ASSOCIATION BETWEEN EMBEDDED CELLULAR PHONE CALLS AND VEHICLE CRASHES INVOLVING AIRBAG DEPLOYMENT

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Summary: A study was done of a cellular telephone system embedded in a vehicle by the vehicle manufacturer. This study examined voice calls to a service advisor made with a single button press (an OnStar call). The OnStar system also automatically places a call to an advisor notifying of an airbag deployment (an airbag call). The main objective of this study was to determine the probability of an airbag-deployment crash, given that an OnStar call was in progress. The complete OnStar database from October 1996 to May 2001 was searched for all occurrences of OnStar calls associated with airbag calls. In the total population of about eight million OnStar calls, there were eight cases of an OnStar voice conversation being followed in less than 10 minutes by an airbag call. The advisor's written comments in these eight cases indicated there were even fewer cases, likely only two, in which the phone was actually in use at the time of the crash. The comments contained no specific indications that the OnStar calls contributed to causing the crashes, but did contain indications of other possible causes, such as a driver's self-report of drowsiness. The conclusions are: (1) An embedded cell phone call with an advisor followed by airbag-deployment crash within 10 minutes is rare, occurring at a frequency of one event per million calls during the five-year period of the study; (2) An embedded cell phone in use at the time of an airbag-deployment crash is even more rare, occurring at a frequency of one event per four million calls; (3) Embedded cell phone usage uniquely causing an airbag-deployment crash occurs even more rarely.

INTRODUCTION AND OBJECTIVES

There are more than 100 million portable cellular phone owners in the United States and 73 percent of them report using their phone while driving.[1] At the same time, there has been a lack of accurate real-world scientific data to analyze cell phone use in vehicles and its relationship to crashes. Laboratory studies purporting to reach conclusions about real-world driving rarely report validating their methods or findings with on-road testing, leaving generalizations to real-world driving speculative at best. The few real-world studies to date make only statistical inferences from small samples in limited geographic regions. Also, the crash times recorded by observers at crash scenes may not be accurate or synchronized well with call times recorded by cellular telephone service providers. Therefore, it has not been possible to determine accurately which came first, the call or the crash. A random error of even a few minutes in estimating the time of a crash may overestimate the number of calls before the crash, because of misclassification of calls after the crash.[2]

The OnStar embedded cellular phone system offers a unique opportunity to gain insight into this issue. OnStar is an "embedded" cellular phone, which means the vehicle manufacturer permanently installs it in the vehicle. A single button press can place or receive a call from a service advisor (here termed an "OnStar call"). The system also generates an automatic call to an advisor for emergency notification of an airbag deployment following a crash (here termed an "airbag call"). Time-stamps are automatically placed on call events connected with each call to an advisor, for OnStar calls as well as airbag calls. These time-stamps are stored in an OnStar database. Accurately synchronized times are thus known for all OnStar and airbag calls in the database. Hence, a census of all OnStar calls and airbag crashes can be directly made without the need for statistical sampling.

Specifically, this study investigates the relationship between airbag-deployment crashes and in-vehicle calls with advisors using the OnStar embedded cellular system by comparing time-stamps for OnStar calls with time-stamps for airbag calls. There were three objectives:
1. Count the number of OnStar calls associated with an airbag call less than 10 minutes later.
2. Count the number of OnStar calls actually in progress at the time of a crash.
3. Identify possible causes of crashes that were preceded by an OnStar call.[3]

METHODS

Privacy

To ensure privacy, care was taken to omit any identification of persons involved in the cellular calls made or the people involved in the crashes.

Scope

The scope of this study was restricted to:
1. *Crashes*: Only crashes in which a frontal or side airbag deployed, and for which an airbag call was received at the service center.[4]
2. *Airbag calls.* Only those airbag calls signifying an actual airbag deployment due to a crash.[5]
3. *OnStar voice calls:* Calls between a person in the vehicle and an OnStar advisor that were manually initiated using the OnStar embedded cell phone system.[6]
4. *Vehicles*: Only GM vehicles.
5. *Time period*: October 1996 to May 2001 (the complete OnStar database in the five years from the introduction of OnStar to the time of the study).

Operation of OnStar System

OnStar is a safety, security and information service, with a three-button user interface built into the vehicle (see photo).[7] OnStar uses the Global Positioning System (GPS) satellite network and embedded cellular technology to link the vehicle and driver to one of two OnStar service centers.

OnStar and Emergency Calls. When the driver presses the OnStar button (pointed at by the finger) a cellular call is made to an OnStar service center. Pressing the emergency button (to the right of the OnStar button), places a priority call to a service center. Once the call is connected to an OnStar center, there is a data transmission that includes the account identification, the vehicle

location, and the type of call. The call is then transferred seamlessly to the first available service advisor. Once the advisor answers the call, a "start" time-stamp is recorded in the database. A microphone is embedded in the vehicle to pick up the driver's voice so the advisor can hear the driver, and the driver hears the advisor over the audio system of the vehicle. After the customer has received safety and routing assistance, the call is typically disconnected and the advisor enters text comments concerning the call. (The white-dot button to the immediate left of the OnStar button allows the driver to voluntarily disconnect the call, or answer an incoming call from the advisor.) When the advisor completes the text comments, a "comment" time-stamp is recorded. Finally, the advisor clicks on a "close" button to close the case, at which point a "close" time-stamp is recorded.

Airbag Call. In the event of a crash that deploys an airbag, there is an automatic airbag call to the service center made by the embedded OnStar hardware module in the vehicle. After the service center software identifies the incoming call as an airbag call, the call receives the highest priority for routing to an advisor. An airbag call receives the same time-stamps as an OnStar call, only they are identified as being initiated by an airbag deployment, not an OnStar or emergency button press.

Airbag Deployment During OnStar Call. The cellular phone in the embedded module in the vehicle, like most phones, cannot make two calls at once. Therefore, if an OnStar call is in progress at the time of an airbag deployment, the embedded module is programmed to maintain the OnStar call connection to allow the advisor to begin following OnStar emergency procedures as soon as possible. The airbag call is queued up by the embedded module, and is then automatically made to the service center when the OnStar call ends.

Time-stamp Data

Time-stamp Definitions. There were three types of time-stamp data for a call recorded to the nearest second in the database:

1. *"Start" time-stamp*. The start of the voice portion of a call. There can be "OnStar," "emergency" or "airbag" start time-stamps.
2. *"Comment" time-stamp*. The time the advisor pressed the "enter" key on the computer keyboard to signify the finish of typing a particular comment on a given call.
3. *"Close" time-stamp*. The time the advisor clicked on the "close" or "close all" button on the computer screen window used for displaying and entering information about a given call.

Time-stamp Benefits. Once the voice call begins, the time-stamps are identical and synchronous for events in the vehicle and events in the service center, since the voice call occurs in real time. Also, the time-stamps are automatically produced and highly accurate, so the relative times between time-stamped events can be accurately determined.

Time-stamp Limitations. Because of the inherent delays between the initiating event in the vehicle and the start of the voice call at the service center, the times of the voice call "start" time-stamps at the service center are necessarily later than the time of the key press or the crash in the vehicle. However, for the objectives of this study it is not necessary to determine the absolute start times of the prior vehicle events themselves; the relative times between the vehicle events suffice, and these are provided by the time-stamps. Also, there are no delays once the voice

portion of a call begins, so all events (and time-stamps) are then in real-time synchrony for the service center and the vehicle.

Another time-stamp limitation is that before 1998, a given workstation clock was individually synchronized to a master clock only when an advisor logged into that workstation at the beginning of a shift. In the rare combination of events that workstation clocks drifted slightly within a shift, and also an OnStar call and an airbag call happened to come into different workstations, there could be a possible error in determining which came first – the call or the crash. (But only if the OnStar and airbag calls were separated by a time interval shorter than the relative time error between the workstations.) One such discrepancy was found at short time intervals for associated OnStar and airbag calls and was resolved by analysis of the "incident number," which is a common counter for all calls into or out of the service center on all telephone trunk lines.[8] Since January 1, 1998, all workstation clocks in the OnStar service center have been continuously synchronized to Universal Time derived from the Global Positioning Satellite (GPS) system, so this limitation does not apply to time-stamps for 1998 or later in the database.

A final time-stamp limitation is that the "close" time-stamp does not correspond to the end of the voice call. Methods to control for this limitation are described below under "Controls."

Procedures

Database Methods. The study analyzed the complete OnStar database of time-stamped data in the five-year period, involving: (1) embedded cell phone calls from a GM vehicle to the OnStar center (and vice versa); (2) automatic airbag calls; (3) OnStar advisor text comments for OnStar calls near the airbag call, to better understand the nature of each call event.

Objective 1. Count all embedded cellular phone calls with any usage during the 10-minute period before an airbag call time-stamp using a database query program.[9] The database contained no other calls matching these criteria other than those presented in the Results. Also, these criteria were logically exhaustive of all possible OnStar call conditions relative to an airbag call and would therefore have found any such calls had they been present in the database.

Objective 2. A review of the advisors' text comments for the cases found in Objective 1 determined whether a call was actually in progress at the time of the crash. The comments were examined because one could not be certain from the time-stamps alone whether a person was on the phone at the time of the crash (see "Controls").

Objective 3. A review of the advisors' text comments for the cases found in Objective 1 identified possible causal factors related to the crashes and associated phone calls.[3]

Measure. The basic measure used in this study was the count of embedded cell phone calls meeting the criteria for each objective, compared to the total count of all embedded cell phone calls in the database within the scope of the study. This measure gives the frequency (probability) of a crash, given that a call was made, which is the focus of the current analysis. The data in the current study is unusual in that one can directly calculate the probability of a

crash, given that a call was made – a direct measure of risk that due to data limitations can seldom be calculated.

Controls

Time-stamps. The time-stamps for all cases with phone usage in the critical period as found by the database query program were individually validated on a case-by-case basis by direct visual inspection of the database time-stamps using an independent computer program at the service center. No discrepancies were found.

Another time-stamp validation experiment simulated OnStar and airbag calls at the service center. An experimenter wrote down the times on a clock for the various test events to a precision of one second. These events were time-stamped in the database by the same methods in the service center that are used on a daily basis for real calls. A subsequent examination of the stored time-stamps by the database query program found no discrepancies with the times experimentally recorded.

Underestimation. Certain unusual circumstances might lead to possible underestimation of the duration and counts of phone usage before a crash. For example, consider an OnStar call that had "start" and "close" time-stamps just before the 10-minute critical period before the airbag call. The voice call might have continued beyond the "close" time-stamp into the 10-minute critical period before the airbag call (although it would be extremely unlikely because of typical advisor procedures). To ensure that such a call, if it existed, would still be counted in the 10-minute critical period, a control experiment set the search interval to the 20-minute period before the airbag call (instead of only 10 minutes). All comments for calls captured in the 20-minute period were studied in detail to determine if any usage could have possibly continued into the 10-minute critical period. This control experiment confirmed that the counts as given in the Results contained all cases in the database with either actual or possible usage in the 10-minute critical period. This control experiment also found that a critical time period of 10 minutes was not important – choosing a critical period at any duration up to 20 minutes would have led to essentially the same conclusions.

Overestimation. An overestimate of the time duration (but not the counts) of OnStar phone usage before an airbag call would occur in cases where the driver was on the phone at the time of the crash. As stated earlier, the OnStar hardware module in the vehicle intentionally delays the airbag call until the OnStar call ends. Therefore if a crash happened during the OnStar call, the intentional delay would falsely add to the apparent time duration of phone usage before the crash. However, this hardware feature also guarantees that all calls in progress at the time of a crash would be correctly found and counted with the methods of this study.

A possible overestimate of both the counts and durations of embedded cell-phone usage in the critical period would occur if the voice portion of the call ended in fact before the critical time period, but the advisor closed the case within the critical time period. Such cases were still counted as being in the critical time-period, because it is possible (but not certain) that the conversation could have continued into the critical time period. It was deemed more important to accept some false positives to ensure that all possible calls were counted in the critical period. As

a result, the counts in the critical period in the Results of this paper should be regarded as "worst-case" counts. The actual counts may be lower than the counts given.

Misclassification. Control experiments ensured calls were correctly classified as pre- or post-crash.

First, all calls with "start" time-stamps in the 20-minute post-interval after the airbag call were tabulated. About 200 OnStar calls were counted in this post-interval (these were in addition to the automatic airbag calls guaranteed to be subsequent to the crash). The comment records for all putative "post-airbag" OnStar calls that had a "start" time-stamp near the airbag call were examined. All such comments referred to the crash events or emergency crash assistance by the advisor, and not to the usual benign OnStar information services.

Second, all comments with time-stamps in the 10-minute critical period before the airbag call were examined to make sure they contained no references to the crash or crash events. All such comments referred to the usual and customary assistance provided by the advisor, with no references to the crash, except in the one case that was previously noted.[8] In short, the control experiments found that the "pre" and "post" calls near the time of an airbag call had been correctly classified.

RESULTS

For the five-year study period, there were about eight million OnStar calls into or out of the vehicle that involved a voice interaction between the driver and an advisor. Calls out of the vehicle using the OnStar or emergency button accounted for 98 percent of the eight million calls, and the advisor calling into the vehicle accounted for the remaining 2 percent. In the same five-year time period, there were 1,910 actual airbag crashes in the same group of vehicles.[10]

Objective 1

There were initially nine cases found in which the time-stamps indicated that the phone could have been used near the time of an airbag crash (i.e., the OnStar call was followed within 10 minutes or less by an airbag call). An examination of the advisor comments indicated that one of these cases did not have a successful transition from the data to the voice portion of the call. Therefore, there was no interaction with a service advisor, and this call was not considered further. The final count was therefore eight cases out of eight million calls in which the phone could have been used near the time of the crash. The final frequency of association is therefore about one airbag crash per million OnStar calls with a service advisor.[11] The control experiments confirmed that all OnStar calls, all airbag calls, and all cases of association between the two had been found in the database.

Objective 2

The second objective sought to determine cases in which the phone was actually in use at the time of the crash. For reasons stated in the previous section on "Controls," it cannot be determined solely from the available time-stamp information whether the driver was actually on the phone at the time of the crash. To be certain, the advisor's written

comments were examined in all cases of association. In one case it was explicitly stated that the driver was on the phone at the time of the crash. In a second case it was also certain because a vehicle diagnostic procedure was being done at the time of the crash. In the remaining cases, no comment at any time mentioned that the driver was in a call at the time of the crash, and all comments connected with the OnStar call referred to the usual and customary assistance provided by the advisor, with no references to the crash. In short, there were two definite cases out of eight million calls in which the driver was known to be on the phone at the time of the crash. The observed frequency of association is therefore about one airbag crash per four million phone calls where the phone was known to be in use at the time of the crash.

Objective 3

The third objective was to examine possible factors that may have contributed to causing the crash, and also the call, in cases where an association was observed.[3] The two in-use cases from Objective 2 were examined first, since it is more plausible that a call in progress at the time of the crash could be a possible cause of a crash than a call that ended before the crash. In one case, the vehicle was parked off the road, and the occupant was receiving lengthy remote diagnostic services from the OnStar advisor, when the vehicle was struck by another vehicle, deploying the airbag. This case was unusual in several respects – remote diagnostic calls are rare, and the vehicle was parked at the time of both the call and the crash. Most OnStar calls are made and most crashes occur while the vehicle is moving. In this case, it is difficult to conceive how the call was a possible causative factor in the crash. In the second case, the driver called the advisor and asked the advisor to talk to him to keep him awake, as he was extremely fatigued. The vehicle went off the road while the call was in progress, and struck a stationary object. The self-report of the driver indicates that a third variable, fatigue, could have been a possible cause of both the call and the crash.

The written comments for all other cases with phone usage in the critical 10-minute period likewise contained no specific indications that the call itself contributed to causing the crash.[12] However, the comments of the cases of association did contain indications from the driver's self-report as captured by the text comments of the advisor, of other factors that could possibly cause a crash. These other factors could have also conjointly caused an increase in OnStar cell phone use, giving rise to the observed association. These other factors were:

- Fatigue (fatigue is a well-known causal factor in crashes) (three cases)
- Traveling away from home, staying overnight in hotel/motel (e.g., driver is in an unfamiliar area) (five cases)
- Completely lost, going in the wrong direction (three cases)
- Emotional, stressed (e.g., driver is stressed from personal family situation, and calls OnStar advisor to express feelings, but stress is also a possible cause of crashes) (two cases)
- Driver not owner of car, rental car (e.g., driver is not familiar with the operation of the car, which is a possible cause of a crash) (three cases)
- Late at night (nighttime increases crash risk factor almost twice over daytime[13]) (five cases)

The counts add up to more than the number of cases because most cases had more than one

possible factor. Only one case did not have at least one possible confounding factor identified in the comments, but in this case the advisor closed the case window more than five minutes before the airbag call, suggesting at best a tenuous possible causation of the crash event by the OnStar call.

In short, the frequency of an OnStar call uniquely causing an airbag crash approaches zero airbag crashes per eight million embedded cell phone calls.

DISCUSSION

Eight cases out of eight million calls were found in which there was any possible usage of an embedded cell phone in the 10 minutes before an airbag crash. These results indicate an association between embedded cell phone use and an airbag crash at a frequency of one crash per million calls.

However, an association between two variables does not indicate that one causes the other (both could be caused by a third factor, for example).[3] In fact, there was no evidence in the advisor comments that the observed association between embedded cell phone use and the crash in the eight cases could be attributed to a causation effect of the OnStar voice call. Indeed, in only two of the eight cases of association were the drivers even on a call at the time of the crash. In one of those two in-use cases the vehicle was parked and was struck by another vehicle. If the observed association was not due to the OnStar voice call causing the crash, then what could it have been due to? The observed association can be explained if there were other factors that could cause a change in the probability of an embedded cell phone call, and also a change in the probability of a crash. Indeed, there was evidence of a number of such confounding factors that could have contributed to the crash, as well as to the embedded cell phone usage.

Some may assume that OnStar users are older, better educated, or more financially well off than the population of cell phone users in general. The privacy considerations did not give access to this level of detail in the demographics, nor was it part of the scope of the study. However, it is public information that at the time of this study, that OnStar was active on about 1.2 million vehicles, which included 34 of GM's 54 models. These include all brands (from less expensive to more expensive), and all types of vehicles -- trucks, mini-vans, sport utilities, cars, etc.

Limitations of Study

The information as to whether the vehicle was moving or stationary at the time of a call or a crash was not always available for the data examined in this study. However, a survey of service advisors found that greater than 70 percent of the calls within the scope of this study came from vehicles that were moving.[14] Yet even if all the vehicles were stationary at the time of a call or a crash, the conclusions of this study still stand. This study is a census of all OnStar calls and airbag crashes, so it necessarily takes into account the calling and driving patterns of the entire OnStar population during those calls and crashes. For example, the conclusion that an airbag-deployment crash is rare, given that an OnStar call is in progress, is true regardless of whether the vehicle was stationary or not during all or none of the eight million calls and 1,910 crashes.[15]

This study looked at airbag-deployment crashes, not all crashes.[4] There certainly are non-airbag crashes that have occurred that are not recorded in the database. The scope of this study only included airbag crashes, which typically involve a moderate to severe crash with a higher likelihood of personal injury. The conclusions are therefore necessarily limited only to airbag crash cases.

Comparison to Portable Cell Phones

The data in the current study is based on a census of tens of thousands of vehicles and millions of calls. There are no statistical projections or resulting sampling errors in the data; the confidence intervals on the results are all zero (no errors). The procedures counted the entire population of calls and crashes within the scope of the study. The current study also covers a large geographic region (the United States and Canada) in on-road real-world usage conditions. Studies of other types of cell phone devices often involve limited geographic regions, or are laboratory studies with no reported on-road validation of the methods or results.

It is intrinsically clear that the OnStar embedded cell phone system has substantially different human factors properties than a portable cell phone. It requires only one button press to make a call, unlike a portable cell phone, which can require multiple key presses to make a call. Also, the buttons are permanently mounted in one place in the vehicle, so searching for the phone to make or answer a call is not required. It is a hands-free system in that the driver does not have to hold the OnStar phone to converse with the advisor, because the microphone is built into the vehicle and the sound goes through the audio system of the vehicle. It is also a three-watt phone, with an antenna on the roof, so the signal strength is more than three times greater than that of a portable phone, leading to clearer speech, a wider range of geographic access, and fewer dropped calls than with a portable cell phone. The OnStar calls in this study were always with a professional advisor. Also, most OnStar calls are likely longer in duration than portable cell phone calls, since they involve asking for directions, or information about points-of-interest such as restaurants. OnStar calls are always made from a vehicle, most commonly while moving.

Possible Future Work

Some questions about other possible sources of driver distraction are left to future work. For example: (1) How do the absolute observed frequencies of embedded cell phone calls and crashes in this study compare to the estimated statistical frequencies for portable cell phone calls and crashes? (2) How do the absolute OnStar population crash and call risk rates relate to the crash and risk rates found in statistical studies using other units of measure? (3) Is the frequency at which OnStar calls are associated with crashes substantially and significantly less than would be expected compared to other possible sources of driver distraction?

The results presented here are absolute counts of all OnStar calls and airbag crashes for actual on-road usage and driving practices, and therefore the following conclusions can be made about the absolute risk of using OnStar, with no statistical error or confidence limits:

CONCLUSIONS

1. An embedded cell phone call with an advisor associated with an airbag-deployment crash any time in the following 10 minutes is rare, occurring at a frequency of one crash per million calls during the five-year period of the study.
2. An embedded cell phone in use at the time of an airbag-deployment crash is even more rare, occurring at a frequency of one crash per four million calls.
3. Embedded cell phone usage uniquely causing an airbag-deployment crash occurs even more rarely.

ACKNOWLEDGMENTS

I appreciate the technical reviews by Tom Dingus, Walt Dorfstatter, Scott Geisler, M. Laurentius Marais, W. Weston Meyer, Chris Schreiner and William E. Wecker; and the editorial reviews by Kelly Kolhagen and Brian Repa. I appreciate the technical support from Linda Angell, William Ball, Rich Deering, George Economos, Deborah Frakes, Norm Fugate, Renee Gallop, Diane Gibbons, Chet Huber, Lucy Lahood, Joseph P. Lavelle, Carolyn Markey, Mike Merrick, Joe Pillera, Jeff Robinson, Susan A. Schneider, the GM Driver Interface Technical Forum, and the GM SenseAble driving team. Finally I thank Daniel McGehee and the Driving Assessment 2001 Conference team for their co-operation.

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[1] Dennis Utter, "Passenger Vehicle Driver Cell Phone Use Results for the Fall 2000 National Occupant Protection Use Survey," Research Note DOT HS 809293, July 2001, U. S. Department of Transportation, National Highway Traffic Safety Administration.

[2] If there are more calls in the post-crash time period than in the pre-crash time period, then any random error in the estimate of the crash time would lead to more post-calls being falsely counted in the pre-crash time period than pre-calls would be falsely counted in the post-crash time period, biasing the results into overestimating the number of calls before the crash.

[3] Finding an association between cell phone usage and crashes (Objective 1) is not the same as finding causation between cell phone usage and crashes (Objective 3). An association between cell phone usage and crashes will be observed if one or more of the following are true: (a) Cell phone usage causes crashes; (b) crashes cause cell phone usage; and/or (c) one or more other variables cause both crashes and cell phone usage. It is evident that (b) is true for calls in the post-crash period, since a crash gives rise to a large number of drivers using their cell phones to call for emergency assistance. Any error in the time estimate of the crash or calling events could lead (b) to be falsely construed as (a), leading to a spurious conclusion that cell phone usage causes crashes. Determining the correct causal basis underlying an association has practical importance, because for example if (b) or (c) is the causal relation and not (a), then eliminating all cell phone usage would have no effect on crashes, even if there were a strong observed association.

[4] Crashes outside the scope of the study were: impacts in vehicles without OnStar; rear impacts; impacts below the airbag-deployment threshold; side impacts in vehicles without side-impact airbags; impacts of so severe a nature as to have made the OnStar module inoperable, or that terminated battery power to it; impacts outside the coverage area of an analog cellular phone network; impacts when a vehicle is driven after a false airbag call or a crash with a deployed airbag, without a reset of the airbag notification feature.

[5] Some airbag calls in the database did not signify actual airbag deployments, but generally involved tests that were conducted to validate the OnStar system. To exclude such airbag calls from the scope of the study, I asked that a person not aware of the study or its intent classify each airbag call based solely on the comments that a service advisor wrote after an airbag call was received. No information was provided as to the OnStar calls that may or may not have been present in the account. Airbag calls were grouped into one of the following categories: *Production* (actual airbag deployment because of a crash); *Unconfigured /Invalid Account* (vehicle not configured for OnStar); *Test* (comments or account name contained the words "test" or "testing"); *Tech Deploy* (airbag deployed, but no crash -- often occurred while servicing); *False Deploy* (false alarm -- notification was received but airbag had not deployed); *Multiple* (subsequent airbag calls on the same day and vehicle). The multiple airbag calls generally occurred in tests conducted to validate the OnStar system. However, in a few instances there were multiple airbag calls occurring the same day after an actual crash. The OnStar hardware in the vehicle is programmed to keep trying airbag calls to ensure that an airbag call is completed, in the event of a dropped call. In such a situation, only the first airbag call was placed within the scope of the study, and only when it was an actual airbag deployment because of a crash. As a control, a second person with experience in evaluating crash reports (again without knowledge of the OnStar calls) re-examined all the non-production airbag comments to ensure that all actual airbag crashes had indeed been found and correctly classified. A few airbag events initially

labeled "*?*" or "*No Information*," were successfully reclassified into one of the categories labeled above. Two deployments in the "*Unconfigured*" category contained two actual deployments and they were moved into the production category, but they had no OnStar calls associated with them. All other airbag crashes examined were correctly placed into the categories identified above. There were no other changes or differences in the results of this study after this second examination, so there was a high degree of confidence that all actual airbag deployments in the database due to a crash had indeed been found.

[6] Calls outside the scope of the study were: *Portable* cell phone; *Personal Calling* (personal calls to the general public); *Virtual Advisor* (calls to a computer voice-recognition system rather than a human advisor); *Landline* (these were calls into the service center from third parties not in the vehicle, or calls from the service center to locations outside the vehicle); *Theft Notification* and *Theft Reset* from vehicles equipped with theft-detection features (these calls are automatically initiated and not apparent to the driver); *Test/Development (*emergency button test, OnStar internal test); *No Data Available* (collision sensor, empty/unknown, failed to voice). Only 0.2 percent of calls fell into the last category of "No Data Available." "Personal Calling" and "Virtual Advisor" services were newly introduced in a limited geographic region only shortly before this study commenced.

[7] The first version of the OnStar system had the OnStar and emergency buttons built into the faceplate of a custom cell phone that was embedded in the center console area. Later OnStar systems have the three-button interface shown in the photograph, which is placed in the rear-view mirror, in the dashboard, or in the headliner of the vehicle. The OnStar hardware module itself is separate from the buttons, and is typically embedded in the trunk of the vehicle.

[8] The discrepancy in this pre-1998 case was that the "start" time-stamp of an OnStar call on one workstation was slightly before the "start" time-stamp of the airbag call on a second workstation, but the advisor comments for the call on the first workstation stated that the advisor on the second workstation already "had received airbag deployment." The incident counter showed that the OnStar call on the first workstation actually came three calls subsequent to the airbag call on the second workstation, which was consistent with the text comments. This particular OnStar call was therefore counted as occurring after and not before the airbag call. Possible time-stamp synchronization discrepancies were looked for, but not found, in any other case in this study.

[9] The "critical period" was defined as starting at a time of 10 minutes before, and ending at, the "start" time-stamp of the airbag call. The database query program counted an OnStar call as being in the critical period if any of the following criteria were true: (1) the call had a "close" time-stamp in the critical period; or (2) the call had a "start" time-stamp in the critical period; or (3) the call had a "start" time-stamp before the critical period, and a "close" time-stamp after the critical period, and the duration between the "start" and "close" time-stamp was less than 24 hours. (Note that a duration time limit had to be set, because otherwise the query program would have repeatedly searched all time-stamps in each subscriber account, attempting to match up "start" and "close" time-stamps, even for time-stamps weeks, months or even years away from the airbag call time-stamp. This search condition leads to an exponential time complexity and an intractable computational problem. It is unlikely that an OnStar call could last longer than 24 hours; so setting a call time duration limit of 24 hours would not have excluded any plausible cases of association.)

[10] The number of OnStar-equipped vehicles with an active subscriber in October 1996 was 258, which then grew approximately exponentially on a month-by-month basis until the time of the study in May 2001 to about 1.2 million vehicles. The average number of active OnStar-equipped vehicles per month during the 55-month study period was calculated to be about 167,000 by summing the number of vehicles in each month across the 55 months, and then dividing by 55.

[11] The count of eight cases may be an overestimate, since three cases did not have a "start" time-stamp in the critical ten-minute interval, but only a "close" time-stamp (see paragraph labeled "Overestimation" in the Controls section of the Methods).

[12] A lack of evidence to the contrary does not exclude the possibility that the call was still a contributing factor to the crash. That is, the absence of information about the truth of a statement does not indicate its converse is true – it could simply mean the right information was not asked, collected or analyzed. However, it is difficult to conceive how the calls could have been much of a contributing factor, since the results for Objective 2 found only two definite cases of the phone being in use at the time of the crash, and in one of those cases the car was parked.

[13] Ezio C. Cerreli, "Fatal Crash Involvements, What Are the Odds?" Research Note, NHTSA, July 1997 (see http://www.nhtsa.dot.gove/people/ncsa).

[14] The information as to whether the vehicle is moving is indicated to an advisor at the start of a voice call by a direction arrow at the vehicle's location on a map on the advisor's workstation screen. Also, an advisor often asks the driver if they can update the GPS location of the vehicle during an OnStar call, and it is obvious to the advisor from the map display that the vehicle has moved considerably during the call. A survey was conducted of 11 service advisors. Each advisor provided his/her length of service and was asked to provide their estimate as to the percentage of calls from a vehicle that occur while that vehicle is in motion. The responses were weighted based upon the service time of each advisor. The range of service time was between three weeks and 2.5 years. The final weighted average was 72.8 percent. The unweighted average was 70.7 percent.

[15] To control for driving, multiply the eight million calls by the 70 percent driving figure above, leaving 5.6 million OnStar calls made while driving. Likewise, do not count crashes that occurred while not driving, leaving seven cases of association instead of eight in this study. The frequencies adjusted for driving are therefore estimated at one airbag crash per 800 thousand calls (where the phone was used near the time of the crash) and one airbag crash per 5.6 million calls (where the phone was in use at the time of the crash.