

Analysis of rescue operations of injured vehicle occupants by fire fighters

Yoshihiro Sukegawa

Japan Automobile Research Institute (JARI)

Masaaki Sekino

Japan Automobile Manufacturers Association, Inc. (JAMA)

Paper Number 11-0101

ABSTRACT

One of the responsibilities of fire fighters is to rescue injured occupants from crushed vehicles. Such occupants are frequently trapped in vehicles whose structure has been damaged to a devastating extent. However, few studies about the relationship between the original vehicle structure and the rescue procedures have been undertaken. The main reason for this is a lack of details regarding rescue operations.

In this report, rescue cases in which fire fighters rescued injured occupants in a crash using rescue equipment were analyzed statistically. These cases were collected by some fire stations in the area.

Vehicle occupants are often rescued by fire fighters (rescue workers) within five minutes. The rescue time (time lapse from site arrival to rescue of the casualty from the vehicle) required by fire fighters was 20 minutes on average. However, when there were two or more persons to be rescued, the average rescue time exceeded 30 minutes. Rescues involving heavy truck frontal impacts took twice as long as rescues involving passenger car casualties. Moreover, rescue operations in which the colliding vehicle was a heavy truck required more rescue time than passenger car accidents.

Proper casualty rescue from vehicles should be divided into four phases (initial opening, treatment opening, rescue opening, and rescue of the casualty). In these phases, we focused on five tasks (removing windows, vehicle stabilization or pulling the vehicle, door opening using a bar/door opening using hydraulic tools, pillar cutting using hydraulic tools, and pushing away the front end using hydraulic tools). The most frequent task was door opening using hydraulic tools, and next was pushing away the front end using hydraulic tools. Cases involving two tasks required more rescue time. In particular, a frontal impact involving a cab-over vehicle took more time.

In addition, some typical accidents including heavy trucks were reproduced by full crash tests, and the problem of current rescue procedures were investigated by trying these rescue activities. The fire fighters could easily rescue the occupant dummies in a crash test of a car under-ride with a heavy truck rear end. However, a long rescue time occurred if lifting of the rear end of the truck was needed. The operation took over 30 minutes to rescue the truck occupant dummies in a frontal collision. The principal problems were rescue procedures of door-opening and pushing-away the front end using

hydraulic tools.

From these results, we should study original rescue procedures of door-opening and pushing-away the front end, considering the structure of heavy trucks. This should be done in cooperation with fire departments. In Europe, some rescue manuals which specialize in heavy trucks are made, and such manuals would be valuable in Japan.

Because the rescue equipment in fire engines is different in Japan and Europe, an original Japanese rescue guide of heavy trucks is necessary based current rescue equipment available in Japan. We believe that the amount of time needed to rescue vehicle occupants injured in traffic accidents can be reduced by improving rescue procedures.

INTRODUCTION

The number of fatal traffic accidents in Japan has been continuously decreasing since 1993 (Figure 1). The number of traffic-related injuries has also exhibited a decreasing tendency since 2005. For this reason, the Japanese government applied pressure on manufacturers, etc., with the result that the targets initially planned for 2010 (a reduction of 1,200 fatalities by vehicle safety measures) were achieved by 2008, and new targets for further reductions were set^[1].

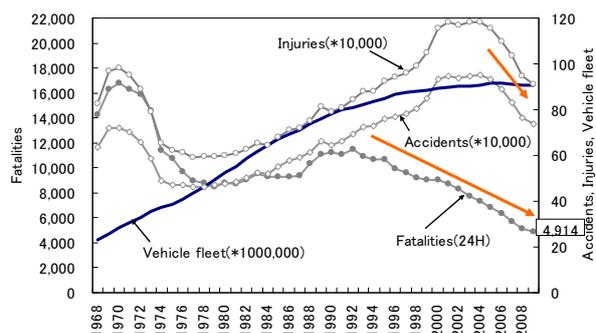


Figure 1. Traffic statistics in Japan

To achieve the new targets, vehicle manufacturers have to think about improving post-crash safety measures in addition to active and passive safety measures. Emergency call systems have been developed by some vehicle manufacturers with the objective of facilitating early assistance to injured occupants^[2]. However, such occupants are sometimes trapped in vehicles where the structure has been damaged to a devastating extent. In these cases, the fire fighters have to safely remove the injured occupants from the vehicle. Improvements in crash safety have recently been

achieved by increasing the complexity of vehicle structures, and the understanding of such changes has become an important issue for fire fighters in carrying out their operations efficiently. Therefore, it is necessary to study vehicles' structure and how it may affect rescue operations. Such information, provided to fire fighters through training programs, may become a valuable asset for improving rescue work in the future.

As a first step, in-depth data collected in Japan were used for this work. The types of vehicles involved and the types of accidents requiring rescue work were analyzed. In addition, some typical accidents were reproduced by full-scale crash tests to investigate the associated problems of current rescue methods.

In the following, these results are described. This research was executed in a JAMA project "research on improvement of vehicle rescue methods".

EMERGENCY WORK IN TRAFFIC ACCIDENTS

Accidents requiring emergency work

A series of 609 vehicle-to-vehicle accidents (involving 905 occupants) collected by the Institute for Traffic Accident Research and Data Analysis (ITARDA) from 1996 to 2006 was analyzed to evaluate the time lapse of the emergency work [3]. All of the selected cases involved an emergency call and the transportation of the injured occupant to a hospital by ambulance. However, it was not recorded whether rescue work was carried out or not.

Figure 2 shows the crashes in which emergency work was done, grouped by accident type. The most common type was the intersection type (348 cases). In these accidents, occupants transported to the hospital included 714 drivers, 133 front-seat passengers, and 58 rear-seat passengers.

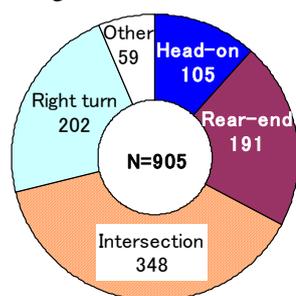


Figure 2. Accident type involving emergency work (ITARDA 1996-2006)

Time lapse required for emergency work

The time required in each case from the moment of the crash to the patient's arrival at the hospital was calculated based on five reported times from two different sources. The first reported time (called Crash) was taken from the police report. The other four recorded times (called Call, Arrival, Accommodation, and Hospital) were taken from fire station reports. Cases that presented incoherent reports were omitted from this study. Terms used to calculate the emergency time lapses are defined below.

Crash: Time at which the accident occurred.

Call: Time at which the emergency call was received at the fire station.

Arrival: Arrival time at the accident site.

Accommodation: Time at which the fire fighters (emergency medical technician) accommodated the injured occupant in the ambulance.

Hospital: The arrival time at the first hospital.

Figure 3 illustrates the average calculated time lapses between reported times from the crash to the arrival of the ambulance at the hospital for different injury levels. 672 (74%) of the transported occupants had minor injuries while fatal and serious injuries accounted for 22% (29+171) of the selected cases.

The average crash-call time lapse for minor/no injury was longer than for fatal/serious injury cases. This may be caused by the fact that people involved in accidents took time to decide whether or not to call an ambulance. No important differences were observed for the call-arrival time lapse. However, a difference of more than two minutes was found for the arrival-accommodation time lapse between the minor/no injury cases and the serious/fatal injury cases. This may be caused by the fact that preparation of the equipment needed for initial treatment takes more time in the case of serious injuries. The accommodation-hospital time lapse for fatal injuries was an average of three minutes longer than for the rest of the injury severity levels. One factor that could affect this delay is the necessity of choosing a hospital that can guarantee an appropriate first intervention when the occupant's life is seriously threatened.

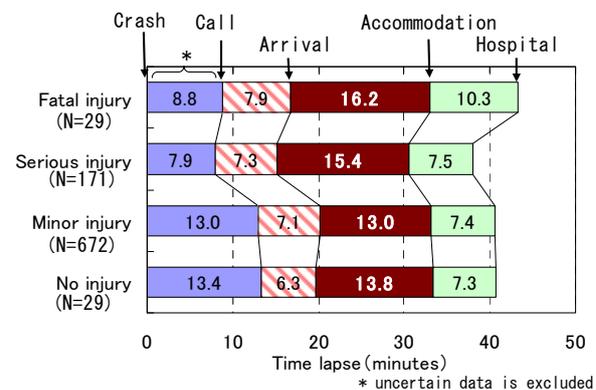


Figure 3. Average time lapse by injury severity (ITARDA 1996-2006)

Figure 4 illustrates the time lapses from the emergency call to the arrival at a hospital by injury severity. In this case, the results are grouped by crash type (frontal impact, side impact, and rear impact). For frontal impacts, the average arrival-accommodation time lapse tends to increase with the severity of injury.

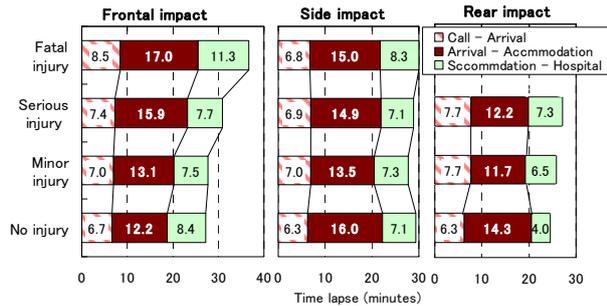


Figure 4. Average time lapse by injury level and crash type (ITARDA 1996-2006)

Figure 5 illustrates the injury severity ratios for the arrival–accommodation time lapse. The ratio of fatal/serious injuries tends to increase with time, and this tendency is seen especially in abdominal injuries. For elapsed time exceeding 26 minutes, the fatal/serious injury ratio rises to 50%. Based on these results, it can be said that when the occupant is severely injured, more time is required for the process from arrival at the crash site to accommodation of the casualty in the ambulance.

An estimated target of 30 minutes from the emergency call to arrival at an appropriate hospital has been reported in Japan as the critical time within which severely injured occupants should be transported^[4].

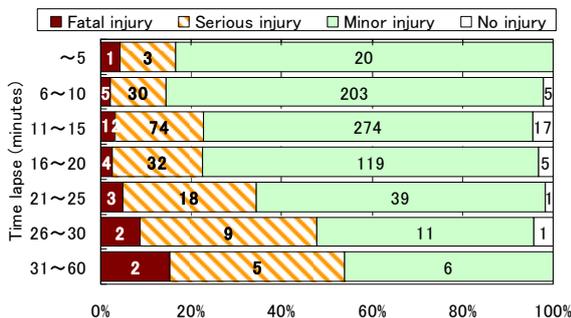


Figure 5. Injury severity ratio for arrival - accommodation time lapse (ITARDA 1996-2006)

To complement the Japanese data, other in-depth data sources such as data collected by the NASS CDS in the US were analyzed. Figure 6 plots the cumulative probability of the time to death by injury location. The cumulative probability of death due to chest injury within 1.5 hours after the accident (considered as instant death) is 68%, and it is 48% for head injuries. However, the cumulative probability of death due to abdominal injury within 1.5 hours is below 20%. This tendency for death due to abdominal injuries changes rapidly as the time to death increases, becoming as probable as head injuries at 7.5 hours.

This is not to say that only a shorter time lapse can increase the survival probability; rather, it is thought that rescuing injured occupants from damaged vehicles at an early stage and performing appropriate treatment early is effective in raising the survival probability. In particular, abdominal injuries are sensitive to this effect.

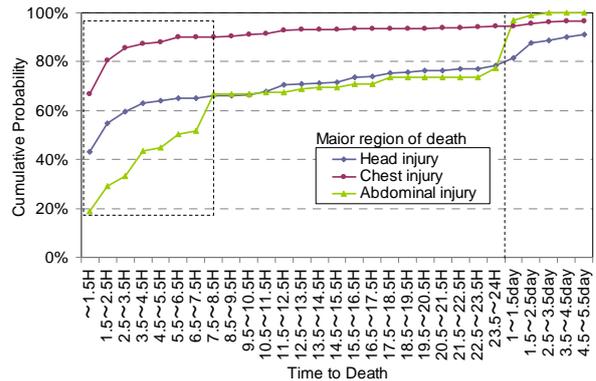


Figure 6. Cumulative probability at time to death by injury region (NASS CDS 2000-2004)

RESCUE WORK IN TRAFFIC ACCIDENTS

Accidents requiring rescue work

Fire fighters (rescue workers) have to rescue injured occupants trapped in devastated vehicle structures. Therefore, rescue work in which rescue equipment was used by fire fighters were collected with the cooperation of some fire stations in the area (see Figure 7). Accident types and rescue operations that required some time were analyzed. The collected data consisted of 78 cases involving 91 occupants trapped in damaged four-wheel vehicles.

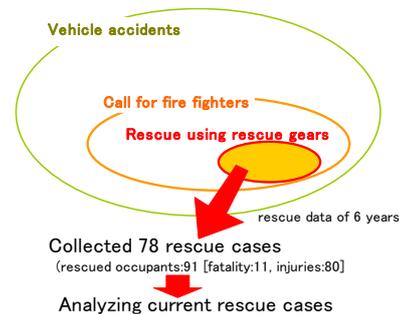


Figure 7. Image of data collection

Figure 8 indicates the number of rescued occupants per case. In most of the cases (85%) only one occupant was rescued. In the rest of the cases, two or three occupants were rescued. By seating position, (see Table 1), 75 (82%) of the rescued occupants were rescued from the driver's seat while 16 individuals were in the passenger area. Rescue operations are often required in the case of rollover (20 cases).

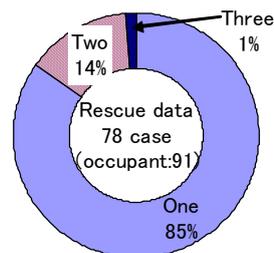


Figure 8. Number of rescued occupant / case (rescue case)

Table 1.
Accident type and seating position of the rescued occupant (rescue case)

Accident type	Rollover	Rescued case	Number of vehicles	Rescued occupant	
				Driver	Passenger
Vehicle to vehicle	w/o	42	43	40	8
	with	10	11	11	2
Single accident	w/o	16	16	16	1
	with	10	10	8	5
Total		78	80	75	16

Rescue time needed by fire fighters

Figure 9 graphs the rescue times for injured occupants. The rescue time is defined as the time lapse from the arrival of the rescue crew at the crash site to the extraction of the injured occupant from the vehicle. When two or more occupants need rescuing, the priority is usually judged on-site based on the injury level and the ease of the operation, among other factors.

Most of the work was finalized within five minutes, while the average rescue time was 20 minutes. However, the rescue of 14 occupants exceeded 31 minutes. If the data is divided by rescue order, the average for a subsequently rescued occupant is 36 minutes. Therefore, the average for the subsequently rescued occupant exceeds the target time lapse of less than 30 minutes for just the rescue work alone.

Figure 10 graphs the rescue times grouped by collision type (front, side, rear, and rollover). The rescue time for a frontal impact was 26 minutes on average, and longer for the other collision types. Most rescue times were less than 30 minutes for side impact and rear impact. Rescue times of less than 10 minutes occurred in 50% of the rollover cases. The reason is thought to be that the occupants could not escape by themselves, though the injury level may have been minor.

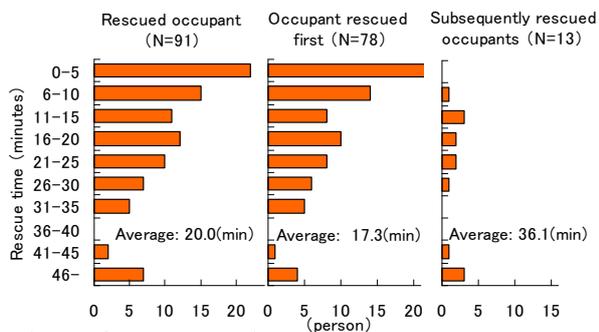


Figure 9. Rescue time divided by rescue order (rescue case)

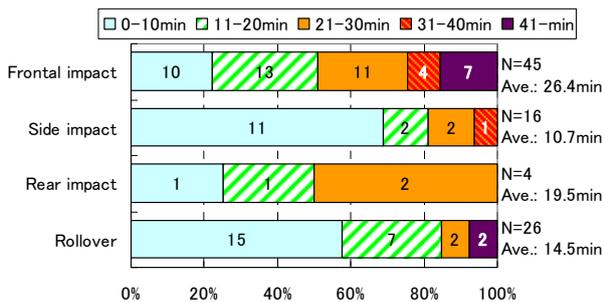


Figure 10. Rescue time divided by collision type (rescue case)

Figure 11 graphs the rescue times divided by vehicle type. For heavy trucks, all of the cases required over 10 minutes, and 3 out of 8 of the cases required over 41 minutes. The average rescue time was 50 minutes, two times longer than for other vehicle types. The rescue of truck occupants tends to take longer than passenger-car occupants. The reason is thought to be that most trucks in Japan are of the cab-over type, and the survival area is often crushed by a frontal impact. In addition, proper rescue from heavy trucks is generally much more complicated than in passenger-car accidents because the rescuers have to work at dangerous heights.

Figure 12 graphs the average rescue times divided by vehicle type and opponent vehicle type for frontal impact accidents. The average for a heavy truck/heavy truck accident is about 18 minutes longer than that for a heavy truck/car accident (**). When these two forms were compared, a significant probability difference was confirmed. The average rescue time for a car/heavy truck accident was longer than that of car/car accident (*). It can be said that rescue work needs additional time when the colliding vehicle is a heavy truck, even if the car occupant is rescued. A significant probability difference was not found in a comparison between car/car accidents and car/structure accidents.

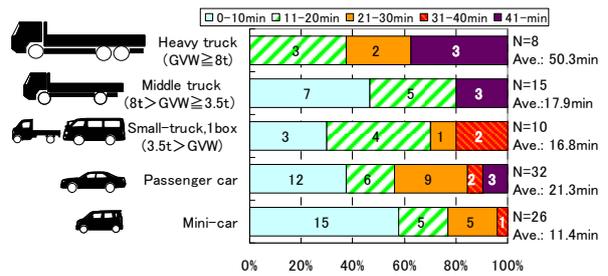


Figure 11. Rescue time divided by vehicle type (rescue case)

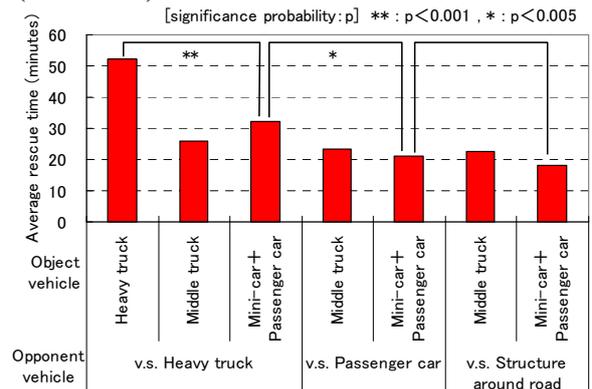


Figure 12. Average rescue time divided by vehicle type and opponent vehicle type in frontal impact (rescue case)

Figure 13 graphs the average rescue time divided by vehicle type and the occupant's injury level. The rescue time tends to be long relative to the injury level. After an investigation of conditions in which the average rescue time was over 30 minutes, the relevant conditions were found to be fatal/serious

injury of heavy-truck and middle-truck occupants and mid-level injury of heavy-truck occupants. Because the injury region of heavy-truck occupants was predominantly the abdomen^[5], improving the rescue work could be expected to lead to an increase in the survival probability.

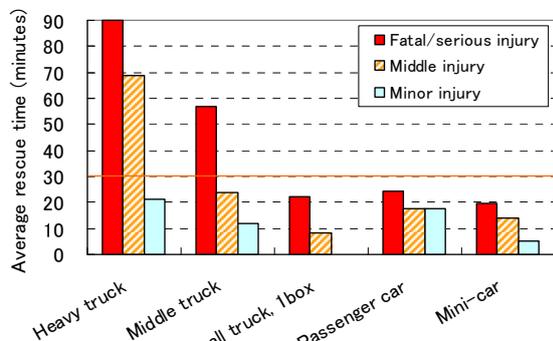


Figure 13. Average rescue time divided by vehicle type and occupant's injury level (rescue case)

Rescue methods used by fire fighters

The appropriate method for rescuing vehicle occupants is divided into four phases, according to the Guide for Rescue Service (for trucks, 2007)^[6]. The rescue procedure is almost the same in Japan. This procedure dictates that the crew chief act based on his experience and knowledge.

- 1st phase, "initial opening": Removal of window glass for the first contact with an injured occupant.
- 2nd phase, "treatment opening": Initial treatment and safe securing of vehicle. (vehicle stabilization, pulling the vehicle)
- 3rd phase, "rescue opening": Door-opening, pillar-cutting, and pushing away the front door to clear a rescue route.
- 4th phase, "rescue of the casualty": The injured occupant is transported out of the vehicle.

In this analysis, attention is focused on five operations (removing windows, vehicle stabilization /pulling the vehicle, door-opening, pillar-cutting, and pushing away the front end) in rescue work. Figure 14 shows executed rescue operations divided by collision type.

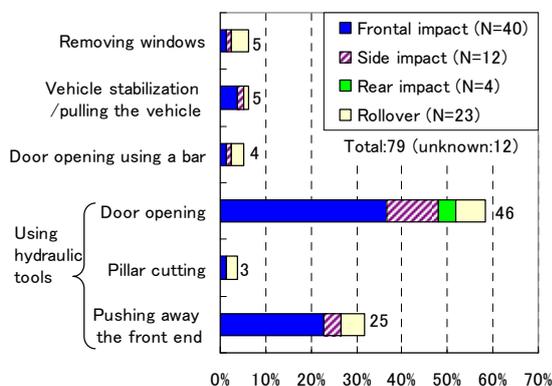


Figure 14. Executed rescue operations divided by collision type (rescue case)

In this graph, the numbers include all rescued occupants. Therefore, when two occupants were rescued in a single case, it was counted as two rescues. Moreover, the door-opening was divided into two operations based on the rescue equipment used (using a bar and using hydraulic tools).

The most frequent operation was door-opening using hydraulic tools, which was executed in 58% of the cases (representing 46 occupants). This is executed especially frequently in cases with a frontal impact and a side impact. The majority of the rescue teams (i.e. fire engines) at Japanese fire station are equipped with hydraulic tools such as a hydraulic cutter and a hydraulic spreader, though few are equipped with a rescue ram (Figure 15). The second most frequent operation was pushing away the front end using hydraulic tools. As mentioned above, rescue operations using hydraulic tools were frequently performed in vehicle accident rescues.



(a) Hydraulic cutter; It uses it to cut pillar and the door hinge, etc. (Weight: 14kg)



(b) Hydraulic spreader; It uses it to expand the collapsing part locally or to break it open. (Weight: 20 kg)



(c) Rescue ram; It uses it to expand the door frame and the roof, etc.

Figure 15. Examples of hydraulic tools

The data was divided into four tasks as follows, and the rescue times were compared.

- Task A: Door-opening using hydraulic tools.
- Task B: Pushing-away front end using hydraulic tools
- Task C: Opening the door and pushing away the front end using hydraulic tools.
- Task D: Without using hydraulic tools.

Table 2 indicates how the rescue work was divided among the four tasks. Task A was performed frequently in the case of collision accidents (frontal, side, and rear impact). In contrast, Task D was performed frequently in rollover accidents.

Figure 16 graphs the average rescue time, divided into four tasks. For a side impact and a rear impact, the analysis is difficult because of the limited number of samples.

Task D did not require rescue time in front impact and rollover accidents. The average rescue time for Task A was almost equal to that for Task B, about 20 minutes. The average rescue time for Task C was over 30 minutes, and over 60 minutes was required for Task C when the crash involved frontal impact in a cab-over type truck. It is thought that cab-over occupants are frequently trapped in frontal collisions and that performance of Task C is required because this type of vehicle does not have a crushable zone in the front.

Table 2.
Rescue method divided four tasks

Rescue method	Task A	Task B	Task C	Task D	Total
Frontal Bonnet type	11	7	4	1	23
Frontal Cabover type	7	1	7	2	17
Side impact	7	1	2	2	12
Rear impact	4				4
Rollover	3	2	2	16	23
Total	32	11	15	21	79

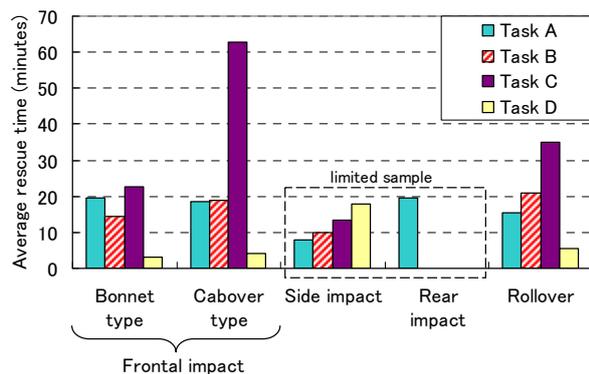


Figure 16. Average rescue time divided into four tasks (rescue case)

ACCIDENT REPRODUCTION AND RESCUE OPERATION OF OCCUPANT DUMMIES

Reproduced accident form

To analyze rescue operations in detail, specific traffic accidents were reproduced by full-scale crash tests, and fire fighters were trained on how to rescue occupants represented by dummies. Two cases were executed. In each case, the vehicles were collided with 100% over-lapped in width.

Case 1 is an accident in which a passenger car collides with the rear of a heavy truck. Adult human dummies (Hybrid-II) were installed in the driver's seat and the passenger's seat of the passenger car. The passenger car was made to collide at a speed assumed to cause it to under-ride the stopped truck. Fire fighters rescued the injured passenger car occupants (two dummies).

Case 2 is an accident in which a heavy truck collides with the back of a heavy dump truck. Two dummies were installed in the frontal-impact truck. The truck was made to collide with a stopped dump truck at a speed at which the occupants were assumed to receive serious injuries. The fire fighters rescued the injured truck occupants (two dummies).

Table 3.
Conditions of reproduced crash test

Case 1		
Accident form		
Vehicle	Object	Opponent
Type	Passenger car	Heavy truck
Rescue	Occupant dummies *2	-
Purpose	Rescue of under-ride accident	
Case 2		
Accident form		
Vehicle	Object	Opponent
Type	Heavy truck	Heavy dump truck
Rescue	Occupant dummies *2	-
Purpose	Rescue of heavy truck occupant at frontal impact	

Current rescue method

Referring to Case 1, the rear under-run protector (RUP) of the heavy truck was deformed in the high-speed collision, though the RUP slightly restrained car under-riding. These rescue operations were conducted by four fire fighters. The fire fighters were easily able to rescue the occupant dummies from the rear door because they could open all doors of the passenger car without pulling the vehicle apart (Figure 17). The rescue time was about six minutes.



Figure 17. Rescue situation of under-ride accident (Case 1)

Though it was unnecessary in this case, fire fighters sometimes perform a rescue after pulling the vehicles apart because the car occupant is trapped by the truck. In Case 1, it took about 24 minutes for the fire fighters to pull the vehicles apart after the occupant dummies had been rescued (Figure 18). The operation of lifting the truck rear end took most of the time.

Therefore, it is necessary to discuss prompt and efficient methods for lifting a truck rear end since it is predicted to take 30 minutes to rescue a trapped occupant.



Figure 18. Rescue situation of pulling apart the vehicles (Case 1)

In Case 2, the cabin of the frontal-impact truck was significantly deformed, and the occupant dummies were trapped in the cabin. Six fire fighters operated in the rescue, working on both sides of the cabin. Figure 19 presents the flow of the rescue operations.

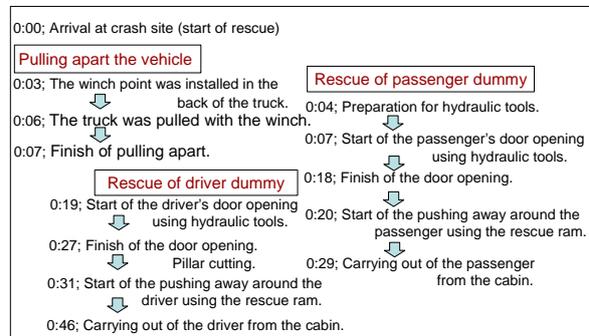


Figure 19. Flow of the rescue operations (case 2)

It took a total of 46 minutes to conduct these rescue operations. The principal problems were thought to be the door-opening and pushing-away operations. A ladder is needed to open the door of the heavy truck (Figure 20). The fire fighters must pay attention to their own movements and to the movement of the door when setting the height point. The process of opening the driver's door might be shortened by acquiring experience with the passenger door.

However, pushing-away operations around the driver took more time because the instrument panel around the driver was complex. Especially, it is important to do this work after looking around the ankles of the injured driver. Relief cutting of the front pillar is effective for pushing away the front end and expanding the space (Figure 21). When the fire fighters carried the occupant out, the supporting rescue ram interfered with the rescue, as the rescuers were inexperienced in using the ram (Figure 22). Because of the high cost, rescue teams (rescue engines) in Japan are rarely equipped with rescue rams, and if equipped, they have only one ram. It takes a long time to push an obstacle away if they have only one ram but it is difficult to equip each rescue team in Japan with two or more rams at once. Therefore, it is important to identify a better rescue method which uses the current rescue gear that rescue teams have.

Current problems and measures discussed of Case 2 are given in Table 4. It is thought that these discussions are necessary to rescue injured occupants from a destroyed cabin safely in the future.



Figure 20. Door-opening operation (Case 2)

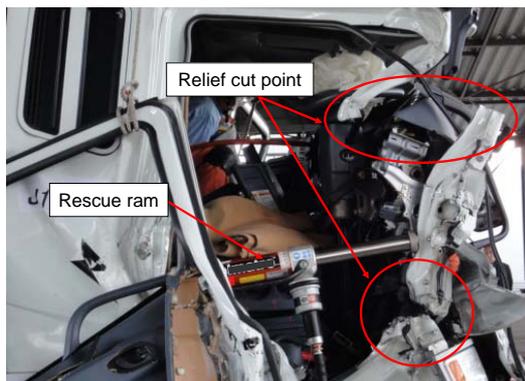


Figure 21. Relief cut points and pushing-away the front end (Case 2)



Figure 22 Rescue of the injured occupant (Case 2)

Table 4.

Current problems and discussed measures of Case 2

Problems	Measures discussed
Safety of rescue worker	Necessity of ladder Fixation of moving parts
Efficient way to remove door	Structural knowledge of door How to use of hydraulic tools (first opening point)
Efficient way to push away the front end	Necessity of relief cut. How to use of rescue ram (fixed point).
How to detach the rescue ram when a injured occupant is transported out of the vehicle	Necessity of splint Structural knowledge of cabin.

Some rescue manuals which specialize in heavy trucks are made in Europe [6] [7]. A working group concerned with truck rescue has been established in Germany, and a more efficient rescue method has been examined. It is also necessary to establish an original rescue method in traffic accidents involving heavy trucks in cooperation with the fire departments in Japan.

CONCLUSION

- 1) The ratio of fatal/serious injury tends to increase by the time lapse of arrival-accommodation length. The average time after receiving a fatal or serious injury is two minutes longer than that with a minor injury or no injury.
- 2) Vehicle occupants are often rescued by fire fighters (rescue workers) within five minutes. The average rescue time is about 20 minutes.
- 3) The rescue of heavy-truck occupants took twice as long as that of passenger-car occupants. Furthermore, frontal-impact accidents of a passenger car with a heavy truck result in a longer rescue time than passenger-car accidents.
- 4) The most frequent operation was door-opening using hydraulic tools, and the next most frequent was pushing away the front end using hydraulic tools.
- 5) Rescue operations that result in long rescue times occur when both door-opening and pushing away of the front end using hydraulic tools are needed. Rescuing occupants in accidents involving frontal impact of a cab-over truck requires a particularly long time.
- 6) The fire fighters could easily rescue occupant dummies in the rescue case of a car under-ride. However, a long rescue time occurred if lifting of the rear end of the truck was needed before the occupant could be removed.
- 7) The rescue operation took over 30 minutes in a case of truck occupants in a frontal collision. The principal problems were rescue methods of door-opening and pushing-away the front end using hydraulic tools.

We believe that the rescue time of vehicle occupants injured in traffic accidents can be reduced by improving rescue methods, and therefore save lives.

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