A20 / MODELING CAMP STUDY 1 DATA FOR CRASH ALERT TIMING PURPOSES

Background of Modeling Effort

The primary goal of the first CAMP human factors study (CAMP Study 1) was to develop a crash alert timing approach for a FCW system by exploring various driver behavior measures. In CAMP Study 1, a strategy was employed to initially develop a fundamental understanding of the timing and nature of drivers' "last-second" braking behavior *without* a FCW system, before conducting the subsequent FCW system driver interface studies. This strategy was taken so that drivers' perceptions of "normal" and "hard braking" kinematic situations could be properly identified and modeled for FCW system crash alert timing purposes. This initial step of understanding drivers' "last-second" braking behavior *without* a FCW system was the focus of CAMP Study 1.

More specifically, in developing a crash alert timing approach for a FCW system, two fundamental driver behavior parameters have to be considered. The first parameter is the time it takes for the driver to respond to the crash alert and begin braking (which includes *driver brake reaction time*), and the second parameter is the driver deceleration (or braking) behavior. In response to this alert across a wide variety of initial vehicle-to-vehicle kinematic conditions, this second parameter was addressed by CAMP Study 1, which is also the focus of this modeling effort.

Characterization of Database Modeled

In CAMP Study 1, under closed-course conditions, drivers were asked to make "last-second" braking judgments while approaching a slowing or stopped "surrogate" (lead vehicle) target, which is described below. Subjects experienced trials in which the lead vehicle (or *Principal Other Vehicle*) was parked (or stationary), and trials in which the Principal Other Vehicle (*POV*) was moving. These two general types of test trials will be referred to as *Stationary Trials* and *Moving Trials*, respectively. During Stationary Trials, subjects were asked to approach the parked surrogate target at an instructed speed, either 30, 45, or 60 mph. During Moving Trials, subjects followed a lead vehicle which towed the surrogate target at these same three speeds, and were given ample time to maintain and stabilize at what they considered to be their "normal" following distance. Next, the POV driver enabled the POV to automatically brake to a stop according to a prespecified braking profile, which resulted in a constant deceleration of either -0.15, -0.28, or -0.39 g's. At that point, the test participant was asked to wait to brake the *subject vehicle* (or *SV*) until the last possible moment in order to avoid colliding with the surrogate target. When both vehicles came to a complete stop, data collection was halted and the trial was ended. During Stationary Trials, subjects were asked to make these same braking judgments while approaching the parked surrogate target.

Drivers were asked to make these last second braking judgments under three different braking instruction conditions, “normal” braking, “comfortable hard” braking, and “hard” braking. Each instruction differed on the instructed braking intensity or pressure. Under one instruction, the driver was asked to brake *with normal braking intensity or pressure*. Under a second instruction (the “*comfortable hard braking”* instruction), the driver was asked to brake with *the hardest braking intensity or pressure that they felt comfortable*. Under a third instruction (the “*hard braking”* instruction), the driver was asked to brake with *hard braking intensity or pressure*. Three instruction conditions were included to provide insight into when drivers should be presented crash alert information, when drivers should not be presented crash alert information (in order to avoid in-path nuisance alerts or any tendency the driver may have to ignore an alert which does in fact signify an alarming situation), and to also explore drivers’ interpretations of “hard” braking and “comfortable hard” braking levels. That is, the use of different braking instructions enabled properly identifying and modeling drivers’ perceptions of “normal braking” (albeit “aggressive normal braking”) and “hard braking” for crash alert timing purposes.

The surrogate (lead vehicle) target was designed to mimic a real vehicle as much as possible with the constraint that it would allow for safe impacts at low impact velocities. The experimenter had access to add-on brakes and an audible crash alert. Thirty-six younger, 36 middle-aged, and 36 older drivers were tested. Eighteen males and 18 females were tested in each age group. Overall, data from over 3800 last-second braking trials were obtained. The critical need for obtaining this type of data under controlled conditions is dictated by the infrequency of near/actual rear-end crashes (and associated “black box” data), the lack of data available to support FCW system “benefits” modeling, and the inherent difficulties associated with accident reconstruction.

Study 1 Results Influential to Modeling Approach

Converging evidence suggested that the 50th percentile required deceleration value observed in CAMP Study 1 under “hard braking” driver instructions appeared very promising as an appropriate (not too early/not too late) estimate of the assumed driver braking onset range for crash alert timing purposes. The required deceleration measure was defined as the constant deceleration level required for the driver to avoid the crash at braking onset. This measure was calculated by using the current speeds of the driver’s vehicle and the lead vehicle, and assuming the lead vehicle continued to decelerate at the prevailing decelerating value (i.e., at the current “constant” rate of slowing).

This required deceleration measure varied with driver speed and lead vehicle deceleration rates, which is in sharp contrast to the “constant (or fixed) driver deceleration level” assumption routinely employed in FCW system warning algorithms and “benefits” modeling. It is also important to note that these required deceleration values were relatively uninfluenced by driver age or gender, which is a desirable finding from a production implementation perspective. Additional evidence suggested that drivers with a FCW-equipped vehicle would be capable of executing the observed hard braking levels without exceeding their “comfort zone” for hard braking.

In the modeling described below, only data from the "hard braking instruction" condition were used, for two primary reasons. First, in educating drivers how to brake (if braking is appropriate) to a FCW system crash alert, using "hard braking" terminology seems to be the most appropriate approach (whereas "comfortable hard" is relatively ambiguous). Second, driver's braking behavior during the "comfortable hard braking" instruction was heavily influenced by the order in which drivers experienced the three braking instruction conditions above (this was not true for the "hard braking" instruction).

Goals of Current Modeling Effort

The primary goal of this modeling effort was to predict "last-second", "hard braking" onsets across the wide variety of initial vehicle-to-vehicle kinematic conditions examined in CAMP Study 1 using the required deceleration value (for reasons described above). These will subsequently be referred to as the *Required Deceleration Parameter (or RDP) modeling* efforts. The results of this portion of the modeling effort were used directly for crash alert timing purposes in the subsequent three FCW system driver interface studies. The underlying assumption is that properly characterizing (i.e., modeling) the kinematic conditions surrounding these hard braking onsets without FCW system crash alert support will lead to a proper estimate for the assumed driver deceleration (or braking) behavior in response to a FCW system crash alert (across a wide variety of initial vehicle-to-vehicle kinematic conditions). The data that was used for this modeling effort included each of the following driver performance measures obtained at SV braking onset:

- Range between the driver's vehicle and lead (surrogate target) vehicle
- Speed of the driver's vehicle (or Subject Vehicle), referred to as SV speed
- Speed of the lead vehicle (or Principal Other Vehicle), referred to as POV speed
- Deceleration level of the lead vehicle (or Principal Other Vehicle), referred to as POV deceleration

It should be noted that SV braking onset was not defined relative to the brake switch trigger point, since it was observed that some subjects had a tendency to momentarily ride the brakes during their last-second braking decision. Instead, SV braking onset was defined as the point in time in which the vehicle actually began to slow as a result of braking. Based on a manual analysis of 10% of the entire data set, SV braking onset was defined as five 30 Hz data samples (or 165 ms) prior to SV crossing the .10 g deceleration level.

A secondary, though important, goal of this modeling effort was to explore the ability to predict these "last-second", "hard braking" onsets based on a subset of the available "raw" data described above. The results of this portion of the modeling effort were not used for crash alert timing purposes in the subsequent three FCW system driver interface studies, but instead were used to explore the consequences of a FCW system with less than an "ideal" level of knowledge of the current kinematic conditions (e.g., limited knowledge of lead vehicle deceleration rates). (This "ideal" level of knowledge was explored with the RDP modeling efforts discussed above). Two modeling attempts were made which examined a "binning" approach for the assumed lead vehicle deceleration. These will subsequently be referred to as *Binning modeling* efforts. In one attempt, it was assumed that the FCW system could discriminate whether the lead vehicle was braking higher or lower than –0.25 g's, as well as whether the lead vehicle was moving or stationary. In a second attempt, it was assumed that the FCW system could only discriminate whether the lead vehicle was moving or stationary. Finally, four modeling approaches examined crash alert timing approaches that assumed both fixed (or constant) driver deceleration rates (either 0.3 or 0.5 g's) and fixed lead vehicle deceleration rates (either 0 or -0.17 g's). These will subsequently be referred to as *Fixed modeling* efforts.

Before discussing these modeling efforts, which developed equations for predicting range values and required deceleration values at SV braking onset, a few comments about the three potential sources of variance for predicting these values are in order.

First, there are differences between braking event circumstances (e.g., SV speed, POV speed, POV deceleration), which will be called *situation variance*. Minimizing situation variance is the focus of this modeling effort.

Second, there are differences between subjects in risk-aversion, which will be called *subject variance*. Subject variance is orthogonal to situation variance and is the variance that would be accommodated by an adjustment knob for use with a FCW system. This variance reflects the consistent bias of a given subject to brake early or late relative to other subjects in the exact same kinematic situation. The proportion of total variance accounted for by subject variance was estimated before performing regressions in order to give an upper limit on the percent of variance the model should account for. This upper limit is not a mathematical limit, but a practical limit. A model that goes above that limit is suspect because it must be accounting for subject variance in addition to situation variance.

Third, there is *random variance*, either due to measurement error or due to the subject braking at a slightly different time than intended due to perceptual error. Nothing can be done about random error, except to estimate the magnitude of its contribution to the total variance.

Each of the Required Deceleration Parameter (RDP), Binning, and Fixed modeling efforts will now be discussed in turn in detail.

Required Deceleration Parameter (RDP) Modeling Efforts

There were two RDP modeling approaches explored. The first, more complicated approach, predicted (or modeled) range where the predicted required deceleration value was part of the predictor set of variables. This will subsequently be referred to as the *RDP-Range* model. The second, more straightforward approach, modeled required deceleration directly using a standard linear regression approach, and is subsequently referred to as the *RDP-Deceleration* model. Each of these two models will now be described in turn.

RDP-Range Model

The first modeling approach taken was to model required deceleration in terms of its effect on range at braking onset. That is, this model predicted required deceleration values by minimizing errors in the predicted range values, which are a function of the required deceleration values. In order to do this, the three equations linking range to required deceleration (and other variables) had to be put into the same general structure.

The appropriate case equation used to calculate the braking onset range (Case 1, Case 2, or Case 3) is based on the projected movement state of the POV at braking onset (POV moving or POV stationary), and the projected movement state of the POV when it contacts the SV barely contacts the POV (contact when POV is moving or contact when POV is stationary) under the required deceleration prediction (or assumption). The braking onset range is then calculated by inputting the predicted required deceleration value into the appropriate case equation below. It should be noted that the variables need to be expressed in common measurement units (e.g., feet), which should be consistent with those used in calculating the predicted required deceleration values. In this equation, braking deceleration values are represented as negative values. In the following case equations, the following notation is used:

R = Braking Onset Range (or Distance) in feet

V_{SV} = SV velocity in feet/sec at braking onset

V_{POV} = POV velocity in feet/sec at braking onset

dec_{REQ} = required deceleration of the SV in feet/sec^2

dec_{POV} = POV deceleration in feet/sec^2

Case 1: POV Stationary →

$$R = \frac{(V_{SV})^2}{-2*(dec_{REQ})}$$

Case 2: POV Moving, contact when POV is moving →

$$R = \frac{(V_{SV} - V_{POV})^2}{-2*(dec_{REQ} - dec_{POV})}$$

Case 3: POV Moving, contact when POV is stationary →

$$R = \frac{(V_{SV})^2}{-2*(dec_{REQ})} - \frac{(V_{POV})^2}{-2*(dec_{POV})}$$

Each of these Case equations can be fit into a more general format, referred to subsequently as the *generalized equation*, as follows:

$$R = \frac{x}{-2*(dec_{REQ} - y)} - z$$

The dec_{REQ} is predicted (or modeled), and the values for x, y, and z are determined by the Case situations above, as follows:

for Case 1: $x = V_{SV}^2$, $y = 0$, and $z = 0$.

for Case 2: $x = (V_{SV} - V_{POV})^2$, $y = dec_{POV}$, and $z = 0$.

for Case 3: $x = V_{SV}^2$, $y = 0$, and $z = ((V_{POV})^2/-2*(dec_{POV}))$.

Each hard braking onset observation (or trial) was defined as belonging to one of the three Cases described above, and the x, y, and z portions of the equations were then calculated. This left range expressed as a function of one unknown, required deceleration. The modeling process was directed at fitting an equation to predict required deceleration. The models considered were all linear with respect to required deceleration. However, when the prediction equation replaced required deceleration in the generalized equation to predict range, the function becomes nonlinear. Thus, a nonlinear fitting procedure was required to determine the best-fit model. The loss function was squared error in range. The portion of the best-fit model that predicts required deceleration is shown below. The right half of this equation can replace required deceleration in the generalized equation in order to predict range at braking onset.

$$dec_{REQ} = -2.727 + 0.897(dec_{POV}) + 2.38(\text{if POV moving}) - 0.113(V_{SV} - V_{POV})$$

The equation above accounts for 76% of the variance in *range*. (The "if POV moving" predictor variable is set to 0 if the POV is projected to be stopped at braking onset , and is set to 1 if the POV is projected to be moving at braking onset). It is important to note that although the loss function and percent variance accounted for were calculated with respect to range, the equation itself predicts required deceleration. In this equation, braking deceleration values are represented as negative values.

Percent subject variance was estimated for the range by calculating the sum of squares for the mean of each subject across conditions. This sum of squares, expressed as a percentage of the total sum of squares (adjusted for the grand mean), gives the percentages of variance accounted for by subject differences (i.e., the extent to which there is a consistent bias of a given subject to brake early or late relative to other subjects in the exact same kinematic situation). The percent of variance accounted for by subject variance (or subject differences) was 14%. Hence, the amount of situation variance left over which could potentially be accounted for by this model was 86%. As mentioned above, the amount of situation variance actually accounted for by the RDP-Range model was 76%.

RDP-Deceleration Model

The modeling procedure for the RDP-Deceleration model followed standard linear regression techniques. The results of the RDP-Range modeling exercise were used to guide the modeling process, but not to the exclusion of other models. Fortunately, the same combination of independent variables produced the best-fit model. The coefficients are somewhat different because the loss function is given in terms of required deceleration instead of range. The equation, which accounts for 63% of the variance in *required deceleration*, is shown below. (Braking deceleration values are represented as negative values.)

$$dec_{REQ} = -5.308 + 0.685(dec_{POV}) + 2.57(\text{if POV moving}) - 0.086(V_{SV} - V_{POV})$$

Like the RDP-Range model, the right half of this equation can be entered into the generalized equation to predict range. As with the range, percent subject variance was estimated for required deceleration by calculating the sum of squares for the mean of each subject across conditions. The percent of variance accounted for by subject differences was 26%. Hence, the amount of situation variance left over which could be potentially accounted for by this model was 74%. As mentioned above, the amount of situation variance actually accounted for by RDP-Range model was 63%.

Comparison of RDP-Range & RDP-Deceleration Models

The RDP-Range and RDP-Deceleration Models are generally very similar. They are identical in structure, which, while not surprising, suggests that they are capturing variability that is consistent across somewhat different measures. The percent variance accounted for in each case cannot be directly compared (76% for the RDP-Range model versus 63% for the RDP-

Deceleration models) because the total variance is in different measures (range versus required deceleration). However, by applying the model to the data and using them both to predict both range and required deceleration, it is possible to more directly compare these two models. Table 14 shows the average residuals (i.e., the observed minus the predicted values) in range and required deceleration for the two models overall, as well as for the three general subtypes of trials. (Note that a positive number in this table implies braking was harder than predicted, and hence, a result in a conservative direction.) Not surprisingly, the RDP-Range model performs slightly better in predicting range and the RDP-Deceleration model performs slightly better in predicting required deceleration. On the other hand, both models perform reasonably (and similarly) well at predicting both variables.

Table 14 Range and Required Deceleration Residuals (Observed Minus Expected Values) for Both the RDP-Range and RDP-Deceleration Models

	RDP Range model		**RDP Deceleration**	
Trial Type	**Req. Dec. (g)**	**Range (feet)**	**Req. Dec. (g)**	**Range (feet)**
Overall	+0.005	+2	0.000	+7
Case 1 Trials	+0.025	-3	0.000	+10
Case 2 Trials	+0.009	+2	-0.013	+20
Case 3 Trials	-0.004	+3	+0.005	+1

The left-hand portion of Table 15provides average range residuals, a somewhat more intuitive measure than the required deceleration residuals to interpret, for both the RDP-Range and RDP-Deceleration Models across all POV speed/POV deceleration combinations examined in CAMP Study 1. (For a point of reference, 1 mid-size car length is about 16 feet.). The left-hand portion of Table 16 provides predicted hard braking onset ranges, once again, across all POV speed/POV deceleration combinations examined in CAMP Study 1. In this table, the delta V assumption ($V_{SV} – V_{POV}$) shown in the second column corresponds to the mean value found for the particular POV speed/POV deceleration combination. In addition, the third column in this table corresponds to the mean braking onset range found for the particular POV speed/POV deceleration combination examined in CAMP Study 1. Overall, across both models, the predicted braking onset range is within 1 mid-size car length from the observed hard braking range for about 70% of these nominal POV speed/POV deceleration combinations. Once again, as can be seen in Table 15 and Table 16, overall, both models perform very similarly at predicting braking onset range.

Another opportunity to make relative comparisons across these two models is to examine whether the predicted hard braking onset ranges are “too early” or “too late”. In this “too early/too late” analysis, a too early predicted “hard” braking onset range is defined to occur when the predicted "hard" braking onset range is greater than the observed braking onset range during the last-second, "normal braking instruction" condition. In addition, a too late predicted "hard" braking onset range is defined to occur when the predicted "hard" braking onset range is less than the observed "hard" braking range during the last-second, "hard braking instruction" condition.

Overall, the percent "too early" predicted "hard" braking onsets for the RDP-Deceleration and RDP-Range models were 5.3% and 6.4%, respectively. Overall, the percent "too late" predicted "hard" braking onsets for the RDP-Deceleration and RDP-Range models were 13.9% and 12.1%, respectively. These results correspond well to the underlying rationale for modeling the required deceleration measure explained in the Task 4-CAMP Study 1 portion of this document. Results from this too early/too late analysis are shown in the left-hand columns of Table 17 for each POV speed/POV deceleration combination examined in CAMP Study 1.

On the whole, the RDP-Deceleration and RDP-Range models are clearly very similar, with similar coefficients and similar results in terms of residuals, and the estimated "too early" and "too late" predicted hard braking onset ranges. The RDP-Deceleration model was ultimately chosen for crash alert timing purposes in the subsequent three FCW system driver interface studies for the following reasons. The first reason was that the RDP-Deceleration model tended to predict slightly later (i.e., slightly more aggressive) braking onsets under kinematic situations when the POV braked at -0.15 g's. Relative to the other more intense POV braking profiles examined (-0.28 and -0.39 g's), this braking profile may be more representative of normal lead vehicle braking intensities drivers encounter during real-world driving. It was suspected drivers were capable of braking harder than what was observed in Study 1 when the POV braked at -0.15 g's, and hence, presenting the alert slightly later under these commonly encountered conditions provided a potential way to minimize in-path nuisance alerts. A second reason for choosing the RDP-Deceleration over the RDP-Range model was the relatively more straightforward, and accessible approach used to develop the model.

Binning Modeling Efforts

Measuring POV deceleration, as well as utilizing POV deceleration information in real-time are difficult technical problems. Hence, a model that predicts required deceleration accurately without using POV deceleration knowledge would be particularly useful. Unfortunately, the Analysis of Variance results reported in Chapter 3 of this document suggest that achieving this goal may be challenging, because these results clearly indicate the strong dependence of drivers braking onsets on the POV braking profile. Nonetheless, the data were modeled in an attempt to explore the consequences of a FCW system with less than an "ideal" level of knowledge of the current kinematic conditions such as POV deceleration level.

Two modeling attempts were made which examined a (non-fixed) "binning" approach for the assumed lead vehicle deceleration. In one attempt, it was assumed that the FCW system could discriminate whether the lead vehicle was braking higher or lower than -0.25 g's, and whether or not the lead vehicle was moving or stationary. In this modeling process, the data were put into two groups. One group, the "hard" braking group, contained data in which the POV decelerations were harder than or equal to -0.25 g's. The second group, the "light" braking group, contained the remaining data, in which the POV decelerations were less than to -0.25 g's. This will subsequently be referred to as *Binning Model 1*. A stepwise regression produced the following model, which accounts for 58% of the variance in *required deceleration*.

$$dec_{REQ} = -4.681 - 4.574(\text{if hard braking}) - 1.059(\text{if POV moving}) - 0.095(V_{SV} - V_{POV})$$

In this equation, the "if hard braking" predictor variable is set to 0 if the POV is braking "light", and is set to 1 if the POV is braking "hard". It should be stressed that the relatively high amount of variance accounted for by this model (58%) is misleading, since the distinction between light and hard braking was optimized for this particular CAMP Study 1 data set. This in effect artificially inflates the amount of variance accounted for. Hence, although this modeling exercise proved interesting in light of the technical challenges in measuring POV deceleration, because of this caveat, this model will not be discussed in any further detail.

In a second "binning" modeling attempt, it was assumed that the FCW system could only discriminate whether the lead vehicle was moving or stationary. This will subsequently be referred to as *Binning Model 2*. This model simply removed the required deceleration variable from consideration. A stepwise regression produced the following model, which accounts for 23% of the variance in *required deceleration*, is as follows:

$$dec_{REQ} = -2.718 - 5.412(\text{if POV moving}) - 0.126(V_{SV} - V_{POV})$$

The left-middle portion of Table 15 provides average range residuals for Binning Model 1 and Binning Model 2 across all POV speed/POV deceleration combinations examined in CAMP Study 1. The left-middle portion of Table 16 provides predicted hard braking onset ranges for these Binning models across all POV speed/POV deceleration combinations examined in CAMP Study 1. Finally, results from the too early/too late analysis for these Binning models are shown in the left-middle portion of Table 17 for each POV speed/POV deceleration combination examined in CAMP Study 1. The most striking, although not surprising, result from these tables with respect to Binning Model 2 is the high percentage of "too early" predicted "hard" braking onsets when the POV braked at -0.39 g's, and the high percentage of "too late" responses when the POV braked at -0.15 g's.

Table 15 Average Range Residuals (Expected - Observed) in Feet for the Various Models Examined (Corresponding Standard Deviation are Shown in Parentheses) Across all POV Speed/POV Deceleration Combinations Examined in CAMP Study 1

	Model							
POV Speed / POV Deceleration Combination	**RDP-Decel. Model**	**RDP-Range Model**	**Binning Model 1**	**Binning Model 2**	**Fixed Model 1** (dec_{SV}= -.3 g, dec_{POV}= -.17g)	**Fixed Model 2** (dec_{SV}= -.3 g, dec_{POV}= 0 g)	**Fixed Model 3** (dec_{SV}= -.5 g, dec_{POV}= -.17 g)	**Fixed Model 4** (dec_{SV}= -.5 g, dec_{POV}= 0 g)
30 mph /Stat.	0 *(22)*	+19 *(22)*	+2 *(22)*	+10 *(22)*	+120 *(28)*	-7 *(22)*	-16 *(22)*	-46 *(23)*
30 mph/0.15 g	-2 *(22)*	+16 *(23)*	+2 *(23)*	-20 *(18)*	-16 *(20)*	-29 *(17)*	-30 *(17)*	-33 *(17)*
30 mph/0.28 g	-1 *(19)*	+1 *(18)*	-10 *(21)*	+1 *(19)*	-15 *(21)*	-33 *(17)*	-34 *(17)*	-39 *(17)*
30 mph/0.39 g	-8 *(18)*	-12 *(18)*	-2 *(19)*	+11 *(20)*	-15 *(21)*	-32 *(16)*	-36 *(16)*	-41 *(17)*
45 mph/Stat.	-8 *(57)*	+7 *(57)*	-7 *(57)*	-9 *(58)*	+313 *(53)*	+19 *(52)*	-1 *(53)*	-71 *(57)*
45 mph/0.15 g	-17 *(35)*	+9 *(36)*	-13 *(34)*	-44 *(32)*	-33 *(33)*	-55 *(33)*	-57 *(33)*	-62*(34)*
45 mph/0.28 g	+1 *(33)*	+1 *(30)*	+16 *(33)*	+3 *(32)*	-27 *(40)*	-58 *(29)*	-60 *(28)*	-68 *(27)*
45 mph/0.39 g	-7 *(30)*	-16 *(30)*	+6 *(31)*	+32 *(32)*	-25 *(40)*	-60 *(27)*	-63 *(27)*	-72 *(27)*
60 mph/Stat.	-23 *(62)*	-18 *(63)*	-26 *(63)*	-41 *(63)*	+56 *(77)*	+67 *(61)*	+33 *(61)*	-85 *(62)*
60 mph/0.15 g	-32 *(44)*	-7 *(45)*	-26 *(43)*	-63 *(42)*	-48 *(43)*	-74 *(41)*	-76 *(42)*	-83 *(44)*
60 mph/0.28 g	+2 *(48)*	-4 *(46)*	-31 *(47)*	+5 *(46)*	-43 *(56)*	-87 *(44)*	-90 *(43)*	-101 *(43)*
60 mph/0.39 g	+3 *(44)*	-17 *(44)*	+29 *(46)*	+68 *(48)*	-32 *(63)*	-82 *(45)*	-86 *(44)*	-99 *(44)*

Table 16 Comparison of the Mean Observed Hard Braking Onsets (which are in bolded font) to the Predicted Hard Braking Onset Ranges (in Feet) for the Various Models Examined Using the Mean Delta V's (V_{SV}–V_{POV}) Observed Across all POV Speed/POV Deceleration Combinations Examined in CAMP Study 1

			Model							
POV Speed/POV Deceleration Combination	**Delta V Assumption in mph** *(not relevant to Fixed models)*	**Mean Observed Hard Braking Onset Range for Cond.**	**RDP-Decel. Model**	**RDP-Range Model**	**Binning Model 1**	**Binning Model 2**	**Fixed Model 1** (dec_{SV}= -.3 g, dec_{POV}= -.17g)	**Fixed Model 2** (dec_{SV}= -.3 g, dec_{POV}= 0 g)	**Fixed Model 3** (dec_{SV}= -.5 g dec_{POV}= -.17 g)	**Fixed Model 4** (dec_{SV}= -.5 g dec_{POV}= 0 g)
30 mph /Stat.	29.8	***106***	106	124	116	108	228	99	90	59
30 mph/0.15 g	8.6	***39***	35	56	16	38	19	8	7	5
30 mph/0.28 g	10.4	***48***	49	49	50	36	28	12	11	7
30 mph/0.39 g	11.2	***52***	45	41	64	51	32	14	13	8
45 mph/Stat.	44.6	***205***	196	211	195	196	511	222	201	133
45 mph/0.15 g	11.4	***77***	53	80	26	56	33	14	13	9
45 mph/0.28 g	13.1	***85***	84	83	84	58	44	19	17	11
45 mph/0.39 g	14.2	***90***	84	74	120	95	52	22	20	13
60 mph/Stat.	58.0	***318***	287	293	269	284	865	375	341	225
60 mph/0.15 g	11.8	***96***	55.	83	27	59	36	16	14	9
60 mph/0.28 g	15.7	***122***	119	114	115	76	63	27	25	16
60 mph/0.39 g	16.3	***124***	121m	104	176	139	68	30	27	18

Table 17 Percent "Too Early" Hard Braking Onsets / Percent "Too Late" Predicted Hard Braking Onsets (the "Too Late" Onsets are in Bolded Font) Across all POV Speed/POV Deceleration Combinations Examined in CAMP Study 1

Definitions of "Too Early" and "Too Late" Predicted Hard Braking Onset Ranges

A *too early* predicted "hard" braking onset range is defined to occur when the predicted "hard" braking onset range is greater than the observed braking onset range during the last-second, "normal braking instruction" condition.

A *too late* predicted "hard" braking onset range is defined to occur when the predicted "hard" braking onset range is less than the observed "hard" braking range during the last-second, "hard braking instruction" condition.

	Model							
POV Speed / POV Deceleration Combination	**RDP-Decel. Model**	**RDP-Range Model**	**Binning Model 1**	**Binning Model 2**	**Fixed Model 1 (dec_{SV}= -.3 g, dec_{POV}= -.17g)**	**Fixed Model 2 (dec_{SV}= -.3 g, dec_{POV}= 0 g)**	**Fixed Model 3 (dec_{SV}= -.5 g, dec_{POV}= -.17 g)**	**Fixed Model 4 (dec_{SV}= -.5 g, dec_{POV}= 0 g)**
30 MPH /Stat.	5 / **16**	8 / **4**	5 / **10**	6 / **6**	88 / **1**	2 / **29**	0 / **38**	0 / **99**
30 MPH/0.15 g	2 / **12**	18 / **1**	2 / **11**	0 / **66**	0 / **53**	0 / **98**	0 / **99**	0 / **100**
30 MPH/0.28 g	5 / **9**	6 / **10**	19 / **28**	6 / **9**	1 / **41**	0 / **99**	0 / **99**	0 / **100**
30 MPH/0.39 g	4 / **30**	3 / **41**	7 / **20**	36 / **6**	2 / **52**	0 / **98**	0 / **98**	0 / **100**
45 MPH/Stat.	3 / **13**	5 / **8**	3 / **12**	3 / **13**	99 / **0**	8 / **7**	3 / **9**	0 / **89**
45 MPH/0.15 g	1 / **11**	7 / **3**	2 / **11**	0 / **91**	0 / **58**	0 / **100**	0 / **100**	0 / **100**
45 MPH/0.28 g	8 / **7**	8 / **6**	13 / **15**	11 / **7**	1 / **32**	0 / **93**	0 / **97**	0 / **99**
45 MPH/0.39 g	10 / **15**	5 / **25**	23 / **8**	56 / **5**	2 / **47**	0 / **99**	0 / **99**	0 / **99**
60 MPH/Stat.	1 / **22**	1 / **22**	1 / **25**	0 / **35**	100 / **0**	21 / **1**	11 / **6**	0 / **69**
60 MPH/0.15 g	0 / **19**	3 / **2**	1 / **20**	0 / **95**	0 / **64**	0 / **100**	0 / **100**	0 / **100**
60 MPH/0.28 g	6 / **5**	7 / **6**	11 / **10**	16 / **4**	0 / **24**	0 / **94**	0 / **97**	0 / **100**
60 MPH/0.39 g	20 / **10**	6 / **16**	36 / **6**	66 / **1**	3 / **38**	0 / **96**	0 / **98**	0 / **100**

Fixed Modeling Efforts

Four modeling approaches examined crash alert timing approaches that assumed both fixed (or constant) driver decelerations rates (decSV) and fixed lead vehicle (or POV) decelerations (decPOV) rates. These deceleration assumptions are characteristic of current crash alert timing approaches. The four combinations of the assumed driver deceleration and lead vehicle deceleration rates are shown below, along with the corresponding model name. It should be noted that Fixed Model 2 and Fixed Model 4 below were the working assumptions for cautionary and imminent crash alert timing as part of CAMP's initial 2-stage alert timing approach, prior to the results obtained from the CAMP Task 4 Human Factors Studies discussed in this report.

Table 18 Fixed Modeling Efforts

Model Name	**Assumed dec_{SV}**	**Assumed dec_{POV}**
Fixed Model 1	-0.30g's	-0.17g's
Fixed Model 2	-0.30g's	0 g's
Fixed Model 3	-0.50g's	-0.17g's
Fixed Model 4	-0.50g's	-0g's

These assumptions were input into the Case 2 equation discussed above, which is shown again below, to calculate the predicted hard braking onset range.

$$R = \frac{(V_{SV} - V_{POV})^2}{-2*(dec_{SV} - dec_{POV})}$$

The right half of Table 15 provides average range residuals for each of these Fixed models across all POV speed/POV deceleration combinations examined in CAMP Study 1. The right half of Table 16 provides predicted hard braking onset ranges for these models across all POV speed/POV deceleration combinations in CAMP Study 1. Finally, results from the too early/too late analysis for these Fixed models are shown in the right half of Table 17 for each POV speed/POV deceleration combination in CAMP Study 1. These results indicate that the predicted hard braking onsets are substantially later relative to the RDP Models discussed earlier across nearly all POV speed/POV deceleration combinations. Results from the too early/too late analysis indicate, across nearly all POV speed/POV deceleration combinations, a near total absence of "too early" predicted "hard" braking onsets, and an extremely high percentage of "too late" responses (particularly when the lead vehicle is moving).

Summary of Modeling Efforts

Together, results from these eight models clearly indicate that a great deal of predictive value is lost if lead vehicle (POV) deceleration cannot be measured. In each of the Required Deceleration Parameter (RDP) and Binning modeling efforts discussed above, POV deceleration was the first variable entered into a stepwise regression, since it accounted for the most variance.

The RDP-Deceleration model was ultimately chosen for crash alert timing purposes in the subsequent three FCW system driver interface studies. This model is distinctly different from commonly employed FCW warning algorithms used for crash alert timing approaches (as well as "benefits" modeling), which assume fixed driver deceleration rates independent of driver speed and lead vehicle deceleration rates. Under the RDP-Deceleration model, the assumed driver deceleration varies as a function of both the speed difference between the two vehicles (i.e., delta V) and lead vehicle deceleration levels. In the remainder of this report, the equation resulting from this RDP-Deceleration model will subsequently be referred to as the *CAMP RDP equation* for brevity purposes. Earlier in this appendix, this equation predicted required deceleration values in feet/second^2. The equation below provides an equivalent, perhaps more accessible, version of this equation, which predicts required deceleration in g's. In this equation, braking deceleration values are represented as negative values, and the following notation and measurement units are employed:

dec_{REQ} = required deceleration of the SV, expressed in g's (negative for braking)

dec_{POV} = deceleration level of the lead vehicle (or Principal Other Vehicle), expressed in g's

V_{SV} = velocity of the Subject Vehicle (or SV), expressed in meters/sec

V_{POV} = velocity of the Principal Other Vehicle (or POV) velocity, expressed in meters/sec

("if POV moving" is set to 0 if the POV is projected to be stopped at braking onset, and is set to 1 if the POV is projected to be moving at braking onset).

CAMP RDP Equation

$$dec_{REQ} = -0.165 + 0.685(dec_{POV}) + 0.080(\text{if POV moving}) - 0.00877(V_{SV} - V_{POV})$$

On a final note, the reader should be reminded that the underlying assumption is that properly characterizing (i.e., modeling) the kinematic conditions surrounding these hard braking onsets without FCW system crash alert support (i.e., the RDP-Deceleration model) will lead to a proper estimate for the assumed driver deceleration (or braking) behavior in response to a FCW system crash alert across a wide variety of initial vehicle-to-vehicle kinematic conditions. This assumption eventually received strong support in the subsequent three FCW system driver interface studies, both from a driver performance and driver preference perspective. Hence, these results clearly indicate the added value obtained by gathering data under highly valid, controlled, realistic conditions involving a wide range of typical drivers braking a real car on a real road to a realistic crash threat.

REFERENCES

American National Standards Institute (ANSI 1997). Criteria for Safety Symbols, Annex B: Procedures for evaluating symbols, ANSI Z535.3-1997.

ISO 3461 (1976). *Graphic symbols – General principles for presentation.* International Organization for Standardization. Switzerland.

Jovanis P.P., Campbell, J., Klaver K., & Chen, W. (1997). Driver preferences for visual and auditory collision warning alerts. *Proceedings of the 4th Annual World Congress on Intelligent Transport Systems.* ITS America. Berlin, Germany.

Tan, A. K., and Lerner, N. D. (1995). *Multiple attribute evaluation of auditory warning signals for in-vehicle crash avoidance warning systems.* (Report No. DOT-HS-808-535). U.S. Department of Transportation. Washington, DC.