Shell Seat
Predictive Safety System
for
Delphi Automotive PLC

Engineering Design 100, Section 025, Dr. Sarah Ritter (scr15@psu.edu) - December 2014

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Stage 1 – Outer layer [head restraint + body portion]  
Stage 2 – Conforming layer [material approaching body]  

Velcro
Executive summary or Abstract:

With 2.5 million Americans receiving emergency treatment in 2012 and $80 billion lost in 2010 because of car accidents, our nation, and really the whole world, needs a safer driving experience [4]. Diverging from the recent surge of efforts to address the issue by developing technologies to reduce the frequency of crashes, Shell Seat offers Delphi a theoretically simple, potentially game-changing solution that minimizes injury when accidents happen. By activating in the seconds before a crash, it more effectively controls the displacement of the passenger and will, in theory, reduce death and serious injury from crashes.

Introduction and Problem Statement:

In an ideal world, people would not die or walk away disfigured from vehicle collisions. Unfortunately, with a single momentary lapse in judgement, drivers on the roads of today can have their lives irreparably changed, or even taken from them. The problem is close to home for some of us, which is unsurprising given that, solely among teens in 2011, there was an average of 7 deaths per day from vehicle injuries [4]. Car customers need something to reduce either the incidence of these crashes or the injuries and deaths that result from them. Since so many efforts lately have focused on the prior, our goal was to generate a technology that would reduce serious injury in the most dangerous of crash scenarios by at least 10% (and hopefully more). We aimed to achieve this goal by acting preemptively to control passengers’ movement more effectively, and our various concepts of quickly surrounding an occupant produced the moniker of “Shell Seat.”

Background:

Even with crash avoidance systems implemented in recent years and the presence of modern airbags, car crashes remain a deadly problem, as the previously mentioned figures (reported by the CDC) indicate. To begin developing a solution, our group began by analyzing the weaknesses of present injury-mitigation methods. According to brain trauma research done by Drexel and Saint Joseph’s University in the late 90s, passengers with smaller, more regular displacements (movement during a crash) are less likely to sustain serious injury [1]. This begs the question of how well seat belts and airbags produce these conditions.

The same study mentioned that, for passengers restrained by seat belts, the average displacement during a 35 mph frontal collision is 56 cm for the head, 40 cm for the pelvis, and 30 cm for the chest area - that’s almost half a meter. The research makes the case that, since seatbelts change, but do not stop, motion in a crash, they end up changing, but not removing or necessarily lessening, injuries to the brain. The takeaway, once again, is that the more we control motion in a crash, the less chance the body has to place stress unevenly on vulnerable components (undergo serious injury). It therefore became a primary goal of our system to deploy before displacement occurs, and to distribute and disperse force evenly to the passenger during deceleration.
There are other cases in which performance by airbags is weak. For one thing, particularly short persons and children have been known to be injured by the bags due to the nature of deploying to oppose predicted forward motion of a head and torso. These injuries can be mediated by Occupant Classification Systems, however this sometimes leaves passengers with only belt restraints in the case of a crash [6]. Additionally, airbags are only fully effective when drivers are wearing their seatbelts, and while the majority of the population has a high rate of seatbelt use, one demographic in particular - teenagers, again - has the unfortunate combination of lowest usage rate and highest incidence of collisions, leading, unsurprisingly, to a disproportionate percentage of the total vehicle fatalities for a group of drivers of their size [4, 5]. In both of these cases, a preemptive deployment that surrounds and controls as opposed to impeding the occupant during motion offers additional advantages.

The actual shell seat design was inspired by Hövding, an inflatable bicycle helmet that is worn as a scarf - designed in Sweden, it was part of a master’s thesis by Anna Haupt and Terese Alstin at the University of Lund [2]. When the helmet is activated, it deploys a contoured airbag around the cyclist’s head to shield the head itself and to prevent neck injury by stopping head movement, specifically. We saw an in-car system that could similarly isolate a person’s body to control movement. Hövding is patented, but the risk of infringement is probably less for that technology than for existing airbag systems, since their patent specifies clearly the isolation of the head by wearable clothing [7].

In order to deploy before an occupant’s motion begins, the Shell Seat cannot rely solely on traditional means (accelerometer-style systems) of detecting an impact. It must therefore make use of a sensor array, ideally of the kind implemented in some recent model-year cars. While such systems operate with the goal of preventing crashes, they cannot always be completely effective. Lane Departure systems, for instance, are relatively ineffective [8]. However, without removing these systems, Shell Seat’s ECU could simply receive position data on its surroundings (particularly from radar-based features) such that it would deploy when an object was on an unavoidable collision course with the vehicle. So in addition to trying to warn drivers drifting out of a lane, the car would recognize when a resultant catastrophe was imminent and activate an appropriate safety system.

There are a variety of types of sensors to consider; radar sensors seem to be the most reliable (optical systems like Subaru’s EyeSight suffer in inclement weather [9] ) and suit the purpose of collecting position data fairly well. Delphi’s radar sensors, for example, have an abundant range and use two simultaneous measurement modes to collect data on up to 64 incoming targets from the front [10]. While Delphi could sell their own sensors with the system, some car companies might have different suppliers for their radar modules, and there is no reason the system could not be made compatible with those sensors as well.
Customer Needs:

Table 1. This matrix shows the criteria used to determine how important each feature is with respect to the others, and gives an overall weight.

<table>
<thead>
<tr>
<th></th>
<th>Durability</th>
<th>Damage Prevention</th>
<th>Convenience</th>
<th>Activation Speed</th>
<th>Ergonomics</th>
<th>Cost</th>
<th>Total</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durability</td>
<td>1.00</td>
<td>0.33</td>
<td>0.50</td>
<td>0.66</td>
<td>0.50</td>
<td>2.00</td>
<td>5.00</td>
<td>0.12</td>
</tr>
<tr>
<td>Damage Prevention</td>
<td>3.00</td>
<td>1.00</td>
<td>2.00</td>
<td>0.66</td>
<td>2.00</td>
<td>3.00</td>
<td>11.66</td>
<td>0.27</td>
</tr>
<tr>
<td>Convenience</td>
<td>2.00</td>
<td>0.50</td>
<td>1.00</td>
<td>1.50</td>
<td>1.00</td>
<td>2.00</td>
<td>8.00</td>
<td>0.18</td>
</tr>
<tr>
<td>Activation Speed</td>
<td>1.50</td>
<td>1.50</td>
<td>0.66</td>
<td>1.00</td>
<td>1.50</td>
<td>2.00</td>
<td>8.16</td>
<td>0.19</td>
</tr>
<tr>
<td>Ergonomics</td>
<td>2.00</td>
<td>0.50</td>
<td>1.00</td>
<td>0.66</td>
<td>1.00</td>
<td>2.00</td>
<td>7.16</td>
<td>0.17</td>
</tr>
<tr>
<td>Cost</td>
<td>0.50</td>
<td>0.33</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>1.00</td>
<td>3.33</td>
<td>0.08</td>
</tr>
<tr>
<td>Grand Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>43.31</td>
<td></td>
</tr>
</tbody>
</table>

During the design process, we rendered our customer needs down into a few metrics and identified criteria for the design to meet based on these metrics. The first of these to appear in table 1, our AHP matrix, is durability, specifically in reference to the product's inactive lifespan. Our metric states that if our materials were to differ radically from those already used for deployment (especially in the case of compressed fluids), they would need to have longevity greater than or equal to existing systems, not to mention the vehicle itself. The second criteria, damage prevention, is actually of cardinal importance - since the purpose of the Shell Seat is to better protect passengers from injury, it follows that damage prevention should factor in most heavily on our definition of success. Our metric for success in this category was that the system allow, at minimum, 10% fewer injuries on activation than the current seat belt and airbag combination. Third on our list is convenience, which we considered to be very important since a safety mechanism is only effective if people are willing to use it (or even put it in their vehicle). The standard was whether or not 7 out of 10 of people would be comfortable with having shell seats in their car. Compared to data from our region, this would be roughly 15% lower than the fraction of people willing to make the comparatively innocuous decision to wear a seatbelt [3]. Activation speed ties in closely with damage prevention, although there is some wiggle room. Deployment must only be fast enough to permit definitive detection of impending crash, although faster is better. In terms of ergonomics, Shell Seat should be able to be installed in the seats of most reasonably sized vehicles. Finally, the cost should be no more than 5% more expensive than standard airbags.

In summary, damage prevention was weighted the highest, followed by convenience and activation speed. The main purpose of airbags is safety, so it makes sense that damage prevention is weighted the highest. Activation speed, convenience and ergonomics are secondary requirements that ultimately permit damage prevention, they were weighted in the middle. The requirements ranking lowest were durability and cost.
Concept Generation:

**Figure 1.** The diagram shows the different design concepts we considered for Shell Seat. In approaching the three component problems, we considered different available sensory systems, potential deployment methods, and solutions for associated safety problems.

Our design classification tree begins with the main goal we are seeking to accomplish with the Shell Seat, which is to protect people. There are three main factors that must be considered in order for the shell seat to function properly. The first is activation and perception, which is how the vehicle will detect an impending crash. The second is how the actual shell seat is deployed and finally the last is safety factors that need to be accounted for because of variation in cars the and the passengers in it. For crash detection, we considered using either detection systems already implemented in higher-end recent model year cars can be used, or new detection systems that could be implemented, such as Delphi’s ESR. For the actual launching of the shell seat, there were four designs that were proposed. Our original design involved a seat that would actually retract into the floor of the vehicle to stabilize occupants, and from there we explored options (like the telescoping sheet design) that
changed the shape of the seat itself. The final set of designs, including the one that was implemented, involved launching any protective “shell” from the seat. As the Design Selection Matrix will illustrate, we felt a body-conforming airbag would do this most reliably. The third category considered different approaches to the issue of safely launching regardless of passenger size and shape variance. The options we considered were a hinged launch, in which a structure would activate and then enclose over the front, and a multi-stage launch, in which an initial stage would surround passengers with a very generous space tolerance, and a second stage of different properties would deploy to close that distance safely. Our final design incorporates OCS technology to further reduce safety hazards in activation.

Concept Selection:

Table 2. This table, a Design Selection Matrix, shows our decision process in determining which design to pursue. It has ranks for the presumed viability of each design by criteria.

<table>
<thead>
<tr>
<th>Feature/Requirement (weight)</th>
<th>Durability (0.12)</th>
<th>Damage Prevention (0.21)</th>
<th>Convenience (0.18)</th>
<th>Activation Speed (0.19)</th>
<th>Ergonomics (0.17)</th>
<th>Cost (0.08)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telescoping sheets</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>2.88</td>
</tr>
<tr>
<td>Body-conforming shapes bags</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3.78</td>
</tr>
<tr>
<td>Descending harness</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3.69</td>
</tr>
</tbody>
</table>

Using a more rigid style of protection, namely a telescoping structure, seemed reliable to start with, but upon consideration appeared expensive, inconvenient, and difficult to place in a car (would also likely make it hard to account for people with different body sizes). The descending harness concept showed promise in that it would not constrict the body, complicating disengagement (high convenience), but the actual deployment of such a system seemed potentially unreliable, as it required a high degree of launch precision and might even require on-board sensing to acquire targets. Not to mention, the potential for limb movement allowed for injury (low safety). The concept for shaped bags launching over the body definitely involved the most bag material (low convenience), but was deemed the best solution overall for its perceived reliability and flexibility. It would allow the use of the multi-stage deployment method, deemed the best for ensuring protection of different body shapes & positions.

We did address the advantages that the other two structures initially held over our selected approach. By launching a more rigid outer stage first, we gained the immediate protection of the sheet method without consuming physical space in the car. To address the problem of constraining the arms, we designated that the bags would launch from above the arm-rest hinges, meaning that as they come forward they will only cover the upper arm. The bags are contoured such that they extend downward as they progress, but only after rolling forward sufficiently that arms on a steering wheel will not interfere with their union in the front.
Figure 2. This systems diagram shows the result of Shell Seat determining that the vehicle is in a given situation, and the kind of data from which it makes that determination.

Our system, summarized in figure 2 above, provides safety by intervening before the body begins moving, combining new and existing sensory infrastructure with the Shell Seat restraint. As with traditional airbags, the system only deploys when an individual (and not a car-seat or baby-seat) is in the seat, based on input from an Occupant Classification System, detailed in figure 3 below.

Figure 3. This representation shows the major components of an occupant classification system, presently used to prevent damaging airbag activation [6].

Delphi produces some OCSs, and the only thing that would have to be tweaked is the logic in the associated Electrical Control Unit (no activation control for underweight passengers, new control to stop activation if weight is concentrated too far to one side) [6]. Shell Seat predicts impacts based on input from a radar sensor, whether Delphi’s own or any
of various existing systems [10, 8]. The operation of these existing sensory arrays would not be impeded, merely their data shared with a new system (in fact, the sensing ability of nearly all systems exceeds Shell Seat’s requirements in terms of effective range). It activates with two successive inflations, which, based on the rate at which current airbags inflate, should take around a tenth of a second - see the appendix [13]. The accelerometer is used to activate a mid-crash re-inflation in a subsequent major impact, or to activate in the case of a side-impact that escaped prediction (this assumes that side airbags were removed when Shell Seat was installed). These side-impacts, which are harder to predict with most sensors, can still be protected against by a later activation, since the yet-unconnected sides act like curtain airbags.

As a footnote, it may not be possible to predict a roll in time to activate our system in advance, but if it were (if sensors could be programmed to sense change in angle of horizon / local ground, or if weight-distribution sensors could predict an impending overbalance), our restraint system would be uniquely prepared to protect passengers in a roll.

Process Model:

![Figure 4](image)

**Figure 4.** This illustration shows the Shell Seat progressing outward from where it is installed in the seat itself; containers on each side hold the bags and their three banks of gas-forming reactive material, and from these containers come the first stage (with purple head-section and blue body-section) which contains the second stage (pictured, aside, in red).
Our final design, whose operation is represented by figure 4, lies initially in two encasements, one on each side of the seat. It will be positioned above the hinge of the armrest so that it can extend forward beside the upper arm and interfere as little as possible with the lower arm.

The first stage of the design, the outer shell, really has two sections, and they are pictured in different colors. The main body, in blue, is for the torso. Its goal is to surround a body with a large tolerance of space, into which the second stage will eventually deploy. Pictured in purple, the section responsible for limiting head movement has oval-shaped cross sections that decrease in size as they progress forward to avoid hitting the face directly and causing concussions. Each bag will meet its counterpart in the center after fully inflating, which should take roughly .03 seconds [13]. Orange strips indicate the presence of velcro.

Upon complete inflation of the first stage, the air will begin to enter the second (which is in red) through a semipermeable membrane - the speed of this process is limited by the membrane, in conjunction with a few small holes on the outside of the first stage; with the initial .03 seconds, this process pushes the activation time to at least .10 seconds. This part of the bag converges on the occupant, creating a body-conforming airbag that maximizes protection without crushing them with the force of the first inflation. To avoid over-inflating and allow escape, this portion has additional air holes on the bottom that supplement the main body’s smaller number of holes, from which the gas can escape during compression. The holes are angled so that the hot gas that escapes won’t burn the occupant.

All stages are inflated with nitrogen gas which comes from the reaction NaN3 (sodium azide) and KNO3 (potassium nitrate); the first reaction will produce the full stage 1 volume, while the second will produce slightly more than enough for the second stage, based on the flow rate of gas exiting through the regulatory holes during inflation. The third stage would produce a smaller amount of gas with the goal of quickly re-buffing the barrier to provide additional padding in a second impact.
Concept of Operations (Scenarios):

Table 3. This list of scenarios details the response by Shell Seat in different circumstances, and shows the distances at which data become grounds for definitive prediction.

<table>
<thead>
<tr>
<th>Deployment</th>
<th>Side Impact</th>
<th>Crash-Related</th>
<th>Speed-Induced</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Straightforward Cases</strong>&lt;br&gt; (garage wall, oncoming car)</td>
<td>1st stage inflates via accelerometer &amp; as fast as conventional side bag</td>
<td>Sensors react to crash &amp; are thus prepared for flip</td>
<td>May be predicted, as horizon shifts or weight distribution changes</td>
</tr>
<tr>
<td><strong>Detection-escaped case</strong>&lt;br&gt; (T-bone goes undetected somehow)</td>
<td>1.46</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Flip</strong>&lt;br&gt; (Car sideways / capsized)</td>
<td>9.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mph, ft from obj.</td>
<td>10</td>
<td>65</td>
<td>105</td>
</tr>
<tr>
<td>(G-minute mile running pace)</td>
<td>(highway speed)</td>
<td>(inevitable speed)</td>
<td></td>
</tr>
<tr>
<td><strong>Any other Impact</strong>&lt;br&gt; At this point, if detection was fail-prone, you’d want to rely on conventional bags</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Thanks to our reasonably fast activation time, the detection system does not have to be hypersensitive, as displayed in table 3. An object would need to be approaching at well over a hundred miles an hour to force the ECU to consider incoming radar data for its position from more than fifteen feet out - if it was, indeed, determined that the distance of an approaching object was 0.1 times its speed, in feet per second, away from the vehicle, then the sensor ECU would send a signal to components in the reactant bank that would ignite the first two stages in .03 second intervals starting from the moment the signal was sent. At highway speeds, the system would activate for a large, directly approaching object within ten feet of you. At a human jogging pace (a bit fast, to be pulling into a garage), the car would only pull the trigger on something coming at you from a foot and a half away. Since the system is not hypersensitive, it has a low risk of activating when not required.

If the radar sensors fail to track an incoming object, the Shell Seat ECU also has data from traditional impact-sensing accelerometers to work with. If a car did not already have curtain airbags, an unpredicted impact would cause the first stage to inflate, which it can do as fast as a conventional bag, and the person’s sideward motion would be slowed as normal. However, if there was really any significant potential for objects to go undetected (as would be determined in testing), it would be better to install the Shell Seat as a supplement to traditional airbags, particularly since the air escape and compression properties are not designed with this kind of activation in mind.

This goes beyond the scope of our initial intentions, but to account for flips, the Shell Seat ECU could additionally receive information from tire-pressure indicators or a modeled horizon based on radar data to activate when a flip became inevitable, depending on the
degree of prediction offered by such systems. Unfortunately, such data would be difficult to include in this report. For now, we can guarantee that if the flip was caused by a crash, the Shell Seat would indeed deploy, and in that case the Shell Seat offers significant safety advantages, since the occupant is prevented from landing on their head. They would stay in their seat until deflation was complete.

After any collision, baseline tests would have to be run to ensure that all sensors were acting properly and that any activated components were replaced. One potential method would be to temporarily re-route data from the sensors to an external record and place the car in scenarios in which objects were approaching it at ordinarily critical speeds.

Cost and Feasibility Analysis:

According to our cost analysis, if Shell Seat were to be sold as one single unit, then the cost to the user would be approximately $301.32, which includes the woven nylon fabric, the steel canister, the sodium azide and its oxidizer, and the crash sensor, all placed within the user’s seat [16]. This price is comfortably within the average cost for one standard airbag, which ranges in price from $200 to $500, thus allowing us to target a broader spectrum of customers [15]. The materials used to make the shell seat are exactly the same as materials used in standard air bags. The only real difference is that more quantities are used, such as the woven nylon fabric, sodium azide and its oxidizer, which would ensure that the shell seat inflates properly and effectively. As for Feasibility, the shell seat can surely replace the standard airbag, since most of the concepts of the airbag are integrated into our design for the shell seat. The only difference would be the sowing of the fabric, which would include the membrane within the shell seat that ensures the adjustment to any body type on the seat.

Life Cycle Analysis:

We decided to break our LCA component of the final report into four sub-categories that would touch on the key events that would potentially occur with our design. First, we have the gathering of materials. All of the materials that are used for a standard airbag are incorporated into our design with a few tweaks plugged into it. These materials are for the most part common, cheap, and easy to handle, and since traditional airbags already use them their acquisition is not a significant change [16]. Next is the production line. Since the materials for an airbag are manually put together, the production line will change in terms of where and how the materials will be placed in the car. Aside from that, since we incorporated larger quantities of it, workers on the production line will need to take extra precaution when placing the sodium azide in to the canister. Sodium azide can turn into a non-scented poison gas if not handled properly [14]. (Note: sodium azide has been a standard chemical used for its rapid inflation reaction for years). After that we have the Shell Seat’s lifetime, and the big question is, how long can the shell seat survive without the use of it. Well, the answer is quite simple, they last just as long as any other standard airbag, which last as long as the lifetime of the car itself. It would be fully functional for a very long time. And finally, the Shell Seat’s post-lifetime. This basically would incorporate the possibility of a buyback program, which
would allow companies to reuse materials used to make the Shell Seat. Thus allowing for minimizing our design’s carbon footprint, and maximizing in efficiency of gathering materials for a newer model.

**Conclusions:**

The Shell Seat has the potential to further protect people in dangerous crash situations by controlling their movement more effectively. However, without testing the involved Radar sensors specifically under the tolerances required by our system, we can’t be sure of its catch rate for crashes. There is the potential that this catch rate could be insufficient to be the sole system for all seats in vehicles, but in that case the Shell Seat would still be viable as a supplement to standard airbag arrays (which would increase its environmental and cost impact somewhat).

In working on this project, our team learned a few things about developing new technological solutions to the world’s problems. On a positive note, we learned that you can’t be afraid to follow a design concept through, regardless of your initial doubts. Our methods of retracting a seat into a car were probably never going to be viable, but that didn’t stop us from improving the design to actualize the same function. On the negative side, we learned that you can’t do anything about how available information is. You have to get good at looking for it. We struggled to find detailed information about different sensory systems in cars, for example, and that information has to be out there since past projects have dealt with that specifically. Probably the most important lesson is to keep improving. Our physical concept continued to evolve as we determined more aspects of the problem to take into consideration. This is why engineering design is an iterative process - in industry, this here would not be the end. It would only be the beginning.

**References:**

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5. NHTSA comprehensive data & trends (older data but fully-compiled)


7. Global Patent Index (Hövding originated in Europe)


10. Delphi Electronically Scanning Radar - Company PDF
http://www.delphi.com/docs/default-source/old-delphi-files/b87cda8b-468d-4f8e-a7a8-836c370fc2c2-pdf.pdf?sfvrsn=0

11. TechRadar on D ESR

12. Birdsong, C, Ph.D. et. all. Test Methods and Results for Sensors in a Pre-Crash Detection System. California Polytechnic State University, Paper Number 06AE-19

13. Takata (airbag producer) website; page specifically contains passenger airbag details

14. Health precautions on sodium azide
http://www.cdc.gov/niosh/ershdb/EmergencyResponseCard_29750027.html

15. Info on Cost and estimates of materials

16. descriptions of gathered materials and production line
Appendices

Calculations and Assumptions:

Predict/Deploy Interval
Since Shell Seat deploys using the same sodium azide potassium nitrate reaction that inflates conventional airbags, the window it would require for inflation (between detection and the crash) can be determined by evaluating the gas volume produced by present systems. Our assumptions were based on data provided by Takata, a somewhat notorious airbag producer, but the only we could name offhand. Based on information available on their site, we determined that the volume required for each of Shell Seat’s two initial stages could be supplied by two successive .03 to .05 second inflations, although our system intentionally reduces the speed of the second for safety [13]. Therefore we defined the interval necessary for definitive crash prediction to be one tenth of a second, in which all of the first and most of the second inflation would be complete.

Operational Scenarios
The distances in the provided scenarios were obtained by taking the feet per second equivalent of a given approach speed and multiplying it by the number of seconds required for the system to activate - in other words, dividing it by ten after converting mph to ft/s. In the sections where human displacement was relevant, max displacement was calculated simply by extending the speed at which they were already traveling, with the car, in feet per second, over the given time interval given that the car had stopped moving from or started moving at that speed as a result of the crash.