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Preliminary Cost-Benefit Analysis of Ultrasonic and Camera Backup Systems

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People Saving People

Introduction

This discussion establishes a method for calculating the net benefits for backup sensors (ultrasonic, camera, and a combination of both). In this model, benefits and costs (excluding injuries and fatality benefits) are examined from a societal perspective to determine the cost-effectiveness of these sensors on property damage.

There are very few studies that have produced the statistics that we need to model the situation. The philosophy behind our model is that the benefits generated by avoiding minor crashes are in direct opposition to the costs of repairing the system, especially in crashes that the system is unlikely or unable to provide assistance. Since system effectiveness and the cost to repair depend so much on the speed before impact, we examined more than one impact speed, and carefully considered the costs and benefits generated by the system at each speed group.

From a NHTSA bumper study[1], we find that the average vehicle is involved in 0.99 low speed rear bumper crashes and .09 high speed rear bumper crashes over its lifetime. In this instance, a high speed crash is any tow-away crash or crash that causes an injury, and low speed crashes are those that meet neither of those criteria. This includes vehicles that are both struck-from-the-rear and backing up. We then note that from the 2004 General Estimates System (GES) data, of all police reported accidents, 30.5 percent are struck-from-the-rear collisions, and 2 percent are backing up. We expect the same to be true of most high speed rear bumper crashes. However, while backing up at high speeds, or while backing onto a road and being struck at high speeds, it is highly unlikely that the backup system will function in time for the driver to react appropriately and avoid the crash.

[1] "Final Regulatory Impact Analysis, Part 581 Bumper Standard" NHTSA, May 1982

Given the GES data, a similar ratio of backing up crashes to struck-in-the-rear crashes would yield 6 percent of the .99 low speed rear bumper crashes attributed to backing up. However, we believe that off-road crashes, non-police reported crashes, and low speed crashes would have a much higher percentage of backing crashes than on-road, police-reported, and high speed crashes. We assume that between 10 percent and 25 percent of the low speed rear bumper crashes to be backing-up crashes. This value is extremely important to the final net benefit of installing these systems, as it controls precisely which segment of the low speed crashes are potentially avoidable using the system. From a NHTSA airbag study[2], we found that 40 percent of all high-speed crashes resulted in the car being totaled. All of these figures will be used later in the model.

On the cost side, we need to know the initial cost to install backup sensors on new vehicles and the incremental cost to maintain and repair them.

The system of damage categories arose because the differences in crash speeds effect the costs and benefits separately. Since the system effectiveness, potential damage for a crash, and incremental cost for a crash all depend upon vehicle speed, and we have an estimate of vehicle speeds for low speed crashes, it makes sense to examine the problem from this perspective. The damage associated with each type of crash is not directly correlated to a specific change in velocity, but rather the kind of crashes one expects to occur when a vehicle is backing up or moving at slow speeds.

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[2] "Final Economic Assessment, FMVSS No. 208 Advanced Air Bags" NHTSA, May 2000 (Docket No. 7013-2), Page VII-27.

System Effectiveness

The technology in the backup systems is far from perfect, but may be highly effective in mitigating a small segment of rear bumper crashes. We decided that a system's effectiveness depends on three criteria: (1) the crash avoidance rate, (2) the driver reaction factor, and (3) the type of object being detected.

(1) Crash Avoidance Rate

First, we examine the crash avoidance rates. The system only produces benefits when the equipped vehicle is moving in reverse at low speeds. Transport Canada referenced a report that contained the maximum crash avoidance rates under ideal conditions (e.g., immediate driver braking, no system errors) for several systems. That report claims that a certain ultrasonic system has a 95 percent crash avoidance rate up to 4 km/h, a 50 percent crash avoidance rate up to 8 km/h, and a 25 percent crash avoidance rate up to 9 km/h. However, there still exists the technological concern of cross-cancellation between two vehicles backing towards each other, effects of adverse weather conditions and other factors regarding detection of moving objects. After conversion to miles per hour, the speeds used in that study roughly correspond to the Ford's parking lot study (used in a NHTSA Bumper Study[3]), which showed that among low speed crashes, speeds of 0-3 mph account for 75 percent, 3-5 mph account for 18 percent, and 5-7 mph account for 7 percent of the low speed crashes. Taking advantage of this correspondence between speeds and effectiveness, a set of three damage categories was created: Light, Medium, and Heavy. Because the camera has a much longer range than the sensors, under good visual conditions we assume that the camera has a 95 percent detection rate at all low speeds. The combination system was given a very generous 100

[3] "Final Regulatory Impact Analysis, Part 581, Bumper Standard", NHTSA, May 1982.

percent detection rate at "Light" crashes among low speeds, and 95 percent for others. Again, weather conditions, humidity, glare, and other factors will impact the camera slightly, but at low speeds and short distances, the effects will be minimized. Finally, all of these values have distributed driver reaction times, but from our understanding of the document, assumes a perfectly reliable driver who will always respond, although perhaps not in time to avoid the collision.

(2) Driver Reaction

A driver's reaction to the backup systems also is not well documented, but a GM's study[4] provides some insight. We do know that some drivers will ignore the warning system, or not know how to respond to it, even after being instructed in its use. Drivers may not know how to respond to the system, ranging from issues such as lack of faith in the system due to false alarms, "not braking hard enough," and simply not realizing that a warning is being given. After the initial human reaction is considered, we also must consider the issues of a driver habitually expecting a warning, and changing their driving habits to be more reckless in their backup maneuvers. In addition, we should also consider the drivers that turn off the system because it gives too many false positives, or because they were involved in a backing crash despite the system, and decided not to depend upon it again. The concerns regarding driver reaction differ from system to system, or could be somewhat negated by a combination of systems. A camera system will display an image, but not alert the driver to the presence of something in close proximity to the vehicle, and an ultrasonic system will only provide audible/visible signals to the driver, leaving a large part of the decision-making process up to the driver. By using the combination, drivers have a way of being alerted in cases where they were not viewing the camera, and a way to look closely behind the vehicle as if with "their own

[4] "Driver Performance Research into Systems for the Reduction of Backing Incidents at General Motors," GM, January 2006.

eyes" to avoid erroneously ignoring a warning. Eventually, a range of 50 percent to 80 percent was used for the driver reaction factor for all damage classes. This means that 50 to 80 percent of the drivers will respond appropriately when given a warning of an impending crash or, when using a camera system, will look at the monitor and not back into objects because of this monitor view.

(3) Type of Object

Lastly, we must consider that even if the system is working under ideal conditions, and the driver is alert and ready to respond to the signal, that an unexpected collision can occur due to an object quickly passing into the range of detection directly behind the vehicle. An example would be a vehicle backing out of a parking space into a vehicle that was driving down the lane of the parking lot. The sensor reacts as per specification, but will not generate a warning in time. The attentive driver proceeds naturally, but cannot respond, since no warning will be delivered until a split second before impact, making it physically impossible to brake the vehicle and avoid the crash. Also, consider another case where a vehicle is backing and turning into a tight parking space. The system may have difficulty discerning between the car adjacent to the vehicle and the car opposite the vehicle. An ambiguous or inaccurate warning may be generated notifying the driver of the closest vehicle, rendering the farthest vehicle invisible to the sensors. In these cases, the system was functioning as it was designed, but the collision occurred. We assume 65 percent of all backing up cases are stationary or otherwise perceptible by the systems in every damage class.

The final effectiveness of the system is the product of the previous three factors, since the object must be within the scope of the system to be detected, the system must detect it, and the driver must respond to the system in order for a crash to be avoided. Below are the final assumptions for the overall effectiveness of each of the three systems, for each damage class.

Table 1
Backup System Effectiveness

	Light	Medium	Heavy
Ultrasonic	49%	26%	13%
Camera	49%	49%	49%
Both	52%	49%	49%

Benefits

The benefits of any backup sensor are produced in the realm of 10 to 25 percent (the percent of backup crashes) of the 0.99 low speed rear bumper crashes that each vehicle is estimated to have over its lifetime.

We define a Light crash to be a paint scratch or light dent. Costs to repaint or do light body work will be the minimal cost for a small crash, and we assume the average cost of such a crash is $500. A Medium crash will resemble a crash with a flat barrier, and according to Insurance Institute for Highway Safety (IIHS) bumper testing, the cost of such a crash at 5mph averages $732. Next, a Heavy crash corresponds to a crash that is more than just a mere fender-bender, akin to backing into a pole, or a flat barrier at higher speeds. The IIHS estimates the cost to be $1,327, but we are using the average cost to society. From the 2000 NHTSA report "The Economic Impact of Motor Vehicle Crashes," the property damage cost of a PDO crash is $1,484. In 2005 economics, the cost comes to roughly $1,664. Because low-speed backing up crashes are very likely to generate less damage than the average crash, this was used as the cost for our heavy damage class. Societal costs were not included in the minor fender benders since the cost to society typically involves things that are not applicable in low-speed collisions, like EMT dispatches, medical fees, work time lost, police time, travel time lost, etc…

Finally, we use the price per crash for each of the crash types, and then multiply it by the number of each of those crash types that the system mitigates.

G = Summation of Benefits generated

Lo = Lifetime low speed crashes per vehicle

$A_{\{L,M,H\}}$ = Percentage of Avoidable (backing up) low speed crashes corresponding to the Light, Medium, or Heavy damage category

$eff_{\{L,M,H\}}$ = Effectiveness of the backup system, corresponding to the Light, Medium, or Heavy damage category. This is the product of the system's crash avoidance rate, the driver reaction factor, and the stationary/perceptible object factor.

$B_{\{L,M,H\}}$ = Benefits gained from avoiding a crash in the Light, Medium, or Heavy damage category

$$G = Lo \cdot A_L \cdot eff_L \cdot B_L + Lo \cdot A_M \cdot eff_M \cdot B_M + Lo \cdot A_H \cdot eff_H \cdot B_H$$
$$G = Lo\left(A_L \cdot eff_L \cdot B_L + A_M \cdot eff_M \cdot B_M + A_H \cdot eff_H \cdot B_H\right)$$

<u>Costs</u>

There are four methodologies NHTSA uses to estimate installation costs. All four of these methodologies attempt to estimate the costs of standard equipment at high production volume, under the assumption that it would be a Federal standard applicable to all new applicable vehicles. In reality, the typical assembly plant has volumes around 250,000 vehicles per year, and the assumption is based on costs for a high production plant that can produce 250,000 vehicles per year. We attempt to estimate "consumer costs". That is the cost that the purchaser of a new vehicle will pay to have that safety countermeasure standard equipment on a vehicle. Others have called this an estimate of the "retail price equivalent" cost. One cannot determine the price of one item on a car by looking at retail prices, but consumer cost is an estimate of how much the retail price of a car will increase to cover the cost to the manufacturer, plus a manufacturer profit, plus a dealer profit for selling the vehicle.

The four methodologies we use are:

A) Hire a contractor to do a weight/cost tear down study. In this study, we purchase the safety countermeasure being studied and estimate, based on the contractor's experience/knowledge, how that part is made, using what materials, what labor, etc. A variable cost is determined for each piece of the safety countermeasure. Then mark-up factors are applied for burden, fixed costs, manufacturer profits, dealer profits, etc. On average the mark-up factor from variable costs to consumer costs is estimated to be 1.51. That is, variable cost x 1.51 = consumer cost.

B) Perform our own cost estimate. If we do not have the time/money to have a contractor estimate costs for us, we may perform our own cost estimate. First, we would look at previous contractor estimates to see if they contain useful information. This useful information may be labor costs or assembly time for similar items. In this case, we need a good idea of the parts that make up a safety countermeasure; we need a good estimate from suppliers of the costs of those parts on a high-volume basis, and we make an estimate of the labor time to assemble and install that part on the assembly line. So, we make our own estimate of the variable costs and multiply that bt 1.51 to estimate a consumer cost.

C) Optional Equipment - Use a rule-of thumb for optional equipment already provided on vehicles. If a safety countermeasure is being sold as a stand-alone option on some vehicles in the fleet, our rule-of-thumb estimate is that this optional price divided by 3 will be close to the consumer cost of the system being supplied as standard equipment on a vehicle.

D) Aftermarket Equipment – A level of subjective judgment is used here. Depending upon how sophisticated the part is and how many competitors there are, we may use different estimating methodologies. We could consider the aftermarket part as just a supplier, if we can find a price for high volumes. If the prices are for low volumes, then we might use the rule of thumb and divide by 3 or use the rule-of-thumb plus add in a cost for labor to install the part.

A search on the Internet allowed us to make our own cost estimate for a manufacturer to install these systems, and we increased these costs to represent the costs to the consumer. A single ultrasonic sensor costs approximately $4 each (a set consists of four sensors); the electronic control unit costs about $6, and the LED or audio device for output was about $3. We assume that the process of punching four holes in the bumper, attaching the sensors, and connecting the wires costs about 3 minutes of work at $22/hour. After including a factor of 1.51 to mark up costs from variable costs to the cost to consumers, we estimated the ultrasonic sensor system costs $41 to install. From the

FMVSS No. 111 Preliminary Regulatory Evaluation[5] regarding rear detection systems on single-unit trucks, a camera system costs $325, plus the factory line time of 2 minutes to install. Thus, we found the camera system costs $326 to install. Although not used in this analysis, we also estimated costs for other devices using prices of aftermarket devices available on the internet, and using the methods described above to estimate consumer costs of $8 to $13 for the Fresnel Lenses, $13 for internal mirrors, and $8 to $19 for external cross-view mirrors. In addition, we expect radar backup sensors to be more complicated than ultrasonic backup sensors and therefore cost more than their sonic counterparts. Thus, we estimate their installation cost would be between $41 and $100. Below is a chart of these findings.

Table 1
Cost to Install Various Backup Systems
On a Per Vehicle Basis ($2006)

Backup System	**Cost to consumer**
Ultrasonic Backup Sensors	$41
Radar Backup Sensors	$41 - $100
Camera System	$326
Fresnel Lens	$8 - $13
Internal Mirrors	$13
External Mirrors	$8 - $19

Next, we need to find the incremental cost of maintaining the devices over the lifetime of the vehicle. Electronic devices such as these typically outlive the vehicle, but in the case that the vehicle outlives the sensor system, the de-valued nature of the vehicle itself would negate any reason

[5] Preliminary Regulatory Evaluation, FMVSS No. 111, NPRM to Require a Rear Detection System for Single-Unit Trucks, August 2005, (Docket No. NHTSA-2004-19239-2)

to install a new sensor, so we are assuming no incremental cost associated with that situation. The crash-related costs of any backup system are produced in the set of all 1.08 rear bumper crashes (0.99 low speed crashes and 0.09 high speed crashes) a vehicle is expected to have over its lifetime. Crashes that affect the costs include both low speed and high speed, except for the low speed, backing up crashes that were avoided using the sensors. To find the incremental repair costs associated with the backup system we called a few local dealerships. This produced values for the increased costs associated with fixing the sensors should the vehicle receive a rear-impact for any reason. A word of caution should be placed on these estimates, as the devices are installed on luxury or expensive vehicles, and in premier-type packages, sometimes integrated into an on-board navigation system with LCD display. It is reasonable to assume that if these devices were installed on all new vehicles, the cost to produce and repair them will decrease. A single sensor costs $136 to replace and a camera costs $658 to replace. The cost to replace all of the sensor system's rear components averaged $616. All of these prices include labor and paint.

In order to more accurately distribute the range of sensor damage, the set of three damage classes was used once again. We assume a Light crash will damage nothing related to the sensors or camera, since they take up such a small portion of the bumper (if the camera is even mounted inside the bumper at all). We assume that a Medium crash will destroy a single sensor, but would not damage the camera (many cameras are mounted in the recessed area of the license plate), and would resemble a crash with a flat barrier. Next, we assume that a Heavy crash will destroy on average between 2 and 3 sensors and/or the camera. This corresponds to a crash that is more than just a mere fender-bender, akin to backing into a pole, or a flat barrier at higher speeds. In the event that the car is totaled, there is no incremental cost to the system, since the vehicle is a complete loss. Now we have the incremental repair cost attributed to the system for the four different crash types (Light, Medium, Heavy, Totaled). However, the model is fairly simple since we do not account for the portion of Heavy crashes that will be reduced to Medium or Light crashes because the driver applied the brakes after the system emitted a warning.

Once we order these crashes by incremental damage, we have three types of crashes. As noted previously, from a Ford parking lot study referred to in the 1982 Bumper analysis, we find that among low speed crashes, speeds of 0-3 mph account for 75 percent, 3-5 mph account for 18 percent, and 5-7 mph account for 7 percent. These speeds are then matched to the damage classes we defined above.

C_i = Cost to Install (during manufacturing)

C_R = Cost to Repair (over the lifetime of the vehicle)

Lo = Lifetime low speed crashes per vehicle (0.99)

Hi = Lifetime high speed crashes per vehicle (0.09)

t = Percentage of high speed crashes which total the vehicle (thereby producing no incremental repair cost) (0.40)

$R_{\{L,M,H\}}$ = Incremental costs associated with repairing the backup system when involved a crash in the Light, Medium, or Heavy damage category

$A_{\{L,M,H\}}$ = Percentage of Avoidable (backing up) low speed crashes corresponding to the Light, Medium, or Heavy damage category

$U_{\{L,M,H\}}$ = Percentage of Unavoidable (struck-from-the-rear) low speed crashes corresponding to the Light, Medium, or Heavy damage category

$eff_{\{L,M,H\}}$ = Effectiveness of the backup system, corresponding to the Light, Medium, or Heavy damage category. This is the product of the system's crash avoidance rate, the driver reaction factor, and the stationary/perceptible object factor.

$$
\begin{aligned}
C_R &= R_L \cdot Lo \cdot \left[A_L \cdot (1 - eff_L) + U_L\right] + \\
&R_M \cdot Lo \cdot \left[A_M \cdot (1 - eff_M) + U_M\right] + \\
&R_H \cdot \left\{Lo \cdot \left[A_H \cdot (1 - eff_H) + U_H\right] + Hi \cdot [1 - t]\right\}
\end{aligned}
$$

Cost-Benefit Analysis

Since repair costs occur over the lifetime of the vehicle, repair costs are discounted back to present value to make them directly comparable to new vehicle costs. After calculating the incremental costs and benefits generated above, we find the difference and multiply it by the 3 percent (0.8155) and 7 percent (0.6490) discount factor. These discount factors are weighted by vehicle miles traveled and survivability by age of the vehicle. Finally, we supply the installation cost from this value; this cost is assumed to be immediate and therefore does not need to be discounted over the life of the vehicle. This gives us the total benefit to society that is generated by each new car that is equipped with the system, over its lifetime.

While there are a large number of estimates and assumption made in the model above, we chose two factors as the most sensitive of the assumptions. These factors are the percent of low-speed crashes that are backing-up rather than being struck from the rear (assumed to be 10 to 25 percent) and the driver reaction to the warning, or the percent of the time the driver looks into the monitor for a camera system and performs this task appropriately, (assumed to be 50 to 80 percent of the time). As shown in Table 1, the incremental repair costs of the sensors far outweigh the benefits they generate (thus net benefits are negative). One would need half of the .99 low speed accidents to be backing up accidents, and a driver factor of about 80 percent in order for the systems to start to break even.

Table 2
Net Lifetime Benefits of Various Backup Systems
On a Per Vehicle Basis ($2006)

3% discount rate	50 % Driver Factor	80% Driver Factor
Ultrasonic		
At low speeds, 10 % are backing up crashes	-$82.73	-$75.34
At low speeds, 25 % are backing up crashes	-$64.26	-$45.78
Camera		
At low speeds, 10 % are backing up crashes	-$375.21	-$365.20
At low speeds, 25 % are backing up crashes	-$350.19	-$325.16
Both		
At low speeds, 10 % are backing up crashes	-$468.57	-$457.54
At low speeds, 25 % are backing up crashes	-$441.00	-$413.43

7% discount rate	50 % Driver Factor	80% Driver Factor
Ultrasonic		
At low speeds, 10 % are backing up crashes	-$74.23	-$68.35
At low speeds, 25 % are backing up crashes	-$59.53	-$44.83
Camera		
At low speeds, 10 % are backing up crashes	-$365.11	-$357.14
At low speeds, 25 % are backing up crashes	-$345.19	-$325.28
Both		
At low speeds, 10 % backing up	-$447.80	-$439.02
At low speeds, 25 % backing up	-$425.86	-$403.92

Due to the easily affected cost-benefit relationship, it is difficult to create one number or even a small range of numbers to represent these systems. In order to produce a meaningful understanding of these systems, a number of scenarios are presented in Table 3 to gauge the sensitivity of the assumptions made for those factors that we have the least amount of information. These should not be interpreted as NHTSA's predictions for these devices, but rather possible predictions to show the sensitivity of the results. All variables "default" values above are kept, including an 80% driver factor.

Table 3
Net Lifetime Benefits of Various Backup Systems
On a Per Vehicle Basis ($2006, 3% discount)

Scenario	Ultrasonic Benefits	Camera Benefits	Combination Benefits
At low speeds, 25% backing up, 75% struck	-$46	-$325	-$413
At low speeds, 50% backing up, 50% struck	$4	-$258	-$340
Benefits for each crash avoided are doubled	$2	-$263	-$349

It is also worth noting that one of our most sensitive variables, the percentage of low speed crashes that are backing-up crashes, is one of the unknowns for which we have the least knowledge. Our current estimate states that 10 to 25 percent of low speed crashes are backing-up crashes, but holding all other variables constant, we would need this number to increase to 50 percent, somewhere between two- to five-fold over our current estimate range, for the ultrasonic system to break even in net benefits. Similarly, another way for the ultrasonic system to break even in net benefits includes having the benefits of each crash avoided to be twice our estimated value. These sensitivity analyses show that you need large changes in our assumptions in the model to get the ultrasonic systems to break even in net benefits.

Thus, based on the assumptions and estimates in this model, which do not include any benefits for injuries or fatalities reduced, backup sensors are not cost-effective to society on a property damage basis over the lifetime of vehicles.

One perspective on this data that may not be obvious at first glance is precisely which person will pay the cost to society in these crashes. While a camera-equipped vehicle may not be very cost effective for society in certain circumstances, the driver pays for its installation, and in the event of an accident, the cost to repair will be covered partly by insurance, and partly by the other motorist if the camera was struck-in-the-rear (except in no-fault States). Therefore, it may be in the driver's best interest to equip their car with a backup sensor to avoid backup crashes, while it may not be in society's best interest due to increases in repair costs in those cases where the vehicle is struck in the rear.

Finally, we revisit the many questions we have considered while creating this model. The costs to repair the systems are currently extremely high, but this may be because they are considered luxury items. The effectiveness of the system is hard to pin down because of the types of property damage crashes it can affect are not well documented, as many of them take place in driveways and are not reported to police. Many assumptions were made setting up the distribution of crashes, regarding Light-Medium-Heavy damage, and the ratio of backing up crashes to struck-in-the-rear crashes.