Systemwide Impacts of Emergency Medical Services Resources on Freeway Crash Severity

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The objective of a study was to examine the systemwide effects of prehospital emergency medical services (EMS) resources quantitatively on crash outcomes throughout the entire South Korean freeway system. Latent class cluster and binomial probit regression models were combined to achieve this objective. In the cluster-based binomial probit regression, surrogate measures for prehospital EMS resources were obtained by combining medical service portals, freeway heliport maps, and freeway network log data in the crash data set. As a result, eight latent class clusters of crashes were determined on the basis of features associated with EMS resources, province, roadway, and traffic conditions at the scene of the crash. On-scene and recovery times were commonly significant in increasing the probability of fatal crashes in both entire groups and in each group of crashes, while the nearest ramp location and number of nearby EMS facilities significantly affected fatal crashes for a certain group of crashes. The findings provide meaningful insights that can enhance EMS training programs for initial medical aid and postcrash traffic management on all provincial freeways. Supplemental nearby EMS facilities and access points to them are needed particularly in South Korea's southeastern and central province freeway sections, respectively. This research is the first data-driven study to assess systemwide EMS resources for the entire South Korean freeway system by using multiple data sources. It would contribute to informed decision making for future EMS provision.

Timely emergency medical services (EMS) contribute to reducing fatalities in the postcrash phase (*1, 2*). Several studies have validated the impact of EMS on crash victim survival and have emphasized initial EMS at the scene of the crash and during transportation to permanent medical facilities (*3–5*). Particularly, the time required for an initial EMS unit to arrive at the scene of a crash and provide acute medical care and the time required for a victim to receive definitive care play significant roles in the crash outcome (*6*).

The freeway system in South Korea stretches into rural areas where access to EMS is more challenging than in urban areas. The rate of death involved in freeway crashes has been approximately 10%, the highest of all roadway function classes (*7*).

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To minimize crash outcomes, especially on rural freeways, the Korea National Emergency Management Agency (NEMA) has begun to collaborate with the Korea Expressway Corporation (KoEX) in support of the freeway EMS system since 2011. As an initial step, the Korea NEMA has provided EMS vehicle units (known as the 119 ambulance in South Korea) and helicopter services to transport seriously injured patients to permanent EMS facilities. KoEX has also supported prehospital EMS resources by assigning available heliports, providing personnel to call ambulances, providing EMS vehicles or emergency towing services, and managing postcrash traffic in freeway system since 2011.

Before these collective efforts, 119 ambulance-centered victim transport was conducted on the South Korean freeway system, and EMS helicopter support was restrictively used for mountain rescue or firefighting. Moreover, there was no manual for role allocation between the Korea NEMA and KoEX. However, the governmental supports regarding prehospital EMS resources have not been quantitatively validated. Especially for South Korean freeways, the support program for prehospital EMS resources is in its initial stage. Therefore, it is necessary to identify the lack of current prehospital EMS resources for South Korean freeways and to provide relevant strategies for updating them.

As a data-driven research initiative to respond to the aforementioned need, this study aims to examine the impact of current prehospital EMS resources on crash outcomes throughout the South Korean freeway system and to identify the prehospital EMS resources required to reduce fatalities. To achieve this objective, crashes that occurred in the entire South Korean freeway system in 2012 were analyzed as an overall set and compared with cluster-based analysis. This study is the first attempt to quantitatively address the systemwide impacts of EMS resources on the entire South Korean freeway system.

LITERATURE REVIEW

Many studies have highlighted the prehospital EMS time data that affect crash outcomes. A crash occupant's survival may ultimately depend on how quickly the individual receives definitive medical treatment. For rapid medical treatment, the golden hour is a well-known concept that refers to the 60 min immediately following the crash occurrence (*1, 8*). Additionally, the crash notification time (CNT) and EMS response time have been identified in previous studies as factors that affect crash severity. CNT is defined as the time between the occurrence of the incident and its being reported. Several studies have considered the impact of the variability of CNT on the reduction of the traffic fatality rate, as well as the necessity of an automatic crash notification system (*4, 9–13*). The EMS response time is defined as the time between the incident being reported and the arrival of the first responder at the scene (*12*). Meng and Weng showed in their study that the uncertainties for CNT and EMS response time are primarily influenced by crash time, road type, weather, and light conditions (*3*).

Lee and Fazio stated that traffic crash severity had the greatest effect on response times in their study (*14*). A study by van Buuren and van der Mei mentioned the threshold of EMS response time (*15*). Their study stated that the EMS response time from crash notification to definitive care should be a maximum of 30 min. Similarly, the U.S. national averages for overall EMS response times (time from crash notification to definitive care) for fatal crashes were reported as approximately 37 min and 54 min in urban and rural areas, respectively (*16*).

In comparison, a Virginia study by McLay and Mayorga showed much shorter response time thresholds (*17*). In their study, a methodology for evaluating the performance of response time thresholds (time from when an ambulance is dispatched until it arrives at the scene) was employed in regard to resulting patient survival rates. The findings showed that 9- and 10-min response time thresholds resulted in more equitable patient outcomes with improved patient survival rates in rural regions. Similarly, Fitch's study stated that the most common EMS performance measure is to respond to 90% of life-threatening calls in fewer than 9 min of EMS response time (*18*).

Several other studies have discussed the differences in the time for a victim to be transported to EMS facilities. Bigdeli et al. showed that the response, transport and total time intervals from notification to arrival at the hospital among EMS responding to road traffic injury incidents were longer for interurban roads compared to city areas (*4*). A study by Rawlinson and Crews also found that the contributing factors in this EMS delivery disparity include geographic barriers; lack of professionals; paraprofessional and financial resources; aging or inadequate equipment; absence of specialized EMS care and local medical facilities; and sporadic nature of rural crashes (*19*).

Similarly, Gitelman et al. introduced the following safety performance indicators to characterize trauma management system levels derived from road crashes (*20*): availability of EMS stations, availability and composition of EMS medical staff, availability and composition of EMS transportation units, characteristics of EMS response time, and availability of trauma beds in permanent medical facilities.

DATA PROCESSING

Data Sources

In South Korea there are 27 freeways. The total length of the entire 27 freeway network is 4,044 km, and the speed limits are 100 km/h and 80 km/h for passenger cars and trucks, respectively (*7*). The crash data used in this study were collected from all freeway sections in South Korea during 2012 and were provided by KoEX. The KoEX crash data set in 2012 contained 1,272 injury crash observations with three outcomes: 299 observations with fatal injuries, 146 observations with severe injuries, and 827 observations with minor injuries. In the crash data set, the crash victim's death is recorded based on the outcome of the crash after 30 days. Crashes that involved individuals who died at the scene were excluded on the basis of this study purpose of reducing fatalities from serious injuries.

A variety of data fields are recorded in the KoEX crash data set, including roadway, environment, traffic, human, postcrash management, and prehospital time-related information for each observation. Postcrash management information includes the following data: time from receipt of the crash notification to the arrival of a towing vehicle at the scene of crash (towing vehicle response time); time between part or full travel lane blockade by the first responder and the release (part or full traffic blockade time); and time after crash clearance to return to normal traffic conditions (recovery time).

The KoEX crash data set also includes part of the prehospital time, duration between an emergency call received and 119 EMS unit arrival at a permanent medical facility (*4*). The prehospital time data recorded in the KoEX crash data set are time from emergency call received to the 119 EMS unit arrival at the scene of the crash (EMS unit response time), and time from the 119 EMS unit arrival to leaving the scene of the crash (on-scene time), as shown in Figure 1 (*4*). Only the ground transportation mode for the EMS unit response and on-scene time data were considered as the 119 EMS unit in this study (Figure 1).

As shown in Figure 1, victim transport time, one of the most significant factors in reducing the severity of crash outcomes, was deficient in the KoEX crash data set. Therefore, to reflect the

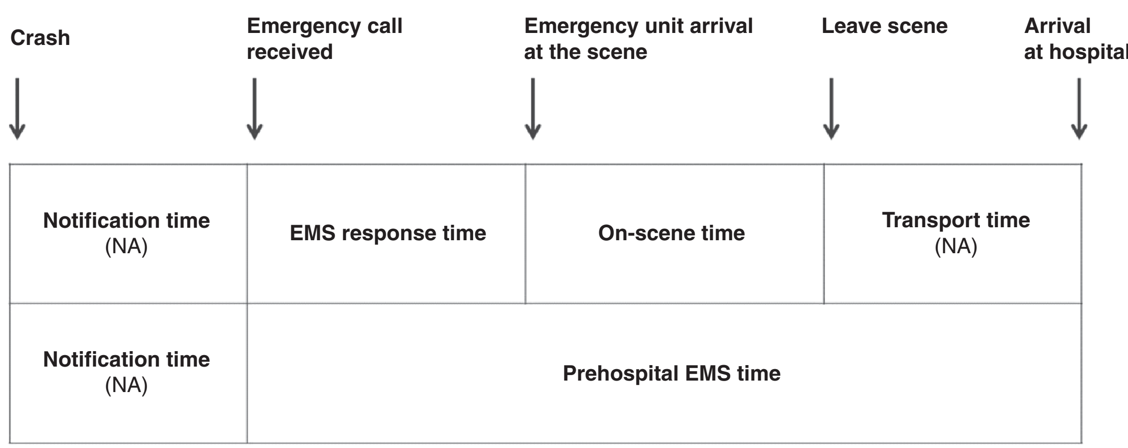

FIGURE 1 Temporal point for victim's injury care (NA = not available).

victim transport time, this study obtained surrogate data by combining freeway network logs, medical service portals, and freeway heliport maps with the KoEX crash data set as follows. The freeway network log involves attributes for each freeway section (ramp to ramp), including freeway number, post mile, section length, number of lanes, and average daily traffic. The freeway medical service portal is a web-based query engine that provides the distribution of hospitals and their EMS availability scale around a standard point (such as the scene of crash) that is the keyword input by proximity level. The proximity level is presented as the radius of the distance between a standard point and a hospital location ranging from 2 km to 50 km in the portal. Finally, the freeway heliport map provides the distribution of heliports installed in the entire South Korean freeway network (*21*).

Prehospital EMS Resources for Victim Transport

Victim transport time, as shown in Figure 1, was deficient even though it is known to be one of the most significant factors that affect crash outcomes. Considering prehospital EMS-related factors found in previous studies and data availability in this study, four additional types of prehospital EMS resource data were obtained as surrogate measures of the victim transport time. CNT data were not considered in this study because of the deficiency of data sources. The four additional types of surrogate data include ramp proximity, heliport proximity, regional EMS facility proximity, and number of regional EMS facilities.

Victim transport time is the time between leaving the scene of a crash and reaching permanent medical facilities. The surrogate data for the victim transport time should reflect the time from the crash location to the nearest freeway exit (t1) and the time from the nearest freeway exit to nearby permanent medical facilities (t2). The distance between the scene of the crash and the nearest ramp (ramp proximity) was determined to reflect t1. When helicopters transport crash victims, the victim should first be moved to the nearest heliport. Therefore, the distance between the scene of the crash and the nearest heliport (heliport proximity) was also selected to reflect t1. The distance between the nearest ramp and the nearest regional EMS facility (EMS facility proximity) was used to reflect t2.

On the basis of EMS equipment and human resource availability, South Korea's Ministry of Health and Welfare has designated three categories of medical facilities in order of facility size: regional medical centers, local medical centers, and local medical departments. Only the regional medical center contains sufficient medical facilities and trained personnel to provide EMS, particularly for seriously injured patients. Therefore, this study considered only the regional medical center as the EMS facility because the goal of this study is associated with reducing fatalities from serious injuries. On the basis of previous EMS studies, the number of regional EMS facilities within a 50-km radius of the scene of the crash (the number of EMS facilities) was also used as surrogate data for t2.

Because reference post miles recorded in the KoEX crash data set, freeway heliport map, and freeway network log are consistent, four types of prehospital EMS resource data were additionally obtained by combining all data sources. Consequently, 10 types of prehospital EMS resource-related data were obtained in this study. Table 1 summarizes all variables employed in the latent class (LC) cluster-based binomial probit regression models described in the next section (Table 1).

LATENT CLASS CLUSTER-BASED REGRESSION

One of the major tasks in this study is to identify whether the effects of prehospital EMS resources on fatal crashes were consistent for the full crash observations. To conduct this task, clustering analysis with standard regression was employed in this study. The clustering approach allows one to identify factors that contribute to death within homogeneous groups of crashes and mitigates the influence of confounding and unavailable variables that may lead to biased results.

The most common cluster analysis methods are partitioning-based (such as *K*-means); hierarchical-based (such as Ward's method); and density-based (such as LC clustering) methods (*22*). Among these cluster analysis methods, this study used the LC cluster model.

The advantages of the LC cluster model over traditional ad hoc types of clustering methods include several model selection criteria, such as Akaike information criterion (AIC), Bayesian information criterion (BIC), or consistent Akaike information criterion (CAIC) to select the optimum number of clusters and probability-based classification (*23, 24*). Additionally, the LC cluster model has a flexible model formulation that does not imply any assumptions in regard to the nature of the variables, their underlying distributions, and the correlation patterns across observations and variables.

Each element cluster membership in the LC cluster model is computed from the estimated model parameters. The basic LC cluster is formulated as follows (*25*):

$$P\left(Y_{i|\theta}\right) = \sum_{k=1}^{K} f_k P\left(Y_i | C_k, \theta_k\right) \tag{1}$$

where

P = probability;
Y_i = vector of variables observed from ith case;
k = a latent class number, 1 to K;
f_k = prior probability of data in latent class C_k;
θ_k = vector of cluster model parameters to be estimated; and
$P(Y_i|C_k,\theta_k)$ = mixture probability density.

The LC cluster model addresses information criteria such as the AIC, BIC, or CAIC to determine the number of clusters. The lower the score of these criteria, the more appropriate the number of clusters. In addition, the entropy criterion was used to examine the quality of the resultant clusters, computed by the following (*23*):

$$E(k) = 1 - \sum_{i=1}^{I} \sum_{k=1}^{K} \frac{P_{ik} \ln(P_{ik})}{I \ln\left(\frac{1}{k}\right)} \tag{2}$$

where P_{ik} indicates the posterior probability that case i belongs to cluster C_k.

Values in the entropy criterion range from 0 to 1, indicating the worst to perfect separation between clusters. The number of clusters was determined in the current study by combining all four criteria, but BIC was emphasized owing to its superiority in regard to consistency and accuracy (*26*).

LC cluster modeling is only useful if the detected clusters reduce heterogeneity in such a way that new information is gained when conducting explanatory crash analysis (*23*). Cluster-based regression was also conducted to examine the relationship between independent

TABLE 1 Variable Characteristics

Independent Variable	Values[a] (minimum, maximum, mean, SD)[b]
Ramp proximity (km)	Distance between crash location and nearest off-ramp (0, 15.2, 2.7, 2.5)
Heliport proximity (km)	Distance between crash location and nearest heliport (2.4, 90.3, 32.3, 20.1)
EMS facility proximity (km)	Distance between the nearest ramp around crash location and nearest regional EMS facility (2.0, 50, 19, 13.4)
Number of EMS facilities	Number of regional EMS facilities within a radius of 50 km around crash location (0, 66, 16, 20)
EMS unit response time (min)	Time interval between EMS call received and surface vehicle EMS unit arrival (0, 120, 14, 11.0)
On-scene time (min)	Time interval between starting medical treatment by surface vehicle EMS unit and EMS unit leaving (0, 159, 9, 11.9)
Towing vehicle response time	Time from receipt of crash notification to towing-vehicle arrival (0, 131, 12.9, 10.6)
Part traffic blockade time (min)	Time interval between partial travel lane blockade by first responder and release (0, 1,469, 23.6, 52.0)
Full traffic blockade time (min)	Time interval between full travel lane blockade by first responder and release (0, 153, 1, 7.3)
Recovery time (min)	Time after crash clearance to return to normal traffic conditions (0, 407, 43, 32.6)
Driver maneuvering	At-fault driver's maneuvering preceding crash: driving travel lanes, changing lanes, mistaking wheel operations, other violations
Administrative district	Eight provinces: Gyeonggi-Do, Gangwon-Do, Chungcheongbuk-Do, Chungcheongnam-Do, Gyeongsangbuk-Do, Gyeongsangnam-Do, Jeonrabuk-Do, Jeonranam-Do
Highway direction	1 if south- or northbound, 0 if number for east- or westbound
Travel lane	Number of travel lanes at scene of crash
Crash location	Travel lane, ramp, acceleration–deceleration lane, shoulder, bridge, within rest area
Horizontal curve	Curve to the right ($R^c > 1{,}000$ m), curve to the right ($R < 500$ m), curve to the left ($R > 1{,}000$ m), curve to the left ($R < 500$ m), tangent
Vertical curve	Flat, downgrade <1%, 1% < downgrade < 3%, downgrade >3%, upgrade < 1%, 1% < upgrade < 3%, upgrade > 3%
Type of road side slope	Flat, cut-side slope, fill-side slope
Work zone	1 if crash occurred in work zone, 0 if otherwise
Lighting condition	Daytime, darkness at light, darkness with lighting system that did not work, darkness without lighting system
Roadside safety facility	Guardrail, concrete wall, guard fence, other, no fence
Traffic speed (km/h)	Traffic speeds preceding the crash occurrence
Main-line occupied	1 if postcrash vehicles occupied in travel lanes, 0 otherwise
Shoulder occupied	1 if postcrash vehicles occupied in shoulder, 0 otherwise
Auxiliary lane occupied	1 if postcrash vehicles occupied in auxiliary lanes, 0 otherwise
Cause of crash	Speeding, drowsiness, forward negligence, failure in car-following distance, failure in passing, malfunction of vehicle equipment, animal or road surface interruption, others
Type of crash	Head-on, rear-end, sideswipe, vehicle to animal or people[d], vehicle to roadside facilities, vehicle to median, other types
Season of the year	Spring, summer, autumn, winter
Weekday	1 if crash occurred on weekday, 0 if crash occurred on weekend
Hour of the day[e]	Night–dawn (0–5 h), morning (6–8 h), daylight (9–17 h), dusk–dark (18–23 h)
Weather	1 if crash occurred in adverse weather[f], 0 if crash occurred in clear weather

NOTE: Crash outcome: 299 fatal crashes versus 973 nonfatal crashes.
[a]All values were employed in both LC clustering and binomial probit regression.
[b]Minimum, maximum, mean and standard deviation are applicable to only prehospital EMS resource-related variables.
[c]Radius of horizontal curve.
[d]The people include jaywalkers, work zone–related workers, or people related to the crash or vehicle in trouble.
[e]Hour of the day is classified by daily traffic trends on Korean freeways.
[f]Adverse weather indicates rainy, snowy, foggy, or cloudy weather conditions.

variables and crash outcomes in each cluster. The prehospital EMS resource provided for the entire South Korean freeway system is of interest in this study to reduce the potential of postcrash fatalities. Accordingly, crash outcome was classified into binary categories: fatal crashes and nonfatal crashes with severe and minor injuries. On the basis of two categories of crash outcomes, the current study combined the binomial probit regression with LC cluster model. The binomial probit regression is specified as follows (*27*):

$$P(Y = 1|X) = \Phi(X'\beta) \tag{3}$$

where

Y = response with two outcomes of 1 and 0 (a binary crash outcome),
X = vector of regressors,
Φ = cumulative distribution function of the standard normal distribution, and
β = parameters estimated by maximum likelihood.

The binomial probit regression is motivated as a latent variable model such as

$$Y^* = X'\beta + \varepsilon \tag{4}$$

where Y^* is a latent variable that is assumed to influence outcome Y, and ε follows the standard normal distribution.

The outcome Y can be observed as an indicator as follows:

$$Y = \begin{cases} 1 & \text{if } Y^* > 0 \\ 0 & \text{if } Y^* < 0 \end{cases} \tag{5}$$

Consequently, Equation 3 is presented by

$$\begin{aligned} P(Y = 1|X) &= P(Y^* > 0) = P(X'\beta + \varepsilon > 0) \\ &= P(\varepsilon > -X'\beta) = P(\varepsilon < X'\beta) = \Phi(X'\beta) \end{aligned} \tag{6}$$

RESULTS AND DISCUSSION

This study employed LC cluster analysis to determine the optimal number of clusters. Then binomial probit regression models were developed to examine the impacts of contributing factors on crash severity levels.

The LC cluster analysis avoids an abundance of clustering variables because it increases the odds of similar variables. One of two continuous variables with a 0.9 or higher Pearson correlation coefficient was eliminated if it was correlated with a greater number of other variables than the other continuous variable (*28*). The log-likelihood ratio statistic was also investigated to examine the independence between two categorical variables. If the log-likelihood ratio statistic value is less than the conventional significance level of .05, one of two dependent categorical variables was deleted through the same elimination process as that for continuous variables. To determine the number of clusters, all AIC, BIC, CAIC, and entropy criteria were considered.

In the cluster-based binomial probit regression models, the response variable was the crash outcome (fatal and nonfatal crashes). All categories involved in the independent variables were converted into dummy variables, and the parameter significance level used in this study was .1. The goodness-of-model fit was compared on the basis of a log likelihood ratio test, significance of the parameter estimates, and classification accuracy in the cluster-based binomial probit regression. Comparative cluster-based binomial logit regression was also conducted, and the log likelihood ratio test, parameter estimates, and classification accuracies were similar to those in the cluster-based binomial probit regression. The AIC values and parameter significance levels suggest that the cluster-based binomial probit regression model is superior.

Determination of Latent Class Cluster

The following variables were eliminated because of their dependence on the other variables: towing vehicle response time, partial traffic blockade time, highway direction, crash location, type of road sideslopes, shoulder occupied, and weekday. By modeling LC clusters, crashes that occurred throughout the entire South Korean freeway system during 2012 were separated, as shown in Figure 2.

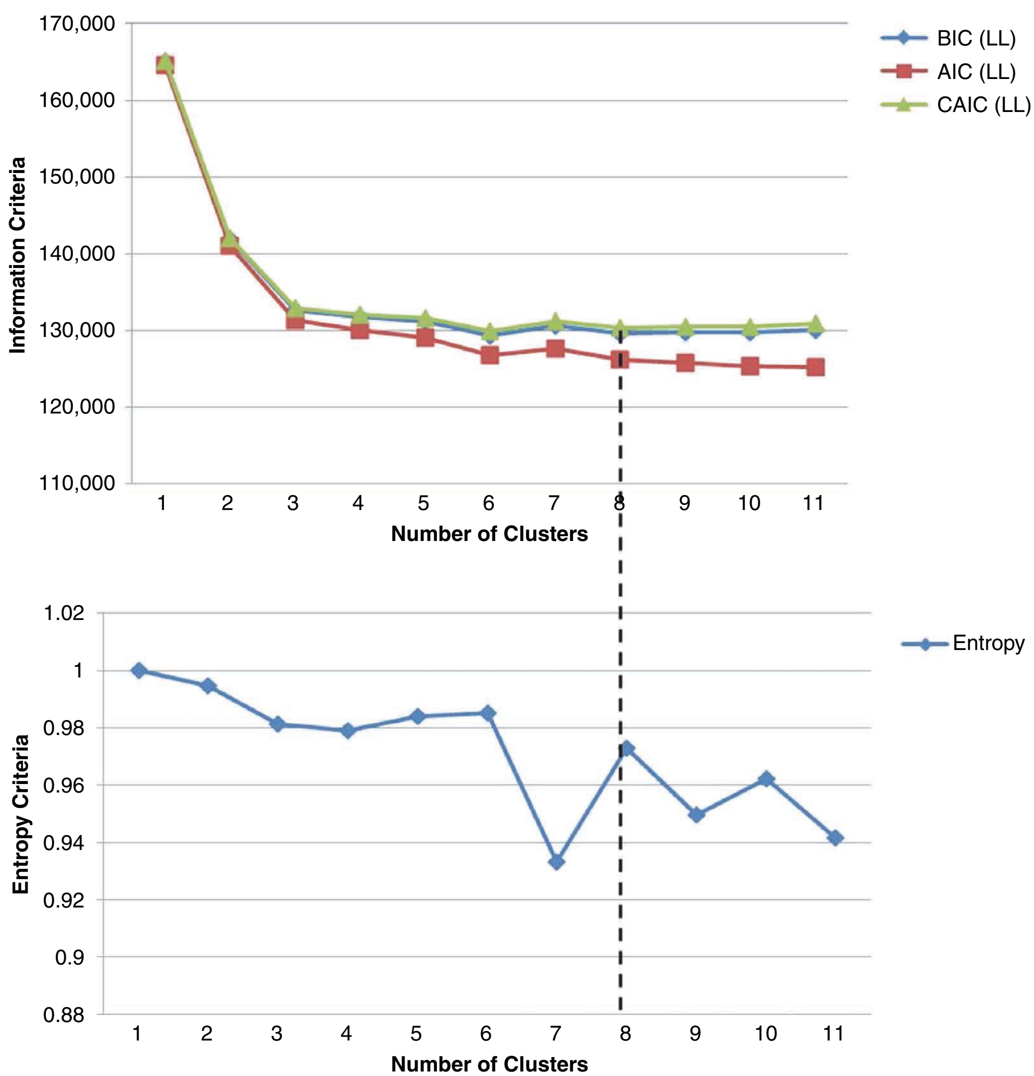

FIGURE 2 Information criteria to determine the number of clusters (LL = log likelihood).

According to Figure 2, AIC, BIC, and CAIC apparently decreased with increasing cluster number up to six clusters. However, these three criteria increased for seven clusters and apparently decreased again for eight clusters. For eight clusters, BIC and CAIC showed the lowest scores and then monotonically, but very slightly, increased again afterward. The BIC values, in particular, which are known to be more reliable (*25*), were almost the same after eight clusters. Although the AIC monotonically decreased after eight clusters, it showed almost the same levels of values from eight clusters onward. Moreover, the entropy criteria decreased after eight clusters without any apparent changes, and it was approximately 0.98 at eight clusters, high enough to confirm the quality of the eight-cluster solution. Considering all of the criteria information, eight clusters were finally selected to group the crash observations.

In the eight-cluster model, the significance of each variable effect was assessed by parameter effect estimates. The log-linear parameter estimates use the effect coding, indicating that the estimates for each variable sum to zero over the categories of that variable. The effect coding was used for the clusters. As shown in Table 2, as a measure of the ability to discriminate between clusters, the R^2-value indicates how much of the variance of each variable is explained by this eight-cluster model. For each variable, the knowledge of the response to the variable contributes to the discrimination of clusters (Table 2).

Considering the variables with high R^2-values in Table 2, the eight-cluster model was found to discriminate the following variables: six prehospital EMS resource variables, travel lane, traffic speed, and administrative district in which the crash occurred. The R^2-values for those nine variables were greater than the R^2-values for the other variables, which were 10% or greater.

Table 3 presents crash data included in each cluster. As provided in Table 3, the resultant cluster profile is expressed by conditional probabilities with the use of only the nine variables (referred to as clustering variables) (Table 3).

The specific feature of Cluster 1 is an administrative district. Approximately 17% of crash cases in Cluster 1 occurred in the center of South Korea, Chungcheongbuk-Do (Province 3), which is high compared with those occurring in the other clusters. Cluster 2 distinguishes itself by a long distance between the crash location and the nearest heliport (48.6 km on average) and a high percentage of crashes (40.2%) occurring in Gyeongsangbuk-Do (Province 5) in southeastern South Korea. The special features of Cluster 3 include a relatively high percentage of crashes (approximately 30%) occurring in Jeonrabuk-Do (Province 7), also in South Korea's southwestern area, with 100% of crashes occurring in nearly stopped traffic conditions (5 km/h on average).

In Cluster 4, the nearest regional EMS facility is close to the scene of the crashes (5.8 km on average). Additionally, all crashes occurred on freeway sections in Gyeonggi-Do (Province 2), South Korea's capital area, and approximately 76% of the cases in the cluster occurred on four-lane freeways. Cluster 7 is similar to Cluster 4 in that a high proportion of the crashes occurred in the capital area freeway sections (98.6%). The additional feature of Cluster 7 is five travel lanes. Clusters 4 and 8 share similar levels of EMS facility proximity and administrative district but differ in the number of travel lanes. Crashes occurred dominantly on three-lane freeways in Cluster 8 (30.4% of all cases) compared with four-lane freeways in Cluster 4 (75.5% of all cases). However, Cluster 8 contains only 23 crashes, and the sample size is too small to generalize cluster characteristics.

Crashes involved in Cluster 5 are characterized by EMS resource data, including a long on-scene time (19 min); full traffic blockade time (16 min); and recovery time (87.6 min). Crashes involved in Cluster 6 are described by the number of EMS facilities within 50 km of the crash (19 on average). According to Table 3, Cluster 6 shows different averages and trends in crash cases by six levels of the number of EMS facilities compared with those in all of the other clusters. Another special feature in Cluster 6 is the province in which crashes occurred: approximately 30% of the crashes in the cluster occurred in the southeastern area (Gyeongsangnam-Do) freeway sections, apparently a high proportion compared with the other clusters.

In summary, eight clusters are labeled as follows:

Cluster 1. Crashes occurred on freeway sections in the central area (16.6%) of South Korea.

Cluster 2. Crashes occurred in southeastern province (40.2%) freeway sections with large heliport spacing (48.6 km).

Cluster 3. Crashes occurred in southwestern province (28.9%) freeway sections in nearly stopped traffic conditions (5 km/h).

Cluster 4. Crashes occurred in capital area (100%) freeway sections with four-travel lanes where the nearest regional EMS facility was located nearby (5.8 km).

TABLE 2 Percentage of Variance of Each Variable Explained by Eight-Cluster Model

Variable	R^2-Value
Prehospital EMS Recourses	
Ramp proximity (km)	.083
Heliport proximity (km)	**.225**
EMS facility proximity (km)	**.244**
Number of EMS facilities	**.928**
EMS unit response time (min)	.035
On-scene time (min)	**.317**
Full traffic blockade time (min)	**.395**
Recovery time (min)	**.251**
Human	
At-fault driver maneuvering preceding crash	.016
Region and Roadway	
Administrative district	**.266**
Travel lane	**.282**
Horizontal curve	.013
Vertical curve	.021
Work zone	.014
Lighting system	.035
Roadside safety facility	.019
Traffic	
Traffic speed (km/h)	**.660**
Main-line occupied	.024
Auxiliary lane occupied	.020
Crash	
Cause of crash	.008
Type of crash	.015
Temporal and Environment	
Season of year	.008
Hour of day	.010
Weather	.014

NOTE: Boldface indicates the variables with comparatively high R^2-values that are significantly explained by clusters.

TABLE 3 Cluster Profiles by Clustering Variables

Variable	C1	C2	C3	C4	C5	C6	C7	C8	Full
Response									
Cluster sample size	373	266	218	151	84	84	73	23	1,272
Fatal crash (%)	11.3	33.8	13.3	31.8	42.9	44.0	15.1	26.1	23.5
Nonfatal crash (%)	88.7	66.2	86.7	68.2	57.1	56.0	84.9	73.9	76.5
Contributing									
EMS resource–related									
Heliport proximity (km) (average)	29.0	**48.6**	37.7	16.9	36.6	16.5	23.8	15.3	32.3
EMS facility proximity (km) (average)	20.1	24.9	24.4	**5.8**	23.8	13.5	10.4	**4.5**	19.1
Number of EMS facilities within 50 km of crash (%)									
<5	45.8	51.9	27.1	0.0	39.3	0.0	0.0	0.0	31.9
5 and <10	47.2	42.1	62.4	0.0	46.4	3.6	0.0	0.0	36.2
10 and <20	7.0	6.0	10.6	0.0	14.3	**50.0**	0.0	0.0	9.2
20 and <30	0.0	0.0	0.0	0.0	0.0	**34.5**	0.0	0.0	2.4
30 and <40	0.0	0.0	0.0	5.3	0.0	**8.3**	1.4	0.0	1.3
40 and <50	0.0	0.0	0.0	23.8	0.0	3.6	16.4	8.7	5.6
50 and <60	0.0	0.0	0.0	41.7	0.0	0.0	42.5	47.8	6.8
60+	0.0	0.0	0.0	29.1	0.0	0.0	39.7	43.5	6.6
Average	5.1	4.6	5.9	53.8	5.5	**19.0**	55.0	57.3	15.7
On-scene time (min)									
Average	4.0	13.4	6.5	8.4	**19.0**	15.2	6.7	10.8	8.9
Full traffic blockade time (min)									
Average	0.0	0.0	0.0	0.0	**16.0**	0.0	0.0	8.3	1.2
Recovery time (min)									
Average	31.9	53.2	34.3	40.2	**87.6**	54.6	39.2	31.5	43.4
Province and roadway (%)									
Administrative district									
Gangwon-Do (Province 1)	6.7	5.3	3.7	0.0	10.3	0.0	0.0	0.0	4.6
Gyeonggi-Do (Province 2)	4.3	1.1	1.8	**100.0**	15.0	69.0	**98.6**	**100.0**	26.2
Chungcheongbuk-Do (Province 3)	**16.6**	7.5	6.9	0.0	9.1	0.0	0.0	0.0	8.5
Chungcheongnam-Do (Province 4)	13.9	17.3	12.4	0.0	15.5	0.0	0.0	0.0	10.8
Gyeongsangbuk-Do (Province 5)	23.6	**40.2**	17.0	0.0	14.3	1.2	1.4	0.0	19.3
Gyeongsangnam-Do (Province 6)	15.5	18.0	10.6	0.0	15.5	**29.8**	0.0	0.0	13.1
Jeonrabuk-Do (Province 7)	6.2	7.9	**28.9**	0.0	14.3	0.0	0.0	0.0	9.4
Jeonranam-Do (Province 8)	13.1	2.6	18.8	0.0	6.0	0.0	0.0	0.0	8.0
Travel lane									
1	1.3	7.9	1.4	0.0	6.0	2.4	1.4	4.3	3.0
2	70.2	60.9	73.4	2.0	78.6	28.6	34.2	4.3	55.2
3	7.2	18.0	12.8	19.1	9.5	19.0	19.2	**30.4**	13.8
4	20.9	13.2	12.4	**75.5**	4.8	48.8	38.4	60.9	26.8
5	0.3	0.0	0.0	3.4	1.2	1.2	**6.8**	0.0	1.2
Traffic (%)									
Traffic speed (km/h)									
<80	3.5	5.6	**100.0**	2.0	50.0	27.4	76.7	78.3	30.5
80 to <100	52.3	50.4	0.0	53.6	23.8	34.5	9.6	17.4	40.0
100 to <120	43.2	42.5	0.0	44.4	25.0	36.9	11.0	4.3	31.6
120 or 120+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Average	99.6	99.7	**5.0**	99.0	58.0	83.1	34.2	26.4	73.6

NOTE: C = cluster; boldface indicates the value of special features that contribute to discriminating a certain cluster.

Cluster 5. Crashes occurred on freeway sections with long on-scene times (19 min); postcrash full traffic blockades (16 min); and recovery times (87.6 min).

Cluster 6. Crashes occurred in southeast province (29.8%) freeway sections where 19 EMS facilities exist within 50 km of the crash.

Cluster 7. Crashes occurred in capital area (98.6%) freeway sections with five travel lanes.

Cluster 8. Crashes occurred in capital area (100%) freeway sections with three travel lanes where the nearest regional EMS facility was located nearby (4.5 km).

Cluster-Based Crash Outcomes

The resultant eight cluster-based crash severity estimation models are provided in Table 4. As presented in Table 4, all cluster-based regression models showed small p-values in the log-likelihood ratio test for global model fit and high classification accuracies for both overall and fatal crash estimations, ranging approximately from 62% to 83%. This goodness-of-fit indicates that the estimated models with parameters are sufficient to correctly predict the probabilities of crash outcomes.

TABLE 4 Cluster-Based Binomial Probit Regression Models

Variable	C1[a]		C2[a]		C3[a]		C4[a]		C5[a]		C6[a]		C7[a]		C8[a]		Whole[a]	
	Coeff.	*p*-Val.	Coeff.	*p*-Val.	Coeff.	*p*-Val.	Coeff.	*p*-Val.	Coeff.	*p*-Val.	Coeff.	*p*-Val.	Coeff.	*p*-Val.	Coeff.	*p*-Val.	Coeff.	*p*-Val.
Intercept	–3.168	<.0001	–0.677	<.0001	–3.289	<.0001	2.632	.091	–1.025	<.0001	–1.475	<.0001	–1.666	<.0001	–2.306	.017	–1.957	<.0001
Ramp proximity	0.020	.078	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Number of EMS facilities	—	—	–0.108	.003	—	—	—	—	—	—	—	—	—	—	—	—	—	—
On-scene time	0.052	.016	0.034	<.0001	0.065	.002	0.041	.009	0.025	.006	0.031	.008	—	—	—	—	0.033	<.0001
Recovery time	—	—	—	—	0.150	.039	0.024	.019	—	—	—	—	0.020	.022	0.042	.044	0.007	<.0001
Gangwon-Do	—	—	–1.059	.022	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Gyeonggi-Do	—	—	—	—	—	—	—	—	0.984	.091	—	—	—	—	—	—	0.232	.019
Chungcheongnam-Do	—	—	—	—	—	—	—	—	0.918	.030	—	—	—	—	—	—	—	—
Gyeongsangnam-Do	—	—	—	—	—	—	—	—	1.096	.009	0.806	.020	—	—	—	—	0.396	.002
Work zone	0.841	.062	—	—	—	—	1.872	.020	—	—	—	—	—	—	—	—	—	—
Dark without light[b]	—	—	—	—	—	—	—	—	—	—	—	—	1.029	.100	—	—	—	—
Daylight	—	—	—	—	—	—	–0.615	.022	—	—	—	—	—	—	—	—	—	—
Guardrail	—	—	—	—	—	—	—	—	—	—	0.942	.004	—	—	—	—	—	—
Forward negligence	0.515	.023	0.483	.015	—	—	—	—	—	—	—	—	—	—	—	—	1.203	<.0001
Drowsiness	0.547	.036	—	—	—	—	—	—	—	—	0.756	.020	—	—	—	—	—	—
Vehicle to median	0.518	.016	—	—	—	—	—	—	—	—	—	—	—	—	—	—	–0.937	<.0001
Mainline occupied	—	—	—	—	0.506	.062	0.559	.052	—	—	—	—	—	—	—	—	0.181	.046
Traffic speed	—	—	—	—	—	—	—	—	—	—	—	—	–0.021	.018	—	—	0.002	.031
Winter	—	—	—	—	0.686	.015	—	—	—	—	—	—	—	—	—	—	—	—
Time: 0–5 h	—	—	0.812	<.0001	—	—	—	—	—	—	—	—	—	—	—	—	0.440	<.0001

NOTE: — = significant parameter coefficient was not identified; coeff. = coefficient; val. = value; cluster characteristic: C1 = central province; C2 = sparse heliports, southeast province; C3 = nearly stopped traffic, southwest province; C4 = close to nearest EMS facility, four travel lanes, capital area; C5 = long on-scene, full traffic blockade, recovery times; C6 = 19 EMS facilities within 50 km of crash, southeast province; C7 = five travel lanes, capital area; C8 = close to nearest EMS facility, three travel lanes, capital area. Log likelihood ratio test statistic (*p*-value > chi-square): C1, C2, C3, C4, C6, and whole = <.0001; C5 and C7 = .001; C8 = .008.

[a]Sum of correctly estimated fatal and nonfatal crashes divided by total crashes = proportion of fatal crashes correctly estimated as such (sensitivity). Accuracy (%): C1 = 67.0/62.0; C2 = 70.7/70.0; C3 = 78.0/79.3; C4 = 71.5/68.8; C5 = 70.2/66.7; C6 = 67.9/62.2; C7 = 76.7/72.7; C8 = 78.3/83.3; whole = 73.3/67.0.

[b]Darkness without road lighting system.

In the full data-based model, on-scene and recovery times were found to be significantly influential on increasing fatal crashes. Province, main-line traffic, and night time features were apparently significant for increasing fatal crash occurrences in the entire South Korean freeway system. To reduce fatal crashes in the entire South Korean freeway system, these results support prehospital EMS resource enhancement strategies associated with site- and time-specific traffic management, as follows.

The impacts of several variables on fatal crashes were not specific to a certain group of freeway crashes. On-scene time was commonly significant for increasing the probabilities of fatal crashes in both full data- and cluster-based models 1 to 6. The prehospital EMS system in South Korea is firefighting centric. For example, 119 ambulances, as the prehospital EMS surface vehicle units, belong to fire stations. In this firefighting-centric system, medical treatment consultancy and evaluation are strongly required. Therefore, to enhance EMS training programs for professional and initial medical aid, medical consultancy and evaluation should be implemented to reduce on-scene time.

Recovery time was also significant in both full data- and four cluster-based models (Clusters 3, 4, 7, and 8). To reduce recovery time, postcrash traffic management strategies, such as EMS priority signals, towing vehicle services, personnel training, and intelligent transportation system–based lane control, should be further implemented throughout the entire South Korean freeway system.

Moreover, the effects of the postcrash main-line occupation and crash time from 0 h to 5 h on increasing fatal crashes were consistent in both the full data- and cluster-based models. This result implies that it is worthwhile to enhance EMS personnel training and postcrash traffic management strategies for the entire freeway system in harsh conditions, such as limited lane use or the middle of the night.

The variables only within each crash cluster provide additional insights specifically into the single groups of crashes as follows. Cluster 1 is the group of crashes that occurred in South Korea's central province (Chungcheongbuk-Do) freeway sections. According to Table 4, the distance between the scene of the crash and the nearest off-ramp (ramp proximity) was significant to an increased probability of fatal crashes only within Cluster 1. A long distance between the scene of the crash and the nearest off-ramp implies long ramp spacing in the freeway sections. Therefore, providing supplemental points of access would narrow the ramp spacing; it would be helpful in reducing fatal crashes, particularly in these central provincial freeway sections.

Cluster 2 is the group of crashes that dominantly occurred in South Korea's southeastern province (Gyeongsangbuk-Do) freeway sections, from which the nearest heliport is farthest away. The number of regional EMS facilities within 50 km of the scene of the crash significantly decreased the likelihood of fatal crashes only in Cluster 2. Compared with the full data model, this cluster-based regression is specified by the effect of the number of nearby regional EMS facilities on reducing fatal crashes. Correspondingly, providing additional nearby regional EMS facilities would be a productive safety improvement strategy, particularly in the southeastern province freeway sections with large heliport spacing.

The effect of recovery times on fatal crashes was especially the strongest in Cluster 3, which includes crashes that dominantly occurred in South Korea's southwestern provincial (Jeonrabuk-Do) freeway sections in nearly stopped traffic conditions. In the South Korean freeway system, traffic speed is generally obtained from loop detectors installed in travel lanes. Approximately 99% of all cases in Cluster 3 occurred at zero traffic speed. A traffic speed of zero implies service areas or an area in which the loop detectors are not installed on South Korean freeway sections, such as shoulders, ramps, or gores. Accordingly, postcrash traffic management strategies could be preemptively conducted in South Korea's southwestern provincial freeway sections, such as shoulders, ramps, gores, or service areas.

CONCLUSIONS

The objectives of this study were to quantitatively examine the effects of the current prehospital EMS resources on fatal crashes and to identify the needs of supplemental EMS resources for the entire South Korean freeway system. To achieve the objectives, this study employed LC cluster-based binomial probit regression models.

This study is unique in that it is the first data-driven study to assess the systemwide EMS resources for the entire South Korean freeway system by using multiple data sources. It can contribute to informed decision making for future EMS provision. The current study developed a novel method for a surrogate measure of victim transport time and suggested a comparative utility for implementing different classes of EMS improvement. These efforts resulted in the following conclusions that would have useful implications on the applicability to freeway systems in the United States or other nations. Key findings are summarized as follows:

- On-scene time and recovery time were significant in increasing the fatal crash probabilities in both cluster- and full data-based regression models.
- The effects of a postcrash occupied main-line and night crash time on increasing fatal crashes were consistent in both the full data- and cluster-based regression models.
- Ramp proximity was likely to increase the probability of fatal crashes only in the group of crashes that occurred on freeway sections within South Korea's central province (Cluster 1).
- The number of nearby regional EMS facilities around the scene of the crash significantly decreased the likelihood of fatal crashes only in the group of crashes that occurred on South Korea's southeastern province freeway sections with large heliport spacing (Cluster 2).
- The effect of recovery time on fatal crashes was strongest in Cluster 3, which is characterized by crashes that occurred on certain sections of South Korea's southwestern provincial freeways, such as shoulders, ramps, gores, or service areas.

On the basis of the key findings, meaningful recommendations are provided to further support prehospital EMS resources to the South Korean freeway system as follows:

- For the entire freeway system, enhancing EMS training programs for professional and quick initial medical aid, medical consultancy and evaluation should be implemented to reduce on-scene time. Postcrash traffic management strategies, such as EMS priority signals, towing vehicle service, personnel training, and intelligent transportation system–based lane control, would also be helpful to reduce recovery time throughout the freeway system.
- It is worthwhile to enhance EMS personnel training and postcrash traffic management strategies for the entire freeway system under harsh circumstances, such as a postcrash lane limitation or at nighttime.
- Supplemental points of access to permanent medical facilities to reduce ramp spacing should be installed specifically on freeway sections within South Korea's central province (Cluster 1).

- Nearby regional EMS facilities could be provided, particularly in South Korea's southeastern freeway sections with large heliport spacing (Cluster 2). In addition, the cost-effectiveness of adding access points could be further examined both for emergency medical and law enforcement vehicles only and for all vehicles.
- A postcrash traffic management system could be preferentially emphasized, especially for South Korea's southwestern provincial freeway sections of shoulders, access points, gores, or service areas (Cluster 3).

This study did not consider CNT. Particularly, a quick and accurate crash notification system and accessible EMS are also considered effective means to reduce the risk of death (*29*). Even under the same environmental conditions, variations in exogenous factors can cause variability in CNT. Therefore, future research could be extended with the impacts of variability and reliability in CNT on the risk of death. It would also be interesting to analyze the administrative and operational factors associated with the CNT and EMS response times.

Additionally, this study used 1-year freeway crash observations in South Korea. Specifically, at-fault drivers and victims' ages, genders, vehicle types, and patient treatment content were not considered in this study, because of a lack of data. Therefore, it would be meaningful for more crash data to be combined with medical records and vehicle damage information. Hospital medical records could include the victim's physical features, type of medical treatment, duration of medical treatment, and so on. Vehicle damage information could be exemplified by the collision deformation classification code and the function of the vehicle safety equipment, such as airbags or safety belts. To identify better the shortage of freeway EMS resources, this study could be further extended to spatial analysis with geographic information systems.

Furthermore, the EMS information center would be helpful to support the optimal route information for rapid victim transport by using real-time traffic data and EMS resources. For policy decision making and crash mitigation and reduction, cost–benefit analysis would be also helpful in prioritizing EMS policy implementation.

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