Dynamic Research, Inc.

BRIEF SUMMARY OF A FURTHER ANALYSIS OF THE EFFECTS OF SUV WEIGHT AND LENGTH CHANGES ON SUV CRASHWORTHINESS AND COMPATIBILITY USING FLEET MODELING AND RISK-BENEFIT ANALYSIS

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Section I
INTRODUCTION

The objective of this study was to further evaluate the effects of SUV weight and length changes on crashworthiness based on the 2004 analysis (Ref 1). A sensitivity analysis technique was applied to the fleet model developed in the previous analysis in order to reduce the confidence intervals on driver injury results by expanding the number of accidents cases. This draft summary provides initial results of this further analysis.

In the previous study, only the case vehicle SUV's weight and length were changed, representing a situation where only a portion of the SUV fleet has a reduced weight or increased crush zone. The results of that analysis indicated that reducing the weight of the case SUV is beneficial to the driver of the opposing vehicle but harmful to the driver of the lighter SUV, providing positive net benefits when both drivers are considered together. Adding length to the front end of the case SUV was beneficial to both drivers.

In the study reported herein, the opposing vehicle SUV was also changed in weight and length, representing a situation where the entire SUV fleet has a reduced weight or increased crush zone. Furthermore, situations were analyzed in which the case vehicle SUV was modified such that it had a combination of reduced weight and increased length. This was done in order to investigate the combined effects of changes in both weight and length, which may mitigate the harmful effects of weight reduction for the case SUV driver that was found in the previous study, while still realizing substantial weight reduction.

Section II
METHODOLOGY

The methodology used in this analysis is an extension of the methodology described in Ref 1. The analysis involved computer crash simulations with the Articulated Total Body (ATB) models calibrated against New Car Assessment Program (NCAP) crash tests. For the previous study, 500 crash cases involving single vehicle and two vehicle crashes were sampled from 6 years (1997-2002) of the National Accident Sampling System/Crashworthiness Data System (NASS/CDS) database, and classified into four types: rollover, hit object, hit passenger car (PC), and hit light trucks and vans (LTV) accidents. For each crash case, three different SUV configurations were investigated for the case vehicle: a baseline SUV, a reduced weight SUV, and an increased length SUV. In two-vehicle crashes, the impact partner vehicle was either a baseline PC or a baseline SUV. Based on the simulation results, driver injuries were calculated, and risk-benefit analysis was done for each alternative SUV configuration and crash type.

The baseline SUV configuration was run for comparison purposes. The reduced weight SUV configuration was intended to represent a realistic, achievable weight (20% reduction in mass) with the use of lightweight materials. The increased length SUV configuration was intended to represent a longer front end design (4.6 inch increase) yielding a softer crash pulse with no change in weight, enabled by lightweight materials. In the previous study, the alternative configurations were only applied to the case vehicle SUV and not to the opposing vehicle SUV.

A. SENSITIVITY ANALYSIS

In the previous study (Ref. 1), a case vehicle SUV was simulated in 1) rollover, 2) hit object, 3) hit passenger car (PC), and 4) hit light trucks and vans (LTV) accidents. In this study, sensitivity technique was employed in order to expand the number of accident cases by a factor of six for each accident category according to Table 1. This was done in order to increase the statistical degrees of freedom and therefore reduce the confidence intervals on the injury results.

Table 1. Perturbations for Sensitivity Analysis

<table>
<tr><th></th><th>Rollover</th><th>Hit object</th><th>Hit PC</th><th>Hit LTV</th></tr>
<tr><td>1</td><td>$v_1 \to v_1 - 2$ mph</td><td>$v_1 \to v_1 - 2$ mph</td><td colspan="2">$v_1 \to v_1 - 2$ mph</td></tr>
<tr><td>2</td><td>$v_1 \to v_1 + 2$ mph</td><td>$v_1 \to v_1 + 2$ mph</td><td colspan="2">$v_1 \to v_1 + 2$ mph</td></tr>
<tr><td>3</td><td>$\beta \to \beta - 2^\circ$</td><td>$v_1 \to v_1 - 4$ mph</td><td colspan="2">$v_2 \to v_2 - 2$ mph</td></tr>
<tr><td>4</td><td>$\beta \to \beta + 2^\circ$</td><td>$v_1 \to v_1 + 4$ mph</td><td colspan="2">$v_2 \to v_2 + 2$ mph</td></tr>
<tr><td>5</td><td>$\dot{\psi} \to \dot{\psi} - 2\ {}^\circ/\text{sec}$</td><td>$IP \to IP - 3$ in (narrow objects)
$RHA \to RHA - 5^\circ$ (wide objects)</td><td colspan="2">$RHA \to RHA - 5^\circ$</td></tr>
<tr><td>6</td><td>$\dot{\psi} \to \dot{\psi} + 2\ {}^\circ/\text{sec}$</td><td>$IP \to IP + 3$ in (narrow objects)
$RHA \to RHA + 5^\circ$ (wide objects)</td><td colspan="2">$RHA \to RHA - 5^\circ$</td></tr>
</table>

where

v_1 : impact speed of the case vehicle
v_2 : impact speed of the partner vehicle
β : side slip angle (in rollover accidents)
$\dot{\psi}$: yaw rate
IP : impact point
RHA : relative heading angle

B. FLEET MODEL

The above mentioned sensitivity analysis technique was applied to the following three different fleet models:

1) The case vehicle has alternative SUV configurations while the opposing vehicle SUV is the baseline SUV, i.e., a portion of the SUV fleet has a reduced weight or increased crush zone. This is the same model developed for the 2004 analysis.

2) Both case and opposing vehicles have lighter or longer SUV configuration, i.e., the entire SUV fleet has a reduced weight or increased crush zone.

3) The case vehicle SUV has a combination of reduced weight and increased length while the opposing vehicle is the baseline vehicle SUV.

Table 2. Fleet Models Used in This Study

Fleet Model	Case Vehicle SUV	Opposing Vehicle SUV
1 (reference)	Baseline	Baseline
1	Lighter	Baseline
1	Longer	Baseline
2	Lighter	Lighter
2	Longer	Longer
3	Lighter & Longer	Baseline

C. NET BENEFIT CALCULATION BASED ON IMPACT LOCATIONS

Equivalent Life Units (ELU) and net benefits were also calculated with respect to different impact locations (front, back, left, and right) involving non-rollover (hit object, hit PC, and hit LTV) accidents.

Section III
ANALYSIS 1: SENSITIVITY ANALYSIS OF LIGHTWEIGHT AND LONGER SUV CASE VEHICLES

The sensitivity analysis technique described in Section II was applied to the existing models involving a baseline weight SUV vehicle (baseline vehicle), lightweight SUV case vehicle with no change in length (lighter vehicle), and a SUV case vehicle with increased length (longer vehicle), impacting a baseline weight passenger car (PC) and a baseline weight SUV impact partner. The case vehicle was simulated in rollover, hit object, hit PC, and hit LTV accidents. The increased length SUV case vehicle and the longer SUV case vehicle both have reduced frontal force-deflection characteristics compared with the baseline weight SUV.

Table 3. Total Injuries in ELU for Each Vehicle Configuration Involving Baseline, Lightweight, and Longer Case Vehicles and Baseline Partner Vehicles (Analysis 1)

	Crash Type	Number of Cases	Total ELU's			Net Benefits	
			Baseline Vehicle	Lighter Vehicle	Longer Vehicle	Lighter Vehicle	Longer Vehicle
Case SUV Driver	Rollover	175	2.23	2.48	0.53	-11.2%	76.2%
	Hit Object	420	2.54	1.74	0.81	31.5%	68.1%
	Hit PC	1750	1.21	2.47	1.19	-104.1%	1.7%
	Hit Baseline LTV	1155	25.97	34.02	26.27	-31.0%	-1.2%
	Subtotal	3500	31.95	40.71	28.80	-27.4%	9.9%
Other Vehicle Driver	In PC	1750	28.00	9.70	16.79	65.4%	40.0%
	In Baseline LTV	1155	25.99	11.28	19.59	56.6%	24.6%
	Subtotal	2905	53.99	20.98	36.38	61.1%	32.6%
	Total	6405	85.94	61.69	65.18	28.2%	24.2%

Table 4. Net Benefit for Reduced Weight and Increased Length SUV Involving Lightweight and Longer Case Vehicles and Baseline Partner Vehicles (Analysis 1)

Configuration	Driver	Net Benefit	
		Sensitivity Analysis	2004 Analysis
Reduced weight SUV (20% reduction) with no change in length	SUV Driver	-27.4%	-53.0%
	OV Driver	61.1%	58.9%
	Both Drivers	28.2%	15.1%
Increased length SUV (4.6 inch increase) with no change in weight	SUV Driver	9.9%	12.5%
	OV Driver	32.6%	34.9%
	Both Drivers	24.2%	26.1%

Table 5. Total Injuries in ELU and Net Benefits for Each Impact Location Involving Baseline, Lightweight, and Longer Case Vehicles and Baseline Partner Vehicles (Analysis 1)

	Impact Location	Number of Cases	Total ELU's			Net Benefits	
			Baseline Vehicle	Lighter Vehicle	Longer Vehicle	Lighter Vehicle	Longer Vehicle
Case SUV Driver	Front	2093	20.33	24.39	18.59	-20.0%	8.6%
	Back	154	2.51	2.69	0.95	-7.2%	62.2%
	Left	525	5.25	8.34	6.83	-58.9%	-30.1%
	Right	553	1.64	2.81	1.91	-71.3%	-16.5%
	Subtotal	3325	29.73	38.23	28.28	-28.6%	4.9%
Other Vehicle Driver	Front	1897	33.94	15.05	27.16	55.7%	20.0%
	Back	245	11.07	1.46	3.22	86.8%	70.9%
	Left	301	7.29	4.17	5.46	42.8%	25.1%
	Right	462	1.69	0.31	0.54	81.7%	68.0%
	Subtotal	2905	53.99	20.99	36.38	61.1%	32.6%
	Total	6230	83.72	59.22	64.66	29.3%	22.8%

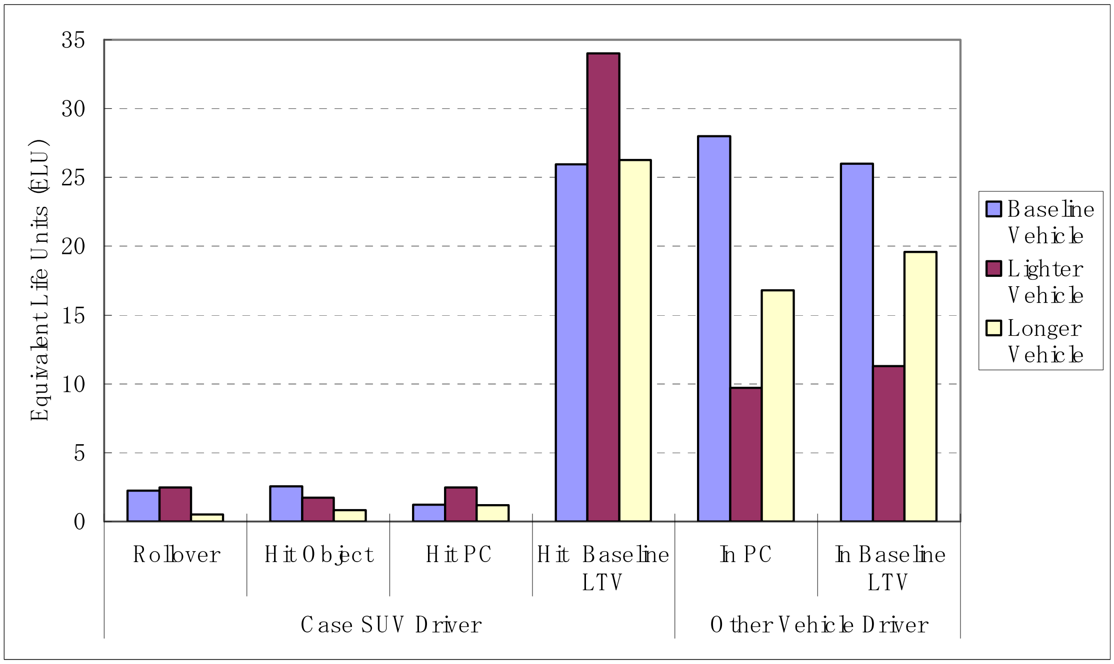

Figure 1. Comparison of ELU for each vehicle configuration with Respect to Crash Types Involving Baseline, Lightweight, and Longer Case Vehicles and Baseline Partner Vehicles (Analysis 1)

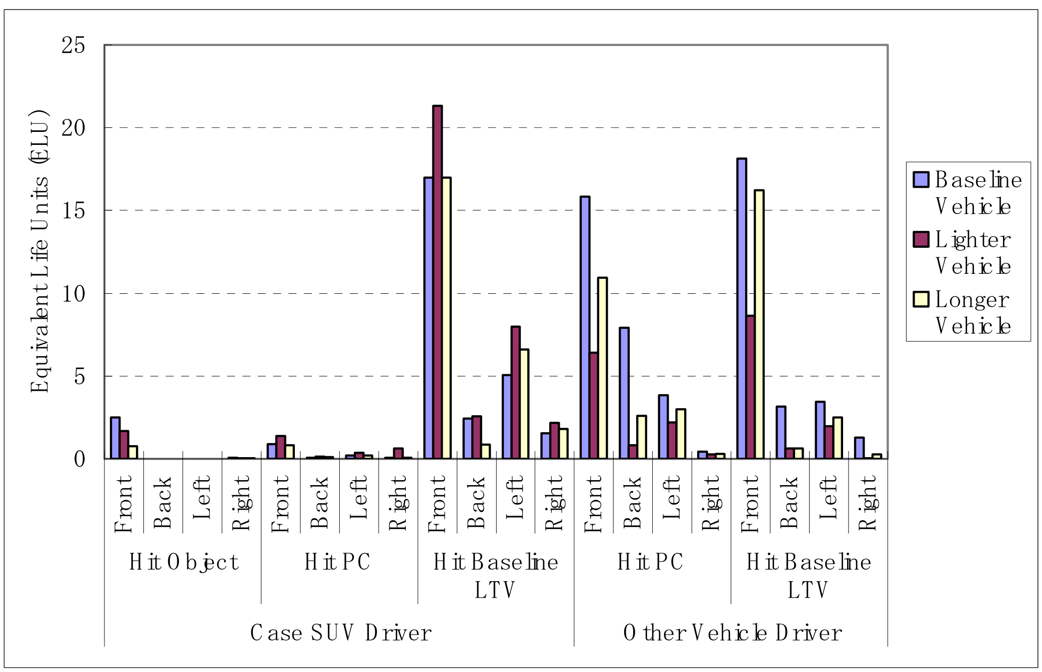

Figure 2. Comparison of ELU for each vehicle configuration with Respect to Crash Types and Impact Locations Involving Baseline, Lightweight, and Longer Case Vehicles and Baseline Partner Vehicles (Analysis 1)

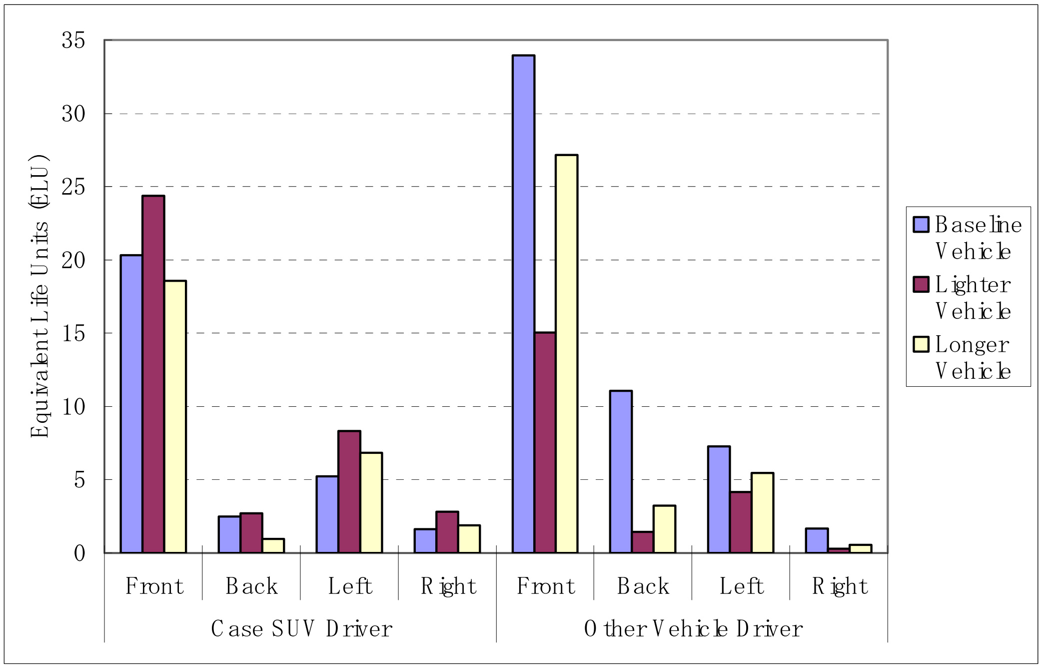

Figure 3. Comparison of ELU for each vehicle configuration with Respect to Impact Locations Involving Baseline, Lightweight, and Longer Case Vehicles and Baseline Partner Vehicles (Analysis 1)

Section IV

ANALYSIS 2: SENSITIVITY ANALYSIS OF LIGHTWEIGHT SUV CASE VEHICLES AND COLLISION PARTNERS

A sensitivity analysis technique was applied to the exiting models involving the same SUV case vehicles used in Analysis 1 impacting a baseline weight passenger car (PC) and lightweight or longer SUV impact partners. In other words, for hit LTV accidents, the case vehicle is the lightweight or longer SUV model, and the impact LTV partner is also the same lightweight or longer SUV model. This requires hit LTV accidents only since the results of Analysis 1 can be used for the other crash types.

Table 6. Total Injuries in ELU for Each Vehicle Configuration Involving Lightweight or Longer Case Vehicles and Lightweight or Longer Partner Vehicles (Analysis 2)

	Crash Type	Number of Cases	Total ELU's			Net Benefits	
			Baseline Vehicle	Lighter Vehicle	Longer Vehicle	Lighter Vehicle	Longer Vehicle
Case SUV Driver	Rollover	175	2.23	2.48	0.53	-11.2%	76.2%
	Hit Object	420	2.54	1.74	0.81	31.5%	68.1%
	Hit PC	1750	1.21	2.47	1.19	-104.1%	1.7%
	Hit Lightweight or Longer LTV	1155	25.97	22.03	21.61	1.52%	16.8%
	Subtotal	3500	31.95	28.72	24.14	10.1%	24.4%
Other Vehicle Driver	In PC	1750	28.00	9.70	16.79	65.4%	40.0%
	In Lightweight or Longer LTV	1155	25.99	23.40	22.09	10.0%	15.0%
	Subtotal	2905	53.99	33.10	38.88	38.7%	28.0%
	Total	6405	85.94	61.82	63.02	28.1%	26.7%

Table 7. Net Benefit for Reduced Weight and Increased Length SUV Involving Lightweight or Longer Case Vehicles and Lightweight or Longer Partner Vehicles (Analysis 2)

Configuration	Driver	Net Benefit
Reduced weight SUV (20% reduction) with no change in length	SUV Driver	10.1%
	OV Driver	38.7%
	Both Drivers	28.1%
Increased length SUV (4.6 inch increase) with no change in weight	SUV Driver	24.4%
	OV Driver	28.0%
	Both Drivers	26.7%

Table 8. Total Injuries in ELU and Net Benefits for Each Impact Location involving Lightweight or Longer Case Vehicles and Lightweight or Longer Partner Vehicles (Analysis 2)

	Impact Location	Number of Cases	Total ELU's			Net Benefits	
			Baseline Vehicle	Lighter Vehicle	Longer Vehicle	Lighter Vehicle	Longer Vehicle
Case SUV Driver	Front	2093	20.33	20.92	19.66	-2.9%	3.3%
	Back	154	2.51	1.32	0.30	47.4%	88.0%
	Left	525	5.25	3.25	3.46	38.1%	34.1%
	Right	553	1.64	0.75	0.20	54.3%	87.8%
	Subtotal	3325	29.73	26.24	23.62	11.7%	20.6%
OV Driver	Front	1897	33.94	24.57	29.69	27.6%	12.5%
	Back	245	11.07	2.69	3.03	75.7%	72.6%
	Left	301	7.29	5.13	5.62	29.6%	22.9%
	Right	462	1.69	0.72	0.54	57.4%	68.0%
	Subtotal	2905	53.99	33.11	38.88	38.7%	28.0%
	Total	6230	83.72	59.35	62.50	29.1%	25.3%

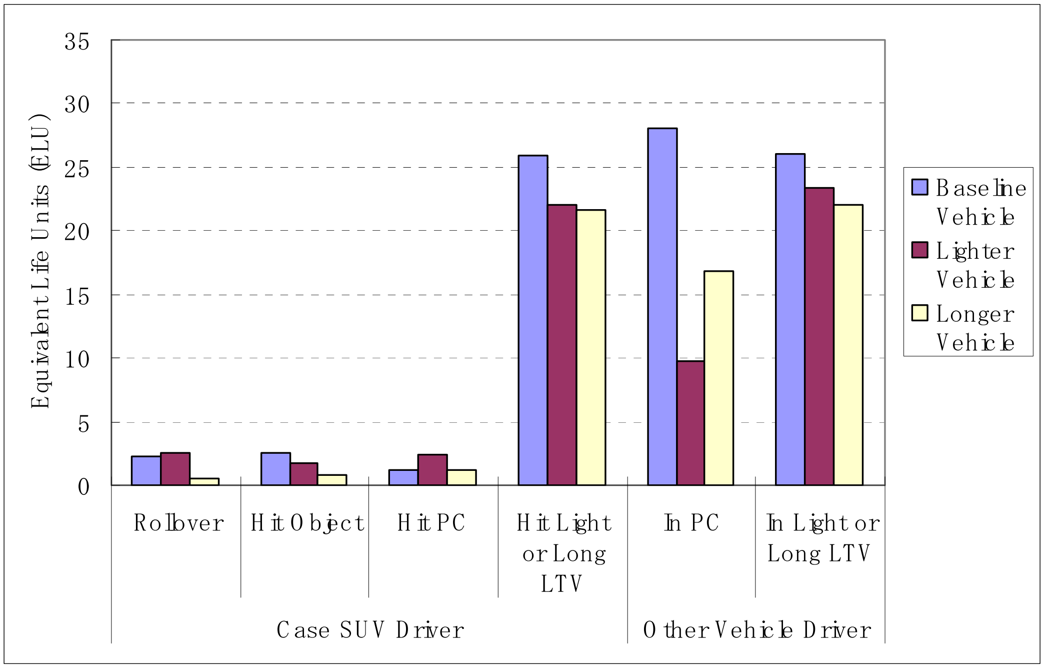

Figure 4. Comparison of ELU for each vehicle configuration with Respect to Crash Types Involving Lightweight or Longer Case Vehicles and Lightweight or Longer Partner Vehicles (Analysis 2)

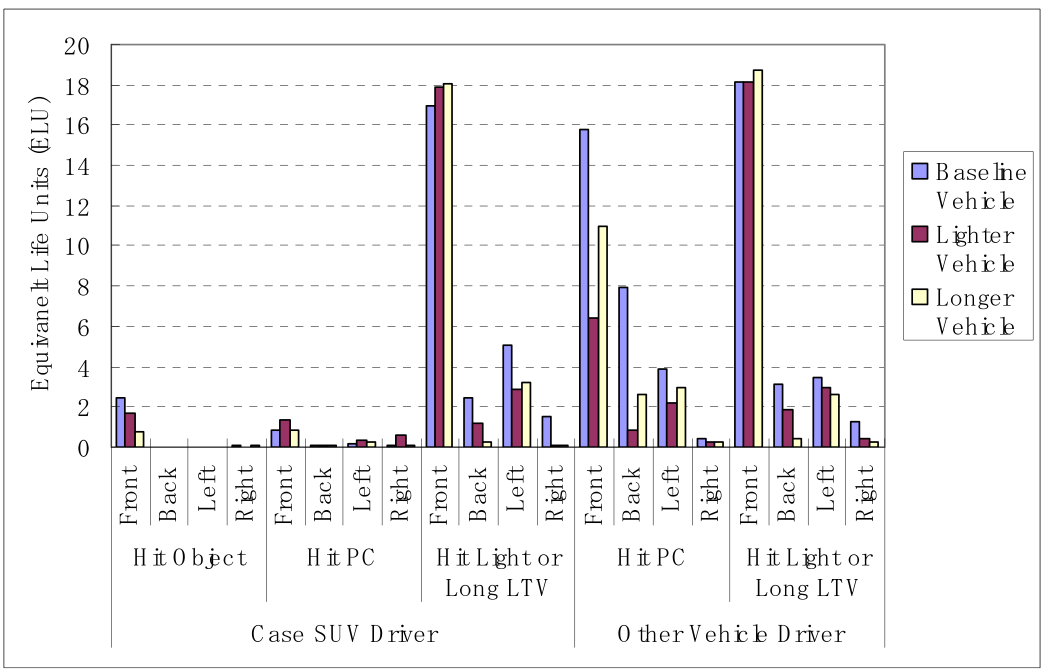

Figure 5. Comparison of ELU for each vehicle configuration with Respect to Crash Types and Impact Locations Involving Lightweight or Longer Case Vehicles and Lightweight or Longer Partner Vehicles (Analysis 2)

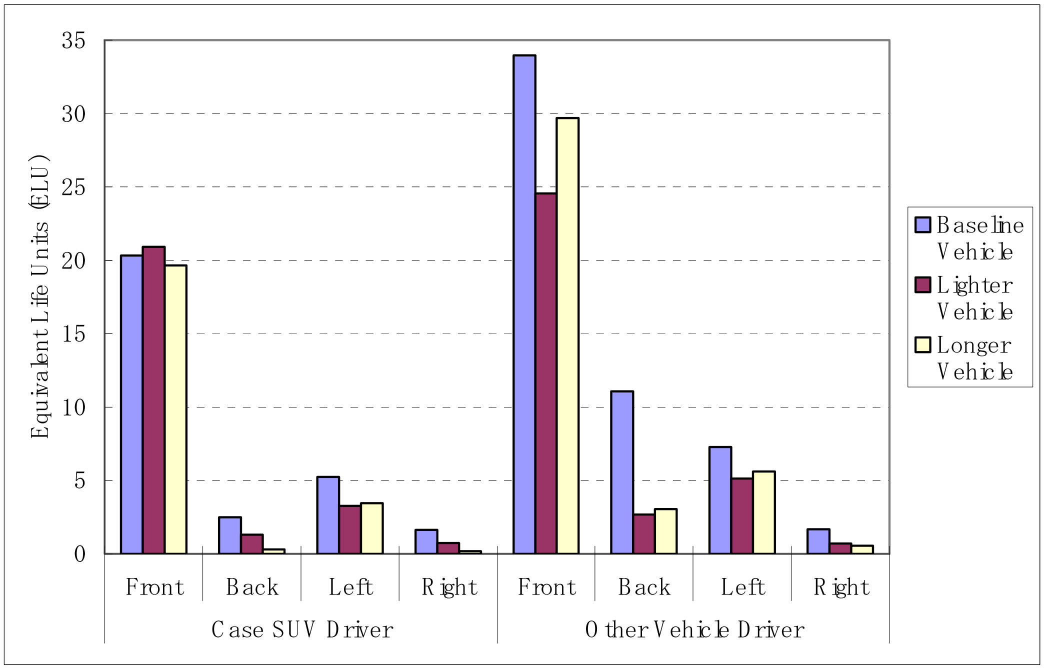

Figure 6. Comparison of ELU for Each Vehicle Configuration with Respect to Impact Locations Involving Lightweight or Longer Case Vehicles and Lightweight or Longer Partner Vehicles (Analysis 2)

Section V
ANALYSIS 3: SIMULATIONS WITH VARIOUS COMBINATIONS OF REDUCED MASS AND INCREASED LENGTH

Using data provided by the Aluminum Association, the lightweight SUV was increased in length and weight in order to investigate whether adding crush space to the front of the light weight SUV could mitigate the harmful effects to the SUV driver of light-weighting. This was done by adding weight back into the SUV model corresponding to a particular length increase. The new longer, lightweight SUV model was developed by adding 4 inches and 30 pounds to the front of the lightweight SUV, resulting in a “softer” crash pulse, i.e. a decreased amplitude and longer duration acceleration pulse. A sensitivity analysis technique was applied to the existing models involving this longer, lightweight SUV case vehicle and baseline SUV impact partner.

Table 9. Total Injuries in ELU for Each Vehicle Configuration Involving Lightweight and Increased Length Case Vehicle, and Baseline Partner Vehicle (Analysis 3)

	Crash Type	Number of Cases	Total ELU's: Baseline Vehicle	Total ELU's: Lighter, Longer Vehicle	Net Benefits: Lighter, Longer Vehicle
Case SUV Driver	Rollover	175	2.23	3.00	-34.5%
	Hit Object	420	2.54	0.70	72.4%
	Hit PC	1750	1.21	2.27	-87.6%
	Hit Baseline LTV	1155	25.97	29.49	-13.6%
	Subtotal	3500	31.95	35.46	-11.0%
Other Vehicle Driver	In PC	1750	28.00	8.32	70.3%
	In Baseline LTV	1155	25.99	6.16	76.3%
	Subtotal	2905	53.99	14.48	73.2%
	Total	6405	85.94	49.94	41.9%

Table 10. Net Benefit for Reduced Weight and Increased Length SUV Involving Lightweight and Increased Length Case Vehicle, and Baseline Partner Vehicle (Analysis 3)

Configuration	Driver	Net Benefit
Reduced weight and Increased length SUV	SUV Driver	-11.0%
	OV Driver	73.2%
	Both Drivers	41.9%

Table 11. Total Injuries in ELU and Net Benefits for Each Impact Location Involving Lightweight and Increased Length Case Vehicle, and Baseline Partner Vehicle (Analysis 3)

	Impact Location	Number of Cases	Total ELU's		Net Benefits
			Baseline Vehicle	Lighter, Longer Vehicle	Lighter, Longer Vehicle
Case SUV Driver	Front	2093	20.33	19.86	2.3%
	Back	154	2.51	1.24	50.6%
	Left	525	5.25	8.28	-57.7%
	Right	553	1.64	3.08	-87.8%
	Subtotal	3325	29.73	32.46	-9.2%
OV Driver	Front	1897	33.94	10.37	69.4%
	Back	245	11.07	0.44	96.0%
	Left	301	7.29	3.39	53.5%
	Right	462	1.69	0.28	83.4%
	Subtotal	2905	53.99	14.48	73.2%
	Total	6230	83.72	46.94	43.9%

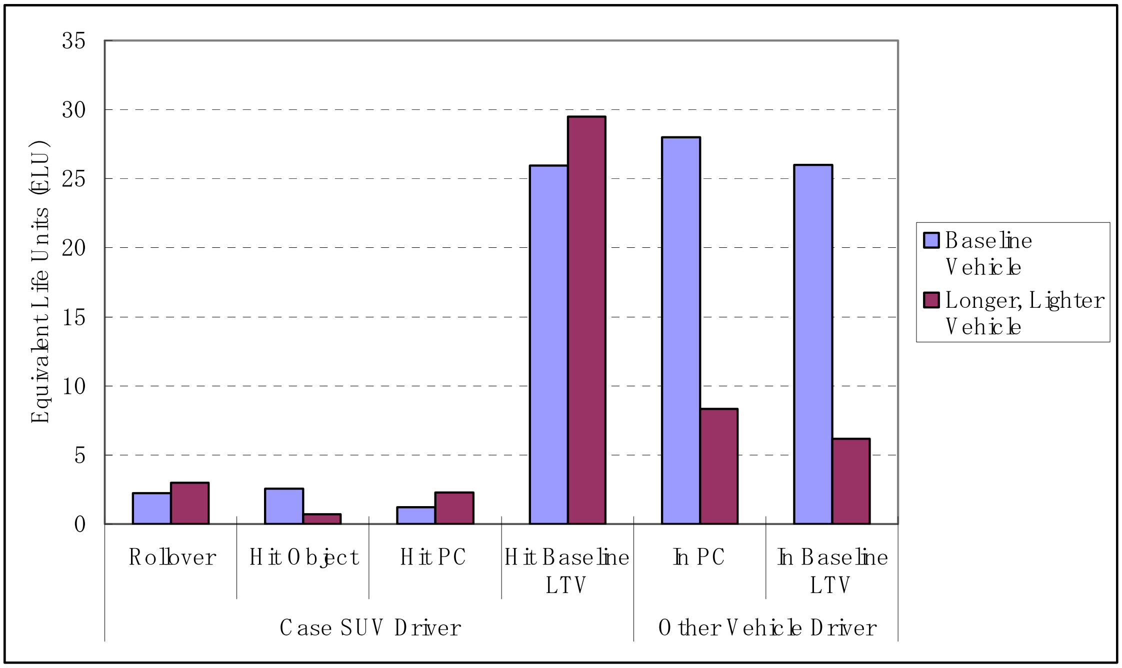

Figure 7. Comparison of ELU for each vehicle configuration with Respect to Crash Types Involving Lightweight and Increased Length Case Vehicle, and Baseline Partner Vehicle (Analysis 3)

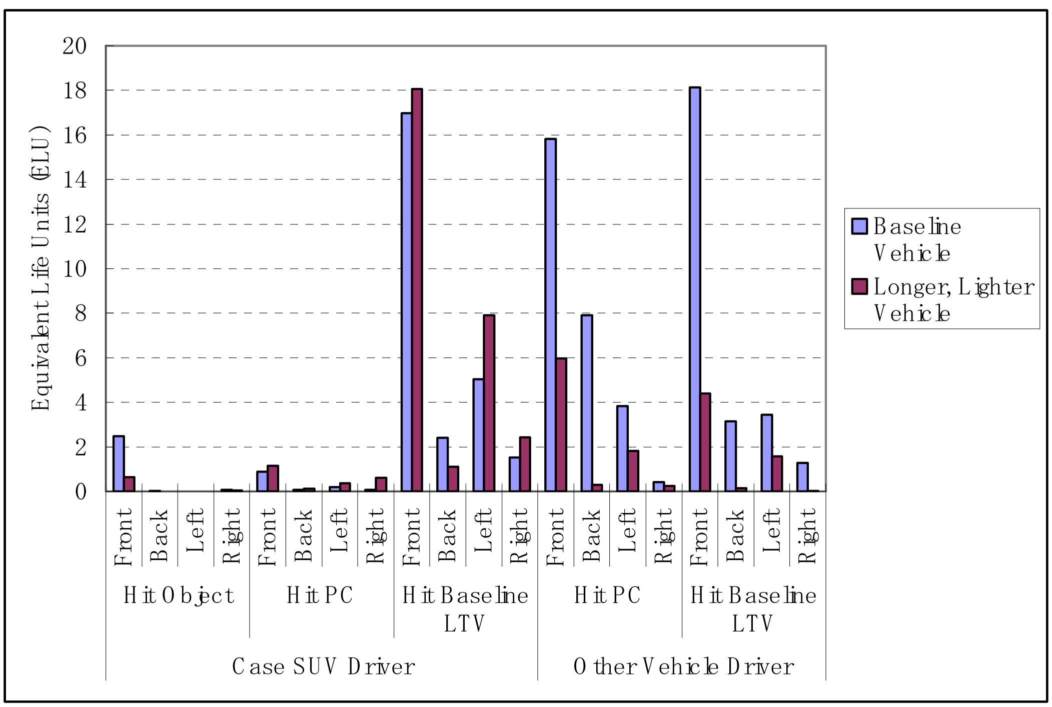

Figure 8. Comparison of ELU for each vehicle configuration with Respect to Crash Types and Impact Locations Involving Lightweight and Increased Length Case Vehicle and Baseline Partner Vehicle (Analysis 3)

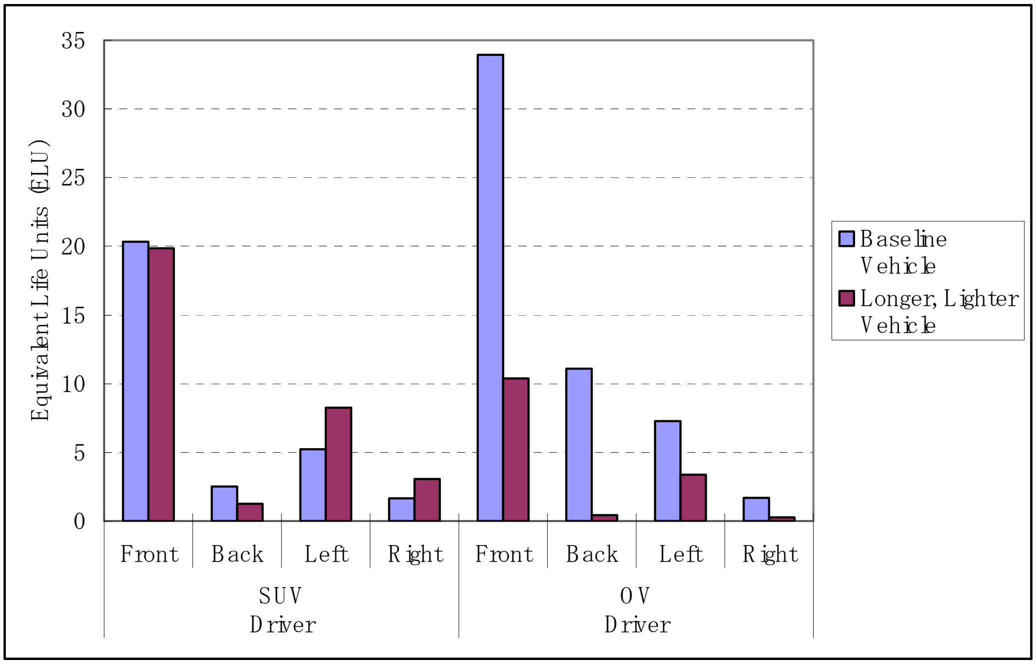

Figure 9. Comparison of ELU for Each Vehicle Configuration with Respect to Impact Locations Involving Lightweight and Increased Length Case Vehicle, and Baseline Partner Vehicle (Analysis 3)

Section VI
SUMMARY

A. ANALYSIS 1

Sensitivity analysis results of the existing fleet models involving lightweight and longer case SUVs and baseline weight impact partner vehicles (Analysis 1) produced somewhat different results than those obtained in the 2004 analysis. Compared to the 2004 analysis,

- Net benefit to the lighter case SUV driver improved (from -53.0% to -27.4%) though it is still negative, and net benefit to the OV driver improved slightly (from 58.9% to 61.1%) yielding increased net benefits to both drivers (15.1% to 28.2%).

- Net benefits to the longer case SUV driver, OV driver, and both drivers all decreased slightly (from 12.5% to 9.9%, from 34.9% to 32.6%, and from 26.1% to 24.2%, respectively) compared with the 2004 analysis.

B. ANALYSIS 2

Comparison of “lightweight case SUV vs. baseline partner SUV” (Analysis 1) and “lightweight case SUV vs. lightweight SUV” (Analysis 2) models indicates that

- Whether the partner SUV has a baseline or reduced weight, net benefits to both drivers involving lightweight case vehicle SUVs, are comparable (28.2% in Analysis 1 and 28.1% in Analysis 2) because

- Net benefits to the driver of the lightweight case SUV increased (from -27.4% to 10.1%) in all impact directions while net benefits to the OV driver decreased (from 61.1% to 38.7%) in all impact directions when the partner SUV weight was reduced from the baseline.

Comparison of “longer case SUV vs. baseline partner SUV” (Analysis 1) and “longer case SUV vs. longer SUV” (Analysis 2) models indicates that

- Net benefit to both drivers, involving longer case SUVs, improves slightly when the partner SUV is also increased in length (24.2% in Analysis 1 and 26.7% in Analysis 2) because

- Net benefits to the driver of the longer case SUV increased (from 9.9% to 24.4%) especially in side impacts while net benefits to the driver of the partner vehicle decreased (from 32.6% to 28.0%) when the partner SUV has a longer front end with a softer crash pulse.

If the partner SUV as well as the case vehicle SUV are reduced in weight or increased in length, injury risk of the lighter or longer case SUV driver decreases while benefit to the partner SUV driver remains positive though decreases compared to the situation where the impact partner is the baseline vehicle SUV.

C. ANALYSIS 3

Four inches of length (crush zone) were added to the front of the lightweight case SUV and 30 lb corresponding to this increase in length were added back in to the chassis, resulting in a “softer” crash pulse, i.e., a decreased amplitude and longer duration acceleration pulse (Analysis 3). The partner vehicle was the baseline weight SUV vehicle. Comparison of “lighter or longer case SUV vs. baseline partner SUV” (Analysis 1) and “lighter and longer case SUV vs. baseline SUV” (Analysis 3) models indicates that a combination of weight reduction and length increase with a softer crash pulse leads to:

– The highest net benefit (41.9%) of any of the analyzed configurations for both drivers compared to those of lightweight SUVs (28.2%) and longer SUVs (24.2%) due to

– Improvement for the case vehicle SUV driver (though still negative net benefit) compared to the Analysis 1 case vehicle driver (from -27.4% to -11%) and

– Improvement also for the OV driver (61.1% to 73.2%)

– Improvement is seen in the front and rear impact performance but not in side impact performance.

Table 12. Comparison of Net Benefit for Analyses 1-3

Case Vehicle	Driver	Net Benefit			
		Opposing Vehicle			
		Baseline Weight Opposing SUV		Reduced Weight Opposing SUV	
Reduced weight SUV (20% reduction) with no change in length	SUV Driver	Analysis 1	-27.4%	Analysis 2	10.1%
	OV Driver		61.1%		38.7%
	Both Drivers		28.2%		28.1%
Increased length SUV (4.6 inch increase) with no change in weight	SUV Driver		9.9%		24.4%
	OV Driver		32.6%		28.0%
	Both Drivers		24.2%		26.7%
Increased length (4 inch increase), reduced weight (19% reduction) SUV with 30lb increase in weight	SUV Driver	Analysis 3	-11.0%		
	OV Driver		73.2%		
	Both Drivers		41.9%		

REFERENCES

1. Kebschull, S.A., Kelly, J., Van Auken, R.M., and Zellner, J.W., "An Analysis of the Effects of SUV Weight and Length on SUV Crashworthiness and Compatibility using Systems Modeling and Risk-Benefit Analysis," DRI-TR-04-04-2, Dynamic Research, Inc., July 2004.