas, A, B and C, depend on the major local hospital. The population of those areas is 40,000, 20,000 and 5,000 respectively.
2. The distance from the hospital to each are is given. The distances of existing roads and those of new roads are 1.3km and 1.2km to A, 2.2km and 1.8km to B, and 5.0km and 4.5km to C.
3. The average driving speed is 30km/hour for existing roads and 45km/hour for new roads.
4. The EMS transportation time to A, B and C from the hospital is shortened by one, two and four minutes respectively.

Multiplying the population of each area by the number of critical care patients with one of the four diseases per 10,000 (AMI: 2.62, CI: 11.98, AD: 1.95 and MT: 0.56) gives the estimated number of critical care patients with that disease for that area. That number with the decrease in the transportation time and the formula can estimate the increase in survivors of critical care patients with that disease.

The following is the estimated annual increase in survivors of critical care patients with each of the four diseases from building new roads.

[AMI]=∑(the population of an area)*(the number of patients with AMI per 10,000)*(the shortened time)*(X)
= 40,000*2.62／10,000*1min*0.016／min
+2*2.62*2*0.016
+0.5*2.62*4*0.016
= 0.4192／year
[CI] = 4*11.98*1*0.0048
+2*11.98*2*0.0048
+0.5*11.98*4*0.0048
= 0.5750／year
[AD] = 4*1.95*1*0.0112
+2*1.95*2*0.0112
+0.5*1.95*4*0.0112
= 0.2180／year
[MT] =4*0.56*1*0.0119
+2*0.56*2*0.0119
+0.5*0.56*4*0.0119
= 0.0670／year

The estimated increase in survivors of critical care patients is 1.278 per year.
From this model, the estimated increase in survivors of critical care patients during 50 years is 63.96 (1.278*50). As mentioned before, the number of critical care patients for 50 years, taking the progressive over-65 ratio and decline in population into account, is 120% of the annual number of critical care patients multiplied by 50 years. Therefore, the increase in survivors changes from 69.36 to 76.75 (20% increase). This result symbolizes the objective of this study which is the effect of building new roads for an exemplary area, taking progressive over-65 ratio and decline in population into account. However, this number is very simplified, so the estimated number of critical care patients for each year can be calculated and used.

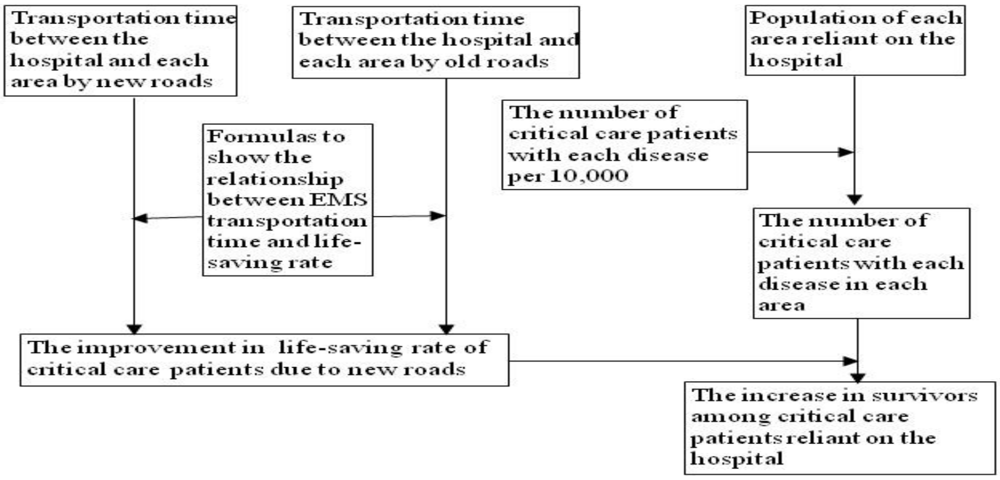
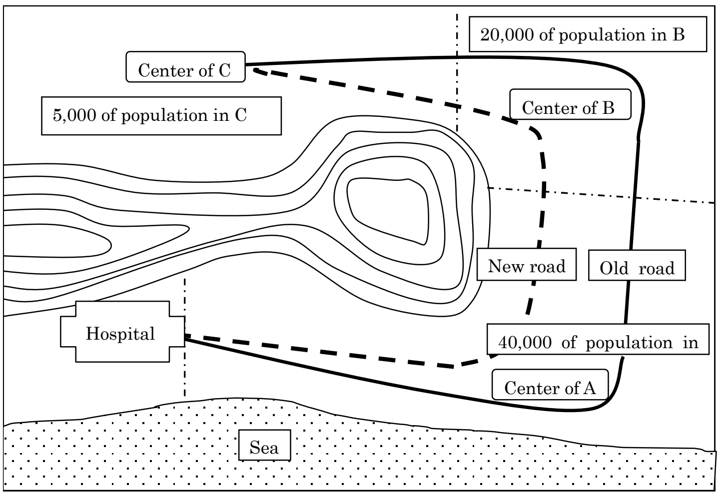


Fig. 5 The flow Chart.



	Hospital ⇔ A	Hospital ⇔ B	Hospital ⇔ C
Shortened EMS transportation time due to a new road (A)	1min.	2min.	4min.
Population of each area reliant on the hospital (B)	40,000	20,000	5,000
Multiplication of (A) and (B)	40,000(40,000)	40,000(80,000)	20,000(100,000)

Fig. 6 The exemplary model.

9. Conclusion and Discussion

Originally, public works should be designed in a wide perspective, such as promoting the public welfare and narrowing gaps among regions. Therefore, a new procedure to evaluate the construction of new roads beside conventional approaches, which are skewed to economic benefits, is suggested in this paper. Even though the effect of building new roads on human lives was considered to be a proper factor to evaluate the construction of new roads, it has never happened due to the heavy reliance of road evaluation on the economic impact and the difficulty of gauging increased survivors because of new roads. Therefore, this paper, which applies our original research, is very significant in that it breaks the dilemma.

The followings are the summaries of this study.

1. The formulas to prove that shortening the EMS transportation time leads to more survivors among critical care patients with the four diseases are presented.
2. The number of critical care patients who are reliant on a major local hospital can be estimated since the number of critical care patients per 10,000 and the population of area covered by that hospital are figured.
3. There is a high correlation between the over-65 ratio and the number of critical care patients per 10,000, and the formula to show the relationship is constructed. This formula combined with the information of future population exhibits the number of critical care patients in the future.
4. The effect of building new roads can be explained in the form of the increase in survivors among critical care patients for coming 50 years, considering the developing over-65 ratio and the decline in population.

In order to enable the result to be applied at the national scale, several points are proposed below.

1. The over-65 ratio and the number of critical care patients per 10,000 should be updated with annual public reports. The research on other areas than Nagasaki-City area should be carried out to examine the effect of locality.
2. The formulas between the EMS transportation time and the rate of survival are required for other areas.
3. If the economic benefits are specifically demanded for road plans, an approach which calculates the economic impact of saved human lives resulted from the plans can be used.

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References

1) The Samples of Research on the Effect of Building New Roads. Road Bureau, MOLIT (2004, 2005, 2006, 2007, 2008).
2) K. Ayukawa, H. Takayama, et al; The Relationship between the EMS Transportation Time and the Survival Rate on the 30th Day in Hospital of the Patients with Fatal Intrinsic Disease or Multiple Trauma, Journal of Japanese Society for Emergency Medicine (2009).
3) A. Fujimoto, K. Ayukawa, et al; Effect of Building New Roads on Saving Critical Care Patients, Japan Society of Traffic Engineers (2010).

4) A. Fujimoto, The Prediction of the Number of Critical Care Patients for Planning the Construction of Roads, Taking Account of the Over-65 Ratio and Decline in Population, Japan Society of Traffic Engineers (2010).
5) Annual Report, Nagasaki City and Nagasaki Network for Practical Emergency Medicine (1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008).