An Insight into Multiple Impact Crash Statistics to Search for Future Directions of Counter-Approaches

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Paper Number 11-0203

ABSTRACT

Multiple impact crashes (MICs) consist of more than 50 percent of all tow-away crashes that occurred on US roadways between 2000 and 2008. The total number of injured occupants with MAIS3+ injury, based on NASS-CDS data for 3-point lap and shoulder belted occupants, without rollover and no-ejection for the model year 2000-08, is 1,571(weighted 109,276). No significant change or variation can be observed with respect to the model year of the vehicle. The probability of higher level of injury (MAIS>3-5) suffered by the occupants inside the vehicle, is more likely to occur in MIC scenario than that in SIC (single impact crash) scenario. As passive safety measures, especially irreversible systems, are generally more effectively designed for occupant protection in single impact, there are opportunities for future advanced active systems as mentioned by Sander (2009).

1. INTRODUCTION

Both crash tests required by legislation and consumer tests reproduce single impact crashes either in vehicle-to-moving carriage or in vehicle-to-fixed object collisions. A multiple impact crash is one in which a vehicle (or surrounding vehicles) undergoes two or more events of impacts during a process of a total crash sequence. The data analysis portion of this research considers only multiple impact crashes that do not involve rollover, where the drivers were not ejected, and where the drivers were belted in the vehicles with 2000+ model year. Neither the initial impact nor the subsequent impact(s) is limited in any direction, sequence, or impacted object. Several recent statistical studies of multiple impact crashes have been published (Digges, 2003, Lenard, 2004, Bahouth, 2005). The purpose of the present study is to introduce in-depth reviews of accident cases involving multiple impacts in order to better understand the percentage of different types of these crashes. The effect of the sequence of impact events in multiple impact scenario have not yet been incorporated in present test procedures. As a consequence, passive safety measures, especially irreversible systems, are generally designed for occupant protection in single impact. The overall economic impact and human toll of multiple impact crashes is significant as mentioned in references (DOT 2000, Fildes 1996). Therefore further basic and applied researches related to accident mitigation and occupant protection based on accident database are necessary to adequately address the counter measures in order to minimize the number of accidents and also the level of injury.

2. OVERALL ACCIDENT STATISTICS

Table 1 shows the percentage distribution of number of occupants with different injury level (MAIS0+ to MAIS5+ and MAIS0 to MAIS5) in tow-away crashes which occurred on U.S. roadways, based on NASS-CDS data. The data refers to impact crashes registered from 2000 through 2008, that do not involve rollover, where the drivers were not ejected, and where the occupants were belted (3-point lap and shoulder) in the vehicles of 2000+ model year (MY). The total number of occupants is 22,795(unweighted) corresponding to a weighted value of 9,126,520 occupants. The values within the bracket "()"correspond to those for individual MAIS(0-5) level.

Table 1: Percentage distribution of injured occupants with different injury level (NASS-CDS, 2000-08, no rollover, no-ejection, MY2000+, belted).

Item	MAIS 0+ (0)	MAIS 1+ (1)	MAIS 2+ (2)	MAIS 3+ (3)	MAIS 4+ (4)	MAIS 5+ (5)
SIC	56% (59%)	51% (51%)	52% (56%)	43% (47%)	34% (34%)	35% (36%)
MIC-MIE=1(Max. injury 1st impact)	27% (25%)	30% (30%)	30% (30%)	32% (30%)	35% (37%)	30% (26%)
MIC-MIE=2+ (Max. injury 2nd+ impacts)	9% (8%)	11% (11%)	13% (10%)	18% (18%)	20% (19%)	22% (23%)
Unknown	8% (8%)	8% (8%)	5% (4%)	7% (5%)	11% (10%)	13% (15%)
Total	100%	100%	100%	100%	100%	100%

With the increase of MAIS+ injury level, in single impact crash (SIC), the percentage decreases from 56% to 35%. In multiple impact crash (MIC) with maximum injury event (MIE) at the event of 1st impact (MIC-MIE=1), the

percentage remains more or less constant around 30%. However, for MIC scenario corresponding to maximum injury event in 2nd+ impacts (MIC-MIE=2+), with the increase of injury level from MAIS0+ to MAIS5+, the percentage increases from 9% to 22%. The decrease in SIC and the increase in MIC-MIE=2+ are especially significant starting at MAIS3+ level. Similar trend can be observed for individual MAIS values written within brackets. According to the data extracted in the present study, there is some indication that the probability of higher level of injury (MAIS>3-5) suffered by the occupants inside the vehicle, is more likely to occur in total MIC scenario (including MIC-MIE=1 and MIC-MIE=2+) than that in SIC scenario. The data for MAIS3+ will be discussed in detail in the later section of this paper.

Table 2: Percentage distribution of MAIS3+ injured occupants with different injury level with respect to the MY of the vehicle.

Item	MY 2000+	MY 2001+	MY 2002+	MY 2003+	MY 2004+	MY 2005+
SIC	43%	42%	42%	41%	43%	43%
MIC-MIE=1 (Max. injury at 1st impact)	32%	31%	31%	31%	32%	30%
MIC-MIE=2+ (Max. injury at 2nd+ impacts)	18%	20%	20%	20%	17%	20%
Unknown	7%	7%	7%	8%	8%	7%
Total	100%	100%	100%	100%	100%	100%

The previous data is now plotted in Table 2 by varying the start of model year from MY2000+ to MY2005+, in order to observe the effect of the model year on the percentage distribution of number of injured occupants with different injury level in SIC and MIC scenario basis. The total number of injured occupants with MAIS3+ injury based on NASS-CDS data for belted occupant without rollover and no-ejection for MY 2000-08, is 1,571 corresponding to a weighted value of 109,276 persons. For example, model year range MY2003+ means 2003-2008. No significant changes or variation can be observed with respect to the start of the model year ranges of the vehicle in SIC and MIC scenario over a span of 6years when relatively older cars are gradually replaced by newer cars.

3. MODES OF MULTIPLE IMPACT CRASHES

In CDC code, the severity of damage related to injury of a particular event for each vehicle is classified as "Rank". Here it is assumed that maximum injury is caused at the most severe event "Rank=1" due to maximum damage at that particular event of impact. Figure 1 shows a typical SIC event with maximum injury of the target vehicle V2 occurred at the event of 1st impact at the intersection.

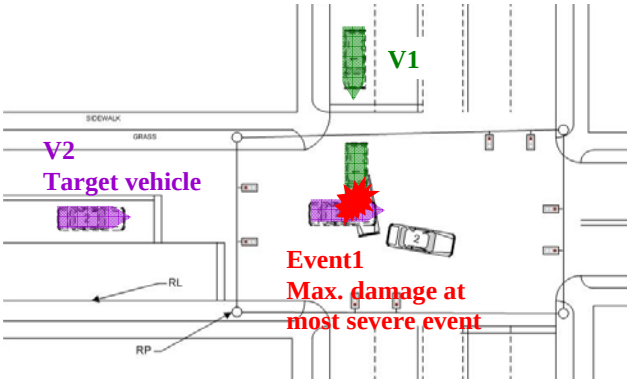

Figure 1: Example SIC: NASS-CDS:2001-045-058

Figure 2 shows a typical MIC event with maximum damage of the target vehicle V1 occurred at the event of 1st impact on the intersection and then pushed away from the center of the road intersection to the ditch/culvert at the road side.

Figure 2: Example of MIC-MI1 NASS-CDS:2000-009-027

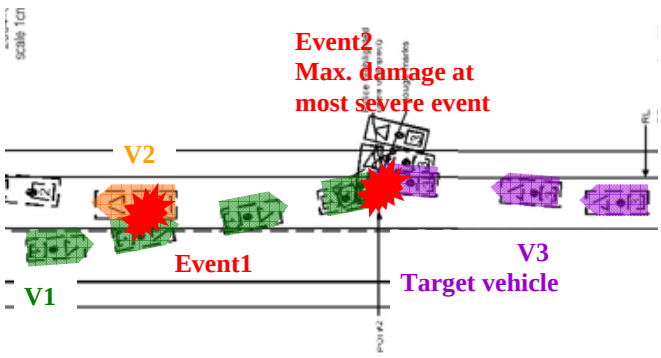

Figure 3: Example of MIC-MI2 NASS-CDS:2004-81-076

Figure 3 is a typical MIC event with maximum damage of the target vehicle V3 which occurred at the event of 1st impact for V3. However, it is the 2nd event within this MIC scenario in which the 1st event corresponds to "V1 hit the left-rear portion of V2" and then the 2nd event is "V1 involved in frontal crash with V3". The above cases are indicated as sample accident cases in the respective areas in SIC and MIC portions of Figure 4 as shown below.

3. MODES OF SINGLE AND MULTIPLE CRASHES

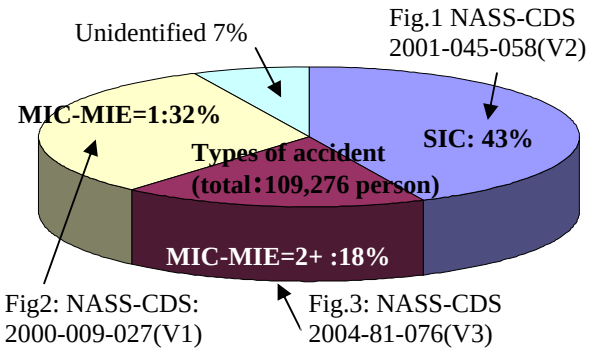

Figure 4: Percentage distribution of SIC and MIC (MAIS3+).

Figure 4 shows the percentage distribution of SIC and MIC related to MAIS3+ cases as highlighted in Table 1. A total of 109,276 persons are involved in these crashes. The percentage of occupants involved in MIC scenario is 50% (MIC-MIE=1: 32% , MIC-MIE=2+: 18%) compared to that of 43% in SIC scenario within a selected set of NASS-CDS dataset as mentioned above. Maximum injury (damage to the vehicle) in those SIC and MIC occurred in the events of first and subsequent second or later impacts, respectively. It also includes small amount about 7% of unidentified cases. Based on the information of NASS-CDS data which indicates the severity of each event, among the above mentioned MIC scenario (i.e., 50%) with MAIS3+ injured occupants, approximately 1/3 (i.e., 18%) of those occupants incurred maximum injury in the event of second or later impacts.

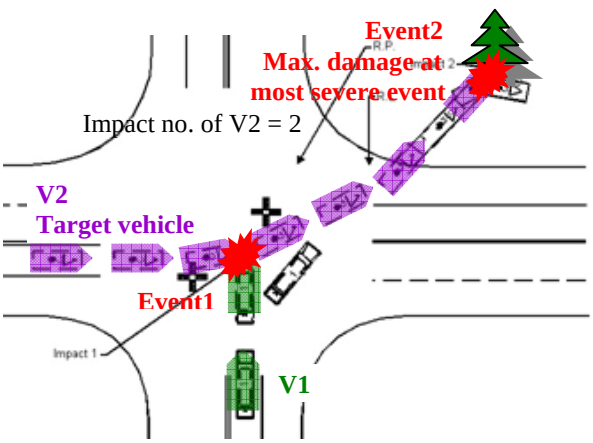

Figure 5: Example of MIC-MIE=2+ NASS-CDS: 2004-12-193.

Figure 5 shows another typical MIC event where the maximum damage of the target vehicle V2 occurred at the event of the 2nd impact against a tree outside the road after being hit at the right front side at the intersection by vehicle V1. Figure 6 also shows another typical MIC event where the maximum damage of the target vehicle V3 occurred at the event of the 2nd

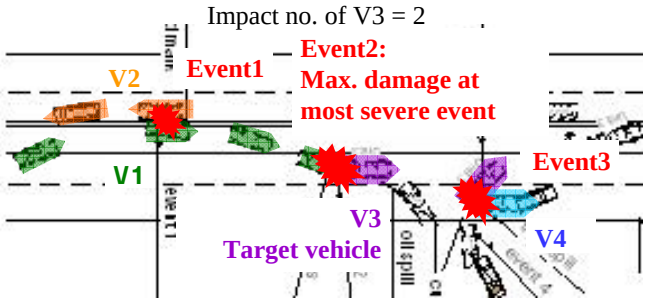

Figure 6: Example of MIC-MIE=2+ NASS-CDS: 2007-012-081.

impact when it is impacted at the rear end by the following vehicle V1. Before this event, vehicles V1 and V2 collided sidewise at the event of the 1st impact. The reference number of the above two cases are indicated in the following Figure 7 and Figure 8 in SIC and MIC portions.

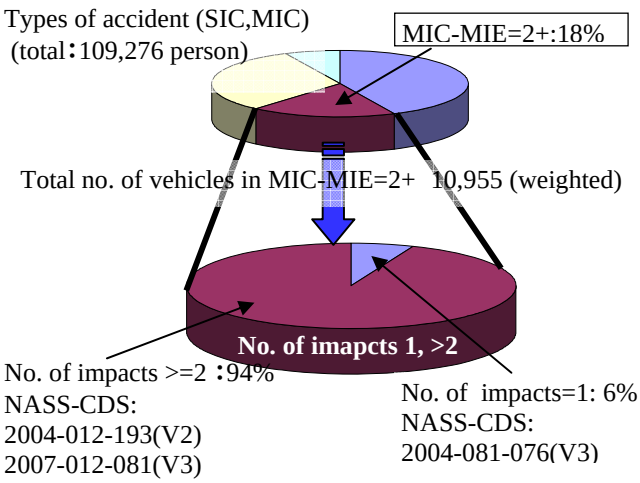

Figure 7: Percentage distribution of number of MIC-MIE = 2+ related vehicles based on number of impacts.

As shown in Figure 7, corresponding to 18% of MIC-MIE=2+ occupants where the maximum injury occurred after the 2nd impact, there are 10,955 (weighted) number of vehicles by counting only once for a particular vehicle even if there are cases where multiple occupants are injured within a single vehicle involved in those MIC scenario. Based on this counting method, 94% of those MIC-MIE=2+ vehicles (for example, NASS-CDS 2004-012-193(V2) or 2007-012-081 (V3) , Figure 5,6) were involved in more than two impacts

and the remaining 6% (for example, NASS-CDS 2004-081-076 (V3), Figure 3) of the MIC-MIE=2+ ended up in only single impact preceded by the 1st impact event within the accident scenario. Hence, the probability of being impacted twice or more before the event of maximum injury, is very high in MIC-MIE=2+ situation. One can think of some possible reasons behind these types of phenomena. They are probably due to the fact that (a) considerable amount of kinetic energy remained in the crashed vehicle after the 1st impact event in those MIC-MIE= 2+ scenario and (b) the initial velocity before the 1st impact event might be high enough to encounter or cause subsequent multiple impacts before coming to rest.

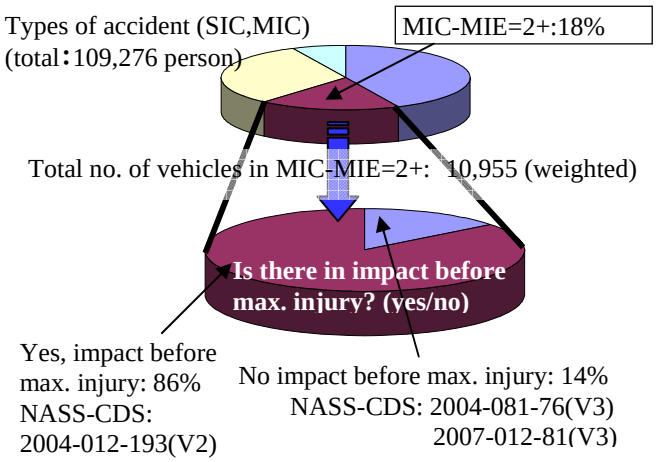

Figure 8: Percentage distribution of number of MIC-MIE =2+ related vehicles based on impact condition before the event of maximum injury.

Based on the previous counting method, Figure 8 shows that 86% of the vehicles in those MIC-MIE=2+ scenario, involved in more than two impacts, there is at least one event of impact before the one which causes maximum injury or damage. The remaining 6% of the MIC-MIE=2+ scenario, do not encounter any impact before the event of maximum damage or injury. Hence, after the 1st impact of the concerned car in that 86% (for example, NASS-CDS: 2004-012-193(V2), Figure 5), there is some possibility of reducing the number of occurrence of consequent accidents and also simultaneously reducing the degree of damage or severity of the accident as a whole. With the progress of future advanced sensing technologies (including vehicle surrounding sensors), accident mitigation may be possible by braking or by intelligent maneuvering (steering action) before and after the impact. This may be one of the different ways of reducing of total number of injuries as well as the degree/severity-level of injuries of the occupants inside those vehicles.

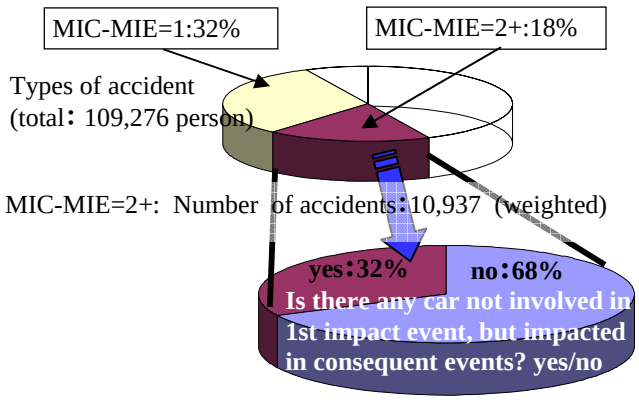

Figure 9: Percentage distribution of number of MIC-MIE =2+ related accidents based on pre-impact condition before the event of maximum injury.

Based on the same counting method as mentioned above, Figure 9 shows that in 32% of those MIC-MIE=2+ scenario, accidents include the vehicle which is not involved in 1st impact event but engaged in accident after the event of 1st impact. Hence, similar benefits may be realized by implementing pre-crash and post-crash braking or controlled maneuvering in those surrounding uncontrolled crashed vehicle after the event of 1st impact.

Advanced systems may also show benefits when it comes to protecting vulnerable road users such as the pedestrians or bicyclists [3, 4]. But the accident report of vulnerable road users are not available in NASS-CDS accident database. However, every year, it is observed that there exists a few number of such MIC related secondary accidents involving pedestrian and bicyclist as recorded in FARS database.

4. CONCLUSION

Overall accident statistics related to the percentage distribution of number of occupants with different injury level in tow-away crashes occurred on U.S. roadways, based on NASS-CDS database are discussed. The data refers to impact crashes registered from 2000 through 2008, that do not involve rollover, where the drivers were not ejected, and where the occupants were belted in the vehicles of MY 2000+ model year. The total number of occupants is 22,795 (unweighted) corresponding to a weighted value of 9,126,520 occupants.

1) When considering MY 2000-2008, no significant changes or variation can be observed with respect to the start of the model year ranges of the vehicle in SIC and MIC scenario.

2) The probability of higher level of injury (MAIS>3-5) suffered by the occupants inside the vehicle, is more likely to occur in MIC scenario than that in SIC scenario.

3) There is some opportunity left for future advanced active safety systems to play an important part in multiple impact crash scenario.

The above study is purely based on accident data of NASS-CDS database system and no definite conclusion can be drawn at present about the effect of such new systems as mentioned above without carrying out detail experiments in various scenario.

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