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Latent Factors of Severity in Truck-Involved and Non-Truck-Involved Crashes on Freeways

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***Abstract*—**Truck-involved crashes have higher crash severity than non-truck-involved crashes. There have been many studies about the frequency of crashes and the development of severity models, but those studies only analyzed the relationship between observed variables. To identify why more people are injured or killed when trucks are involved in the crash, we must examine to quantify the complex causal relationship between severity of the crash and risk factors by adopting the latent factors of crashes. The aim of this study was to develop a structural equation or model based on truck-involved and non-truck-involved crashes, including five latent variables, i.e. a crash factor, environmental factor, road factor, driver's factor, and severity factor. To clarify the unique characteristics of truck-involved crashes compared to non-truck-involved crashes, a confirmatory analysis method was used. To develop the model, we extracted crash data from 10,083 crashes on Korean freeways from 2008 through 2014. The results showed that the most significant variable affecting the severity of a crash is the crash factor, which can be expressed by the location, cause, and type of the crash. For non-truck-involved crashes, the crash and environment factors increase severity of the crash; conversely, the road and driver factors tend to reduce severity of the crash. For truck-involved crashes, the driver factor has a significant effect on severity of the crash although its effect is slightly less than the crash factor. The multiple group analysis employed to analyze the differences between the heterogeneous groups of drivers.

***Keywords*—**Crash severity, structural equation modeling, truck-involved crashes, multiple group analysis, crash on freeway.

I. Introduction

TRUCK-INVOLVED crashes tend to be more severe and more deadly crashes than non-truck-involved crashes [1]-[3]. It is important to reduce both the number and the severity of crashes in order to make the roads and freeways safer. To decrease the severity of truck-involved crashes, the main causes of such crashes must be identified. To do this, it is necessary to determine the specific factors associated with truck-involved crashes. Structural equation modeling (SEM) was used in this study to identify the latent factors associated with crashes, and then, a multiple group analysis was performed to obtain a direct comparison with non-truck-involved crashes. There have been a few studies that developed a structural equation model of crashes to verify the causes that affect the severity of the crashes [1], [4]. Researchers have found that accessibility and driver factors have significant effects on severity, but they have not determined why truck-involved crashes are more severe than other crashes. The aim of this study was to analyze the differences in severity between truck-involved crashes and non-truck-involved crashes.

In 2011, more than 94% of transportation fatalities and more than 99% of transportation injuries involved motor vehicles on U.S. highways. In the U.S. in 2012, on average, 92 people were killed and 6,471 were injured every day in crashes involving motor vehicles [5]. The average number of crash on Korean highway has been decreasing of -3.2% for five years (2010-2014), while the fatality on freeway has the higher than any other highways on 2014 (7.6%). In addition, trucks represent approximately 30% of the total number of vehicles on the freeways. The growth rate of truck-involved crashes is higher than that for non-truck-involved crashes [6]. Because truck-involved crashes occur often on freeways and the number of crashes has increased consistently, this study addresses crashes on Korean freeways preferentially.

In this study, we developed a SEM to quantify the complex causal relationship between severity of the crash and risk factors. Following the basic SEM, the impacts of crashes were divided into direct and indirect effects. The model is ultimately expected to produce a better analysis, as it goes through several modifications that improve the explanatory power of the accident analysis. Crashes were classified as truck-involved crashes or non-truck-involved crashes. The fully developed model was used to analyze the differences between the two groups utilising multiple group analysis. By looking at a number of causes of crashes, conclusions can be drawn regarding the characteristics of truck-involved crashes versus non-truck-involved crashes.

The structure of this paper is as follows. Section II provides a literature review related to the severity of crashes and applications of SEM. Section III describes the data that were used for the analysis. Section IV explains how the SEM was designed and built. Section V shows the severity model of truck-involved and non-truck-involved crashes and provides a comparative analysis of the two kinds of crashes. Section VI provides our conclusions and recommendations for further research.

II. Literature Review

This study can be classified as research that provides analyses of severity of the crash and comparisons of the characteristics of truck-involved and non-truck-involved crashes. The studies of severity of the crash were conducted by using several different methodologies. A model was derived by applying a variety of factors that affect severity of the crash,

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and the results of the analysis were used to develop recommendations for safety measures to prevent truck-involved crashes and to reduce their severity when they occur.

Since the traditional multiple linear regression model is limited in its ability to assess the characteristics of crashes, a Poisson model and a negative binomial model were used to analyze the relationship between geometric elements and the severity of road conditions [7]. The severity of the injuries of the drivers of both trucks and cars sustained in various crashes was analyzed using multivariate logistic regression analysis [8]. Other related research includes a previous study that assessed the factors that influence truck-involved crashes. The seriousness of such crashes, depending on the cause of the crash and the type of incident, was analyzed using a logistic regression model [9]. Another study used three statistical models, i.e. ordered probit, ordered logit, and multinomial logit models, to interpret the relative risks of the significant influential factors concerning the severity of injuries [10]. Also, the binomial probit and ordered probit models were used to analyze the cause of rollovers of large trucks and how they affect the severity of injuries in truck-involved crashes [11].

The potential link between drivers and the probability of a crash was assessed via Poisson regression using detailed information and data related to driving behavior [12]. The factors that affected the severity of injuries in truck-involved crashes were classified by data based on two criteria, and they were presented as parameters related to the degree of severity according to the respective standards of each model [3]. Some researchers have analyzed whether drivers' drowsiness, fatigue, inattention, or distraction leads to drivers' deaths in truck-involved crashes [13]. However, sleepiness/fatigue and distraction/inattention have low reliability as variables, and the study only used a small sample of fatal crashes. In another study, the explanatory variables were chosen as horizontal alignment, longitudinal gradient, and the average annual daily traffic (AADT), and the number of cars involved in crashes was used as the dependent variable to measure severity of the crash [7].

SEM, developed in the field of social sciences, currently is being used in a variety of fields. In the transport sector, which has a close relationship with social phenomena, SEM is generally presented as a methodology for analyzing drivers' characteristics. There was a study that used Korean freeway crash data from 2005 to conduct an exploratory factor analysis of SEM. The variables to be explained were coded as binary variables. Each variable was analyzed to identify the factors that affected the severity of the crash [4]. Another study analyzed the relationship between accessibility and severity of the crash by looking at socio-economic indicators of the local crash data of Hawaii through confirmatory factor analysis of the SEM [1]. SEM and exploratory factor analysis were used to analyze the impacts of various factors [2].

To develop a strategy for reducing the number and severity of crashes, the researcher investigated the causes of crashes and the associated traffic conditions. Four latent variables, i.e. congestion, capacity, speed variation, occupancy variation, were used to identify the effects of the variables [14]. In addition, a study used the logit model (nested logit, multinomial logit model) to compare truck-involved crashes to non-truck-involved crashes and to identify the unique factors that resulted in increasing the severity of crashes [15]-[17]. Compared to non-truck-involved crashes, truck-involved crashes had more factors that further increased the severity of injuries.

The severity of crashes and their potential causes, both direct and indirect, are important to research because causal factors are linked to drivers' injuries/deaths and because it is absolutely necessary to understand causes to develop preventive measures. Occurrences that cannot be explained by observed variables can be analyzed further by latent variables using observation error. In addition, multiple group analysis was used as a method to analyze heterogeneous data and to derive the features of truck-involved crashes separately from non-truck-involved crashes.

III. Data Description

In this study, we used Korean freeway crash data for the years 2008-2014. Based on 2013 statistics, the total length of all Korean freeways is more than 4,139 km with the total 50.8 billion vehicle kilometer traveled per year [18], and there were 66,871 crashes recorded for this seven-year period. The severity of crashes in the entire dataset was established to confirm the effects of the variables. However, the data were missing in some cases. The missing data were treated with the proper method of listwise deletion (56,788 data), which means that the data were deleted even when only one piece of information was missing. Table I shows the statistics of the 10,083 cases of severe crash data that were used in the analysis. The statistics of truck-involved crashes include cases in which trucks caused the crash and cases in which the trucks crashed for other reasons.

TABLE I
CRASH STATISTICS FOR KOREAN FREEWAYS (2008-2014)

Type	Total		Truck-involved Crashes		Non-truck-involved Crashes	
	Number of Crashes	Percentages (%)	Number of Crashes	Percentages (%)	Number of Crashes	Percentages (%)
Total crashes	10,083	100.00	4,421	100.00	5,662	100.00
Fatal crashes	1,058	10.49	508	11.49	550	9.71
Crashes with injuries	2,483	24.63	1,041	23.55	1,442	25.47
Property damage only (PDO) crashes	6,542	64.88	2,872	64.96	3,670	64.82

TABLE II
DESCRIPTIVE STATISTICS

Variable	Type	Frequency	Percentages	No. Deaths	No. Injuries	No. Vehicles
Crash Mainroad	TG (TCS) [a]	524	5.2%	0.019	0.137	1.103
	TG (Hi-pass) [b]	134	1.3%	0.060	0.209	1.261
	Ramp	1,084	10.8%	0.049	0.228	1.120
	Freeway rest area	119	1.2%	0.076	0.437	1.269
	Tunnel	315	3.1%	0.092	0.578	1.886
	Main road	7,907	78.4%	0.141	0.499	1.670
Crash Fault	Vehicle defect	978	9.7%	0.067	0.300	1.222
	Driver's fault	8,688	86.2%	0.126	0.473	1.600
	etc.	417	4.1%	0.141	0.307	1.952
Crash VnV (Type)	Vehicle-facility	6,189	61.4%	0.047	0.293	1.277
	etc.	1,493	14.8%	0.098	0.307	1.268
	Vehicle-vehicle	2,212	21.9%	0.292	0.958	2.599
	Vehicle-pedestrian	189	1.9%	0.735	0.725	1.905
Environment Weekday	Weekday	7,160	71.0%	0.117	0.426	1.577
	Weekend	2,923	29.0%	0.132	0.506	1.579
Environment Bad Weather	Windy	3	0.0%	0.000	0.000	1.000
	Rainy	1,839	18.2%	0.095	0.382	1.420
	Snowy	418	4.2%	0.091	0.404	1.818
	Cloudy	1,706	16.9%	0.136	0.436	1.573
	Sunny	6,066	60.2%	0.127	0.477	1.610
	Foggy	51	0.5%	0.157	0.392	1.569
Environment Night	Daytime	5,865	58.2%	0.093	0.452	1.526
	Nighttime	4,218	41.8%	0.160	0.445	1.649
Road Concrete	Asphalt	4,332	43.0%	0.122	0.438	1.551
	Concrete	5,751	57.0%	0.121	0.457	1.598
Road Curve	Right-curve	1,666	16.5%	0.101	0.396	1.436
	Left-curve	1,636	16.2%	0.114	0.446	1.504
	Straight	6,781	67.3%	0.128	0.463	1.630
Road Downhill	Flat	4,879	48.4%	0.107	0.437	1.586
	Uphill	2,883	28.6%	0.140	0.478	1.580
	Downhill	2,321	23.0%	0.127	0.438	1.557
Driver Male	Female	1,137	11.3%	0.088	0.471	1.469
	Male	8,946	88.7%	0.125	0.446	1.591
Driver Ages over 40	Age under 29	2,039	20.0%	0.104	0.504	1.705
	Age 30-39	2,437	24.0%	0.108	0.426	1.547
	Age 40-49	2,889	29.0%	0.121	0.421	1.527
	Age 50-59	2,105	21.0%	0.137	0.450	1.580
	Age over 60	613	6.0%	0.176	0.488	1.509
Vehicle type	Trailer	2,720	27.0%	0.106	0.297	1.493
	Auto	5,331	52.9%	0.106	0.425	1.535
	Special vehicle	31	0.3%	0.161	0.548	1.613
	Truck	1,659	16.5%	0.181	0.662	1.781
	etc.	11	0.1%	0.182	0.909	1.909
	Van	331	3.3%	0.175	0.991	1.934

[a] TG (TCS) is regular toll collection system in Korea.
[b] TG (Hi-pass) is automatic toll collection system like EZPASS.

Previous studies have employed that they analyzed data by coding variables in arbitrary orders. This was the basis for establishing the variables that significantly influenced the severity of crashes based on previous studies [1], [4]. SEM must be coded in the proper method, depending on the difference between the variable parameters; this is an important factor that influences the results of the analysis. Table II summarizes the basic statistics for type of each variable to code the nominal variables in the binary variable. These variables are related directly to severity of the crash in the endogenous observed variables. And Table III describes each variable and presents the coding order for analyzing the SEM.

IV. Methodology

SEM is a methodology focused on explanation, prediction, and control of social phenomena, and it was developed in the social/psychological fields of study. Based on the covariance matrix between variables, it is necessary to confirm how many variances can explain the model that the researchers set up, so SEM also is called covariance structure analysis. SEM can account for factors that cannot be explained by observed variables alone by using latent variables, and therefore, this methodology has higher reliability than other traditional research methods [19]. There are three kinds of common cause factor (driver, road/environment, vehicle) which contribute to a crash [20]. In this study, the model has been structured by four kinds of factor, and those are crash, environment, road, driver. In the other words, the three kinds of factor in the previous study and additional crash characteristic factor were employed to analyze the SEM. Also, the structured model has been composed with similar in the previous studies [1], [4]. Fig. 1 shows the latent variables which has been chosen before the structuring model.

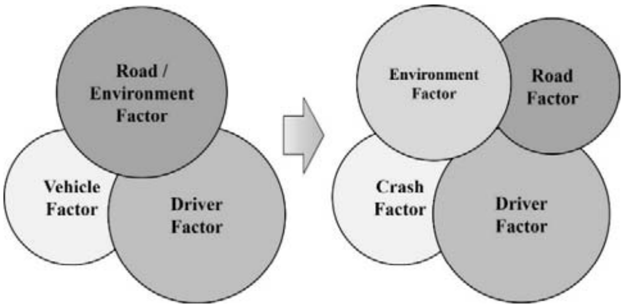

Fig. 1 Latent Factors

Fig. 2 presents the basic framework of SEM. The exogenous observed variables are put in x_i with four latent variables in the measurement model, and the endogenous variables are constructed on y_i with one latent variable in the measurement model. Five latent variables are constructed in the structure model to determine the relationship between them.

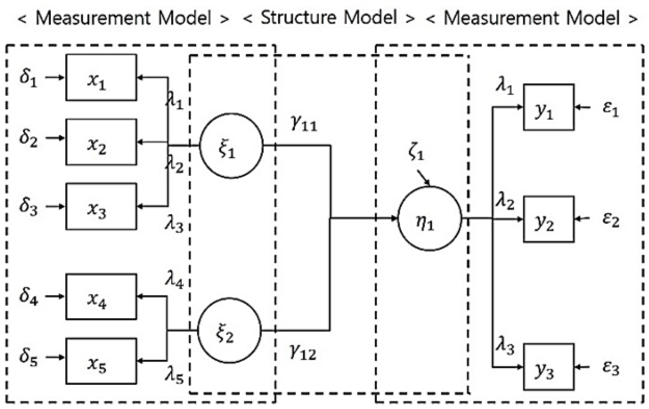

Fig. 2 Structure Map

SEM enables the analysis of multiple sample datasets, e.g. quasi-experimental, experimental, cross-sectional, and/or longitudinal datasets. The analysis method can be used to compare the parameters obtained for each sample for a single model. This methodology is possible under confirmatory factor analysis, and some invariance of the measurement may have to be accepted. However, the methodology should possess different values of error covariance, factor loading, and factor correlations to test across the samples. SEM estimates the suitability of the determinant or parameter estimates of heterogeneous samples. In the case of a measurement model, differences in factor loading, factor variance, and covariance can be tested across samples. In the case of the structural model, it is possible to compare the structural coefficients of each sample. To derive effective results from the analysis, a sufficient sample size is required in each group.

Multiple group analysis is a methodology for analyzing the properties of different groups in one particular model. The model allows comparison of different parameters through examination of different constraints. It is necessary to make sure that the two groups are suitable for a particular model before analyzing the model, and a clear difference should exist between the groups. Social-psychology researchers have used multiple group analysis to determine the differences between public and private school students' dispositions [21]. In addition, the analysis has been used to determine the differences in the nature and abilities of women and men [22].

TABLE III
DATA CORDING

Variables		Descriptions
Exogenous Observed Variables	Crash Mainroad	1: main road, 0: others
	Crash Fault	1: driver's fault, 0: others
	Crash VnV	1: vehicle-to-vehicle crash, 0: others
	Environment Weekday	1: weekday, 0: weekend
	Environment Bad Weather	1: bad weather, 0: others
	Environment Night	1: night time, 0: day time
	Road Concrete	1: concrete, 0: asphalt
	Road Curve	1: curve, 0: straight
	Road Downhill	1: downhill, 0: others
	Driver Male	1: male, 0: female
	Driver Ages over 40	1: age over 40, 0: others
Endogenous Observed Variables	No. of Deaths	Number of deaths (counts)
	No. of Injuries	Number of injuries (counts)
	No. of involved cars	Number of involved cars (counts)

V. RESULTS

A. Truck-Involved Crashes Model

In this research, we set up a relationship between each of the observed variables and the latent variables, and the relationships between these variables were quantified. Crash factor (Main road, fault, VnV), environment factor (weekday, bad weather, night), road factor (concrete, curve, downhill), and driver factor (male, age under 39) were examined to explain the complex causality. The truck-involved crashes model shows that the crash factor had the greatest impact on severity of the crash and that crashes tend to be more severe depending on the facility, cause, and type of the crash.

Fig. 2 shows the connection between severity of the crash and truck-involved crashes. The driver factor can increase the severity of the crash; severity of the crash tended to be higher for certain age groups because, for example, many truck drivers were males over 40 years old. In contrast, the road factor had little influence, which means that a curvy road did not have a significant impact on the cause of severe crashes on freeways.

In addition, the environment factor had the effect of reducing the severity of crashes. This seems to mean that the environment factor in truck-involved-crashes decreased the severity of the crash since truckers are sensitive to the environment and safe driving.

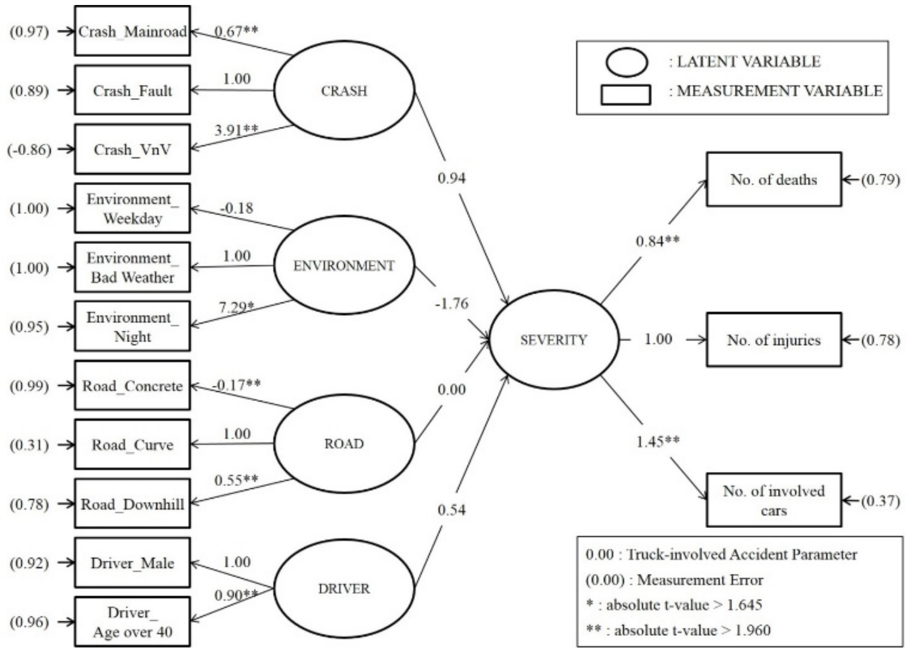

Fig. 3 Results of the analysis of truck-involved crashes

B. Non-Truck-Involved Crashes Model

Similar to the truck-involved crashes model, for the non-truck-involved crashes model (Fig. 3), environment factor shows the greatest impact on crash severity; this result suggests that non-truck-involved crashes can lead to serious crashes depending on the weather, whether it is nighttime, and whether it is a weekday. Crash factor also increases crash severity, which means that these variables generate severe crashes. On the other hand, road factor and driver factor reduce the severity of crashes; non-truck-involved crashes may reduce crash severity, responding to the characteristics of the road alignment and driver characteristics. The factors that affect the severity of crashes have positive (+) impacts on other variables and, therefore, one can conclude that the occurrence of serious crashes increases depending on the endogenous observed variables.

C. Model Comparison

In this study, the authors analyzed the causal relationship between latent and measurement variables to identify the factors of severity of the crash in truck-involved and non-truck-involved crashes. The parameters of each group were normalized. It is possible to analyze the differences in the factors that influence the severity of the crash of the two groups by comparing normalized coefficients.

Fig. 4 shows the differences of the two groups in severity of the crash. Especially, the relationship between latent variables indicated obvious differences between the two groups. Whereas, it indicated that the relationship between measurement variables (exogenous and endogenous observed variables) does not show the direct effect. Crash factor had the greatest effect of severity of the crash in the two groups with the greatest effect on severity of the crash. Conversely, other factors had different effects on severity of the crash. The environment factor affected the severity of truck-involved crashes and non-truck-involved crashes differently; it increased the severity of the crash in non-truck-involved crashes, but it decreased it in truck-involved crashes. From this, one can conclude that truckers tend to be more experienced in driving and to take environment factors into account to drive safely. Road and driver factors had an effect on increasing severity of the crash in truck-involved-crashes. The result showed that the road's structure and the driver's characteristics exerted influence on the severity of the crash in the two groups with different impacts. With this result, it is possible to present a different strategy for improving safety.

We compared the specific results in order to analyze the details involved. Crash type (crash_VnV) had the greatest impact on the causes of crashes, and, from this, it can be concluded that vehicle-to-vehicle crashes have a huge impact on severity of the crash. In addition, the variable (crash_mainroad) had a small positive effect in the two groups. This means that the location of a crash does not have a significant influence on the crash factor. Non-truck-involved crashes, however, tended to be more influenced by the environment factor. The characteristics of groups regarding environment factor were compared depending on the time frame (daytime vs. nighttime). Although truckers can have a significant effect on severity of the crash, the environment factor has a decreased impact on severity of the crash in truck-involved-crashes. It seemed to be because truckers are accustomed to driving late at night. Non-truck drivers tend to reduce severity of the crash through safe driving in accordance with road alignment. Road alignment factor does not have a significant effect on severity of the crash in truck-involved crashes.

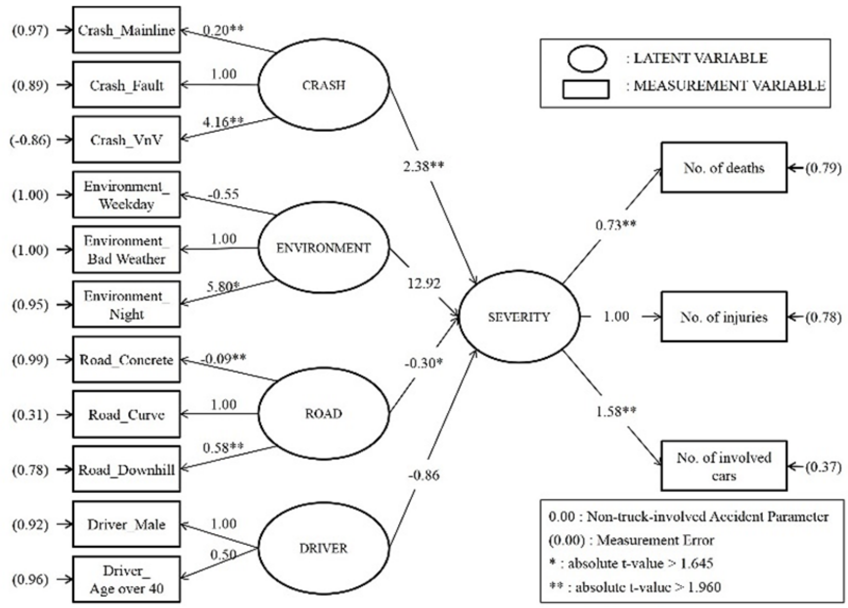

Fig. 4 Results of the analysis of non-truck-involved crashes

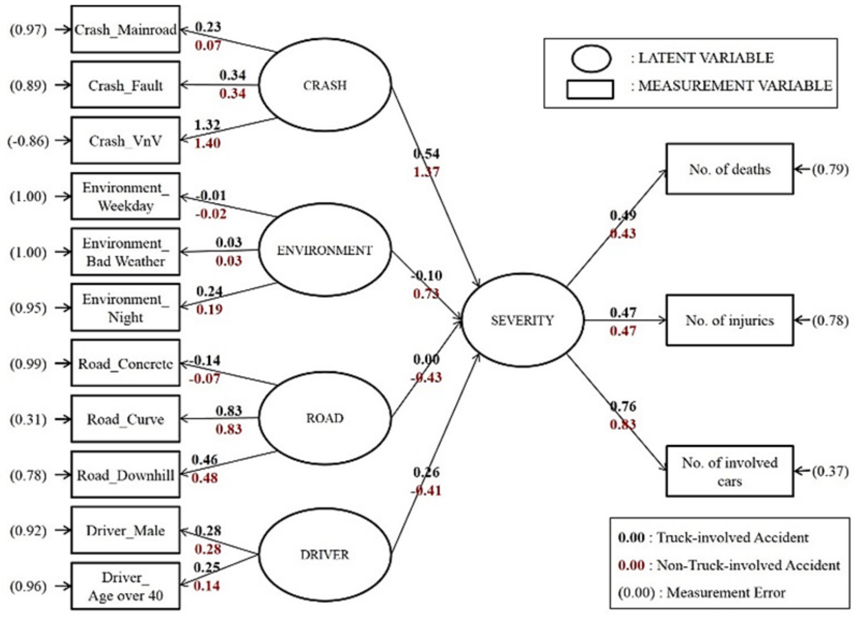

Fig. 5 Results of the comparison of between truck-involved and non-truck-involved crashes

The driver factor indicated differences between the two groups for severity of the crash; it tended to reduce severity of the crash in non-truck-involved crashes, but it increased severity of the crash in truck-involved crashes. Since most truck drivers are males (coded as 1), there would be a positive effect on severity of the crash in generating severe crashes. This result was in good agreement with the results of a previous study [1], [16]. Age over 40 has a positive effect on the driver factor, and the driver factor had a different effect in the two groups. As a result, truckers over 40 tend to generate severe crashes through the total effect on severity of the crash. The results in other research showed that neither young age nor fatigue at the time of driving significantly influenced the seriousness of crashes [2]. The analysis seemed to indicate that drivers over the age over 40 may have dangerous driving characteristics. The severity of the crash scores was based on the abbreviated injury scale (AIS). Research has found that the severity of injuries tended to increase with age, and truck-involved crashes were more likely to produce more severe injuries than non-truck-involved crashes [8]. Likewise, the severity of the crash factor can be described by the three observed variables, i.e. the number of deaths, the number of injuries, and the number of cars involved. From the model, truck-involved crashes results in more severe crashes than non-truck-involved crashes, based on the number of injuries and the number of deaths in truck-involved crashes. This result coincided with the results of previous study [1]. However, the number of cars involved in non-truck-involved crashes was larger than the number of cars involved cars in truck-involved crashes.

TABLE IV
TOTAL EFFECTS BY LATENT VARIABLES

Dependent Variable	Group	Crash	Environment	Road	Driver
No. of deaths	Non-truck-involved crashes	0.589	0.314	-0.185	-0.176
	Truck-involved crashes	0.265	-0.049	0.001	0.127
No. of injuries	Non-truck-involved crashes	0.644	0.343	-0.202	-0.193
	Truck-involved crashes	0.254	-0.047	0.001	0.122
No. of involved cars	Non-truck-involved crashes	1.137	0.606	-0.357	-0.340
	Truck-involved crashes	0.410	-0.076	0.002	0.198

The total effects of the endogenous observed variables by the latent variables are shown in Table IV. Latent variables have an impact on each observed variable of severity of the crash. One can derive the relative differences through a comparison of coefficient values. For non-truck-involved crashes, the environment factor had a significant effect on severity of the crash except for the crash factor. The crash and environment factor increased severity of the crash, but the road and driver factors tended to reduce severity of the crash. For truck-involved crashes, the driver factor had a significant effect on severity of the crash except for the crash factor. The crash, road, and driver factors increased severity of the crash, whereas the environment factor tended to reduce severity of the crash. Interestingly, truck-involved crashes were worse when the driver was a man over the age of 40, while non-truck-involved crashes were worse when the driver was a woman under the age of 40.

TABLE V
TOTAL EFFECTS BY LATENT VARIABLES

Model Fit	Fit Index	Criteria
Degrees of Freedom	159	-
Satorra-Bentler Scaled chi-squared	1,361	-
Root Mean Square Error of Approximation (RMSEA)	0.039	< 0.08
Comparative Fit Index (CFI)	0.956	> 0.90
Normed Fit Index (NFI)	0.951	> 0.90
Tucker-Lewis Index (TLI)	0.950	> 0.90

VI. CONCLUSION

In this study, SEM was used to analyze the factors of severity of the crash. The complex relationship among crash factors were described efficiently by SEM. The model was derived by complex causal relationships between latent variables and observed variables, and it was analyzed by the confirmatory factor analysis method. Crash, environment, road, and driver factors were used to overcome the limitations of existing crash analysis. Severe crashes were explained by three measurement variables, i.e. number of deaths, number of injuries, and number of cars involved. In addition, multiple group analysis was used to compare the cause of severity of the crash between non-truck-involved crashes and truck-involved crashes.

The results identified the main factor that affects severity of the crash, and they also identified the different characteristics of the two groups. The crash factor had the greatest impact on severity of the crash in both groups. When a crash occurs in main road, or when a crash occurs because of the driver's fault, the severity of the crash tends to be higher. The efforts for reducing crashes in main road or by drivers' faults can reduce the overall severity of crashes.

For truck-involved crashes, driver factor affected severity of the crash. When the driver was a man over 40 years old, the severity of truck-involved crashes was higher, while the severity of non-truck-involved crashes was lower. From the results, we can conclude that special countermeasures are needed for male truck drivers over 40. Road factor and environment factor had less effect on the severity of truck-involved crashes than they did on non-truck-involved crashes. We decided this was because truckers are accustomed to driving.

The study overcame the limitations of statistical analysis methods in comparing heterogeneous samples by using multiple group analysis. The analysis suggested factors on severity of the crash through a comparison of truck-involved crashes and non-truck-involved crashes. When the safety measures are developed focusing on the significant factors, severity of the crash can be reduced. It is necessary to develop safety measures in accordance with the causes of crashes and to perform pre- and post-evaluations of crashes. In addition, by using our methods on other data, specific safety measures can be developed by road type or crash type.

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