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PLANNING STUDY FOR LOW SPEED DAMAGE REDUCTION SYSTEMS

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16. Abstract

This report documents the planning study intended to provide the basis from which a comprehensive study of low speed damage systems may be conducted. This planning study and the conprehensive study are in response to Title I of the Motor Vehicle Information and Cost Savings Act.

The basic design features of present bumper systems and alternative bumper systems are discussed. Methodologies for assessing the costs and benefits associated with these bumper systems are addressed. Consideration is given to a technique for determining an optimal impact test speed. Recommendations are provided for the comprehensive study. Requirements for further assessment of cost/benefit data and methodology deficiencies are delineated in draft work statements for a model of cost-price relationships, a survey of repaired and unrepaired damage, and a test program to replicate the real-world test environments.

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PREFACE

The Motor Vehicle Information and Cost Savings Act, Public Law 92-513, requires under Title I that the Secretary of Transportation promulgate bumper standards that "shall seek to obtain the maximum feasible reduction of costs to the public and to the consumer." This report documents the planning study conducted by the Transportation Systems Center in support of the National Highway Traffic Safety Administration. The material presented herein is intended to identify and provide a method for obtaining the inputs necessary for conducting a comprehensive study in response to Title I of the Public Law 92-513.

The authors would like to thank K.H. Schaeffer, G. Kovatch, J. Kakatsakis, J. Picardi, J. Jankovich, and R. Cook of TSC, and E. Swanson of Raytheon Service Company for their assistance in preparing this report.

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1. INTRODUCTION AND CONCLUSIONS

1.1 PURPOSE AND SCOPE

This report documents the planning study intended to provide the basis from which a comprehensive study of low speed damage reduction systems may be conducted. Such a comprehensive study is required under Title I of Public Law 92-513, "Motor Vehicle Information and Cost Savings Act." This law requires that the Secretary of Transportation promulgate bumper standards that "shall seek to obtain the maximum feasible reduction of costs to the public and to the consumer." The material presented herein is intended to identify and provide a method for obtaining the necessary inputs required to perform a comprehensive study. Several elements of this planning study have built upon the previous cost/benefit analysis on damage resistant bumpers performed by the Transportation Systems Center.[1-1]

1.2 BACKGROUND

Standard No. 215, entitled "Exterior Protection", first became effective on September 1, 1972 and established requirements for the impact resistance and the configuration of front and rear vehicle surfaces. The purpose of this standard is to prevent low-speed collisions from imparing the safe operation of vehicle systems, and to reduce the frequency of override or underride in higher speed collisions. Since its inception, the standard has changed considerably, and in March 1976, a new bumper standard (Part 581 of Title 49) was issued under the authority of Title I of Public Law 92-513. This new standard, which becomes effective beginning September 1, 1978, embodies many of the original requirements but specifies broader damageability requirements in an effort to reduce the economic loss to the consumer and the public.

Despite the introduction of the new standard, the following question remains: Has the maximum feasible reduction in costs to the consumer and the public been achieved? This question can only be answered by assessing both the costs and the benefits that would be associated with a particular bumper standard. This report attempts to provide the basis on which a comprehensive study can be undertaken to address this important question.

1.3 APPROACH AND CONCLUSIONS

There were two major purposes of this planning study. The first was to identify all components of costs and benefits of a particular standard and to provide techniques for their assessment. The second was to find a method of determining an optimal bumper impact protection speed.

This report addresses the basic design of the present bumper systems in Section 2. It also provides three alternative bumper systems which are felt to show near term promise. The comprehensive study should further refine these alternative systems and provide detail designs for installation on selected test vehicles.

The costs and benefits associated with a particular bumper standard for a "null" case are discussed in Section 3. With this null case, one can proceed to establish incremental increases or decreases in costs and benefits associated with a particular bumper system or standard.

In order to determine optimum performance test speeds for the barrier and pendulum tests described in MVSS 215, Section 4 presents the idealistic approach and also explores the problems associated with this approach. It is concluded that it is not possible to determine an optimum test speed with any degree of accuracy. When considering the low-speed range which is being considered and the many variables involved, the definition of an optimum speed is questionable. It is recommended that in the comprehensive study a sensitivity analysis be performed on the method outlined in Section 4. Consideration should also be given to approaches other than impact speed as a means of achieving the desired objective.

The available cost data and available cost methodologies are assessed in Section 5 along with their advantages and disadvantages. The cost estimating procedure recommended for use in the comprehensive study is that developed by the Pioneer Manufacturing and Engineering Company of Warren, Michigan. Additional cost methods available for estimating life cycle costs are also outlined.

Available benefit data and methodology are assessed in Section 6. From this assessment, the conclusion is drawn that additional data is needed and should be obtained through a nation-wide survey of repaired and unrepaired damage.

Section 7 assesses the different cost-price relationship models that have been developed for the automobile industry, including new car production and aftermarket. It is recommended that an existing cost-price relationship be modified for use in the comprehensive study. A draft statement of work to accomplish this is also contained in Section 7.

The details of a proposed survey to obtain benefit data and a recommended draft statement of work for the survey are provided, along with cost and time estimates, in Section 8 and in Appendices A and B.

Section 9 addresses the need for testing and the type of testing required. The success of any of the alternative bumper systems can be judged only by its performance in the real-world accident environment. The major recommendation associated with the test program is that prior to the development of a detailed test program, or detailed bumper designs, the real-world accident environment should be defined. It is only after the real-world accident environment has been defined that a bumper system capable of withstanding the diverse impacts of the vehicle population can be adequately designed and tested. Included in Section 9 are a series of guidelines for an RFP and a preliminary draft of a statement of work.

2. DESCRIPTION OF ALTERNATIVE LOW-SPEED BUMPER SYSTEM

2.1 INTRODUCTION

Standard 49 cfr Part 581, issued under the authority of Title I of the Motor Vehicle Information and Cost Savings Act, Public Law 92-513, specifies limits on damage to non-safety related components and surface areas in addition to incorporating the safety requirements of Motor Vehicle Safety Standard 215.

The regulation, simply stated, specifies that vehicles manufactured after September 1, 1978, shall sustain no damage when involved in low-speed (5 mph) front and rear collisions. The term "no damage" means that various safety systems and components, such as lights, brakes, doors, exhaust, fuel, cooling, etc., shall operate in a normal manner. In addition, there shall be no damage to paints and similar coverings, and no permanent deviations to original contours of exterior surfaces. However, damage may occur to "the bumper face bar and the components and associated fasteners that directly attach the bumper face bar to the chassis frame." This last deviation will be disallowed after September 1, 1979, and damage criteria to bumper components will be specified. Detailed information relative to protective criteria, test conditions, and test procedures is presented in the Bumper Standard in the Federal Register.[2-1]

Prior to the 1973 model year, when the first bumper standards were implemented (FMVSS 215), American automobile bumpers were not designed primarily to prevent damage to the vehicle; the principal criteria was appearance and styling. The bumper, supporting structure, and the bumper-vehicle attachment scheme were generally incapable of protecting the vehicle from low-speed collision. The high repair cost to the consumer necessitated by damage from low-speed front and rear-end collisions prompted the passage of the Public Law 92-513.

The purpose of this section is to discuss present bumper systems in general and the design factors which must be considered, and to offer three promising alternate designs for the comprehensive study.

2.2 PRESENT BUMPER SYSTEMS

In general, the principal parts and function of a typical post-1973 bumper system are shown in Figure 2-1 (not shown are the parts which are either used for attachment or for styling). There are minor deviations to these designs, but for the most part, all American automakers have used this basic system.

The face bar is a drawn steel piece, usually chrome plated. The reinforcement bar is usually a formed structural steel structure. The energy absorbers are one of three types; as shown on Figure 2-2.

a. Piston-cylinder
b. Rubber shear pad
c. Leaf spring system

More specific and detailed designs utilized on some of the domestic vehicles will be described later. All designs are basically the same, differing primarily in style, material, and type of energy absorber (EA). There are some isolated variations, such as the soft material used as a face bar for the Mustang. The soft materials, as in the Mustang face bar, have been introduced into bumper systems recently with changes in FMVSS 215. Initially, when FMVSS 215 was implemented, the test requirements allowed only the existing steel technology face bar to be used. In designing present bumper systems to comply with existing standards, several factors must be considered in the design. Among these are the following:

a. Total weight of the system must be minimal so as not to seriously degrade fuel economy.

b. Overhang - excessive weight at the front and rear end of the vehicles can effect comfort and handling. Excess weight requires considerable strengthening of supporting frame members. This cumulative weight increase has an impact on tire size, braking capacity, suspension system, and engine size.

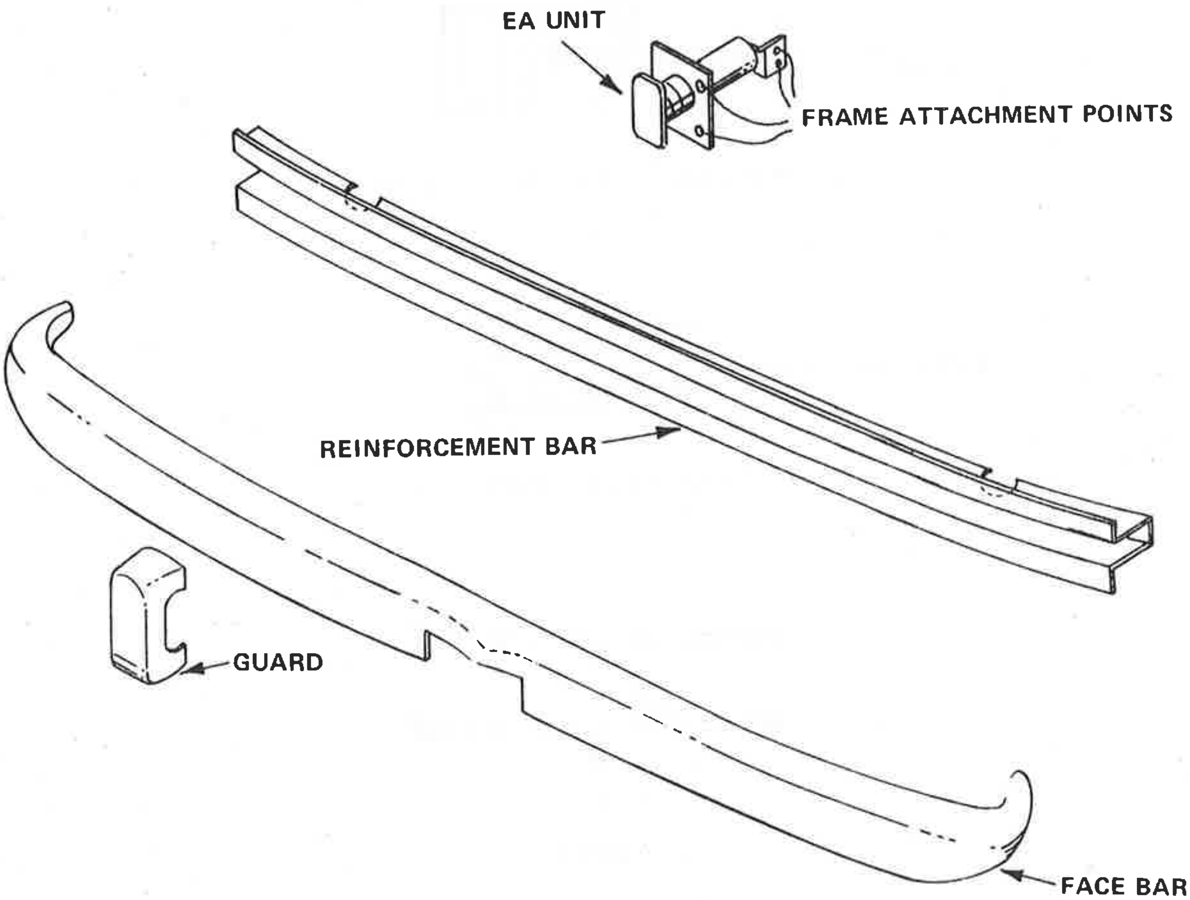
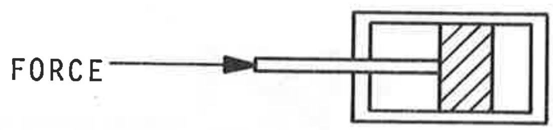
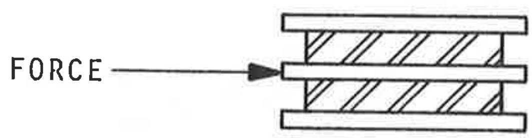


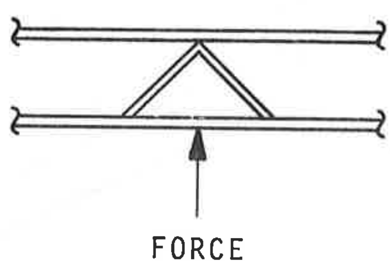
FIGURE 2-1. SCHEMATIC ILLUSTRATION OF TYPICAL BUMPER SYSTEM



a. Piston Cylinder Design



b. Rubber Shear Pad Design



c. Leaf Spring Design

FIGURE 2-2. BUMPER ENERGY ABSORBERS

c. Bumper design height must be such as to not interfere with cooling system, or negate vehicle ramp access.

d. In a car-car collision, bumpers should not override.

e. Aerodynamics must be considered for vehicle cooling and wind resistance.

Table 2-1 presents the energy absorber characteristics for several domestic vehicles and compares vehicles and manufacturers. As mentioned previously, emphasis is placed on styling in domestic vehicles, and as can be seen in Table 2-1, there is no great effort to standardize bumper design or components used within a particular company. Conversely, foreign auto manufacturers appear to emphasize simplicity, utility, and manufacturability.

To give some background and perspective on the basic vehicle bumper designs presently employed, and on the costs for dealer replacement of bumper systems, Figures 2-3 through 2-6 are provided. These give pictorial representations of the components and dealer replacement costs of bumper systems for each weight class of automobile as represented by the 1976 Chevette, Maverick, and Torino, and by the 1975 Oldsmobile.

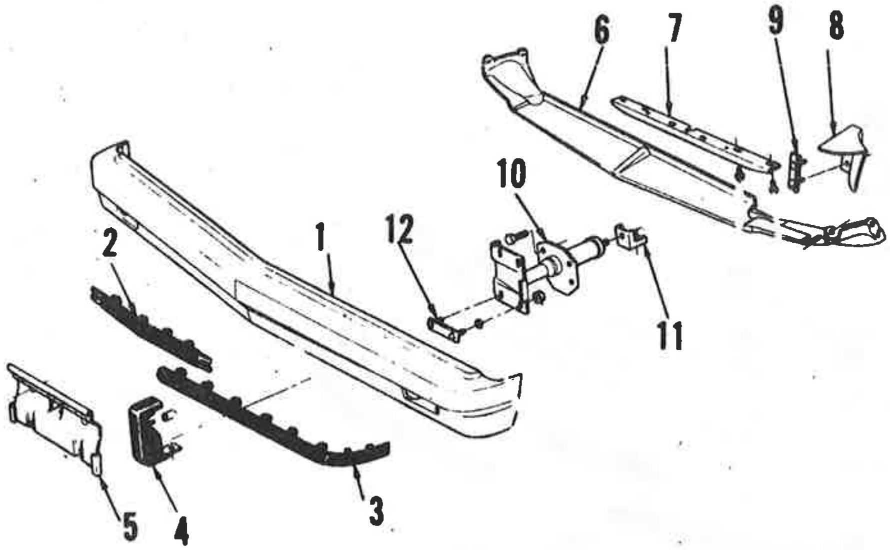
As the tendency is to more fuel-conscious cars, weight is perhaps the most important consideration in the design of bumper systems. Additionally, material and fabrication costs are directly related to weight. Energy usage in the production of raw materials is, of course, also directly related to weight. In examining several bumper systems, it becomes quite evident that the existing bumper/vehicle designs are not necessarily oriented toward vehicle weight reduction. The recent changes in bumper design, resulting from the implementation of the standards, has resulted in the trend toward continued vehicle weight increase as damage protection has increased. It should, however, be noted that several other Federal Motor Vehicle Safety Standards have also added to this weight increase. Tables 2-2 and 2-3 provide examples of the pertinent weight data.

TABLE 2-1. TABULATION OF ENERGY ABSORBER CHARACTERISTICS

MANUFACTURER	VEHICLE MODEL	YEAR MODEL	BUMPER LOCATION	AVERAGE E.A. FORCE LEVEL 5 MPH (lb)	E.A. STROKE (in)	K_c	K_s	VEHICLE KINETIC ENERGY @ 5 MPH K.E. (in. lbs.)	ENERGY CAPACITY OF E. A. UNITS @ 5 MPH E (in. lbs)	RATIO E/KE
AMERICAN MOTORS CORP.	GREMLIN	73 74	FRONT FRONT	7,800 10,000	2.74 2.25	.22 .435	.87 .765	27,250 27,450	42,800 45,000	1.57 1.64
	HORNET 2 DR. HATCHBACK	73 74	FRONT FRONT	7,800 10,000	2.74 2.25	.71 .603	.68 .71	28,750 28,750	42,800 45,800	1.49 1.57
	MATADOR 4 DR. SEDAN	73 74 74	FRONT FRONT REAR	7,700 7,950 7,950	1.93 2.94 2.94	.35 1.12 .62	.95 .73 .96	34,500 35,550 35,550	29,700 47,000 47,000	.861 1.32 1.32
	AMBASSADOR 4 DR. SEDAN	73 74 74	FRONT FRONT REAR	7,800 10,000 7,950	2.74 2.25 2.94	.72 .89 .62	.79 .58 .96	38,850 39,830 39,830	42,700 45,000 47,000	1.1 1.13 1.18
	MATADOR 2 DR. SEDAN	74 74	FRONT REAR	10,000 7,950	2.25 2.94	.89 .86	1.32 1.2	35,970 35,970	45,000 47,000	1.25 1.31
FORD MOTOR COMPANY	PINTO	73 74 74	FRONT FRONT REAR	4,300 4,300 5,000	1.9 1.9 1.78	.91 2.46 .76	1.30 2.17 1.27	22,060 24,360 24,360	16,350 16,350 17,800	.74 .672 .731
	MAVERICK	73 74 74	FRONT FRONT REAR	4,300 4,300 4,950	1.9 1.9 1.88	1.90 3.07 1.52	2.34 2.52 2.0	28,740 28,520 28,520	16,350 16,350 18,600	.57 .574 .653
	TORINO	73 74 74	FRONT FRONT REAR	6,000 6,000 6,000	2.75 2.75 2.75	1.58 2.14 1.47	1.72 1.6 3.1	38,520 40,240 40,240	33,000 33,000 33,000	.86 .82 .82
	LTD	73 73 74 74	FRONT REAR FRONT REAR	6,000 6,000 6,000 6,000	2.75 2.75 2.75 2.75	.57 .49 1.6 .89	1.33 1.7 1.9 1.66	42,940 42,940 43,020 43,020	33,000 33,000 33,000 33,000	.77 .77 .77 .77
	LINCOLN CONTINENTAL	73 73 74 74	FRONT REAR FRONT REAR	6,000 6,000 6,000 6,000	2.75 2.75 2.75 2.75	1.13 - 2.77 1.61	- - 6.7 3.94	52,290 52,290 33,660 53,660	33,000 33,000 33,000 33,000	.63 .63 .62 .62
CHRYSLER CORP.	PLYMOUTH VALIANT	74	FRONT	8,500	1.82	1.15	1.3	31,600	31,000	.98
	DODGE DART	74	FRONT	8,500	1.82	1.18	1.23	31,900	31,000	.97
	DODGE CORONET	74	FRONT	8,500	2.28	1.24	1.16	36,500	38,800	1.06
	PLYMOUTH SATELLITE	74	FRONT	8,500	2.28	1.08	.984	36,950	38,800	1.05
	PLYMOUTH FURY	74	FRONT	8,500	2.5	1.095	1.36	42,650	42,500	.999
	DODGE POLARA/MONACO	74	FRONT	8,500	2.5	1.07	1.49	42,950	42,500	993
	CHRYSLER NEW YORKER	74	FRONT	8,500	2.5	1.22	2.07	45,150	42,500	.945

NOTE: Data for General Motors Corp. models not available.

Source: Reference 2-2.

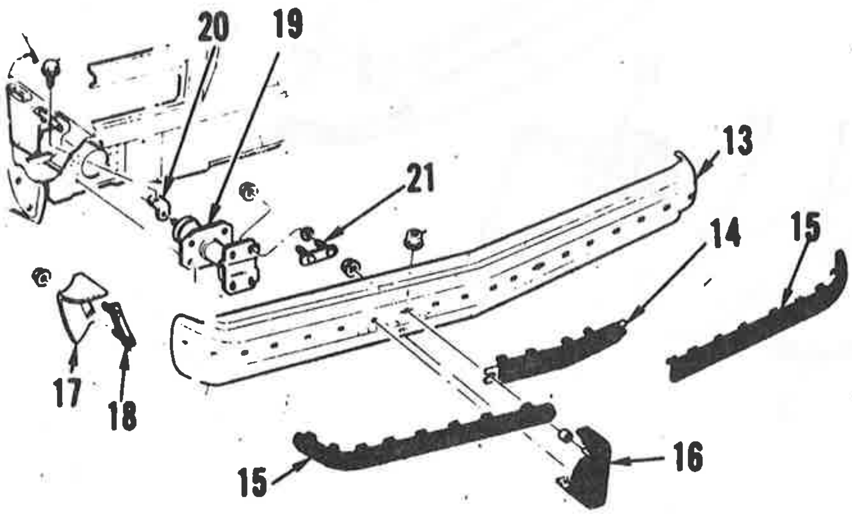


		REPLACEMENT COST($)
1.	Face bar, wo/cushion exc........	79.95
	-Scooter...	59.95
	w/cushion exc.........	79.95
	-Scooter...	59.95
2.	cushion, center................	5.50
3.	side..................	6.25
4.	Guard, R-L.....................	11.60
5.	License bracket..................	2.95
6.	Valence panel	29.95
7.	air deflector..................	2.95
8.	Filler, end	5.95
9.	retainer.......................	1.50
10.	Energy absorber.................	
11.	bracket.......................	.95
	support.......................	7.95
12.	stud plate....................	.95

Front Bumper

Source: Reference 2-3, p 462/463. Reprinted by permission from Motor Crash Estimating Guides C by the Hearst Corp. 1977.

FIGURE 2-3. 1976 CHEVETTE, SUBCOMPACT, FRONT AND REAR BUMPERS (SHEET 1 of 2)

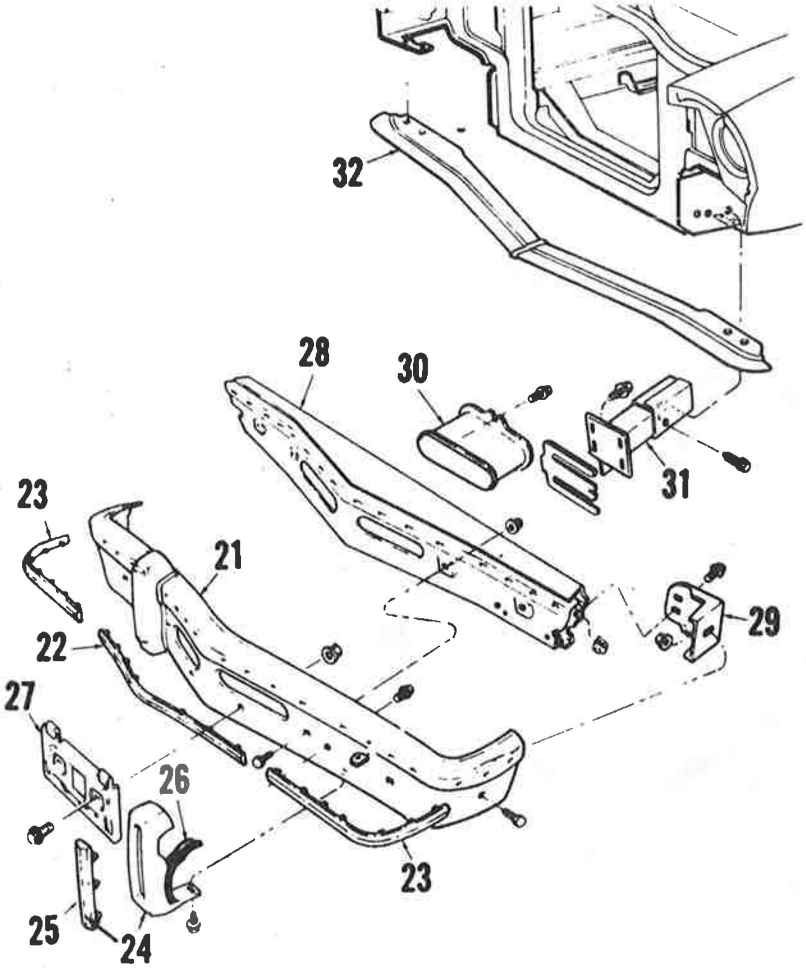


		REPLACEMENT COST($)
13.	Face bar, wo/cushion exc........	79.95
	-Scooter...	59.95
	w/cushion exc.........	79.95
	-Scooter...	59.95
14.	cushion, center...............	5.50
15.	side.................	6.25
16.	Guard, R-L....................	11.60
17.	Filler, end...................	5.95
18.	retainer......................	1.50
19.	Energy absorber...............	
20.	bracket.......................	.95
21.	stud plate....................	.95

Rear Bumper

Source: Reference 2-3, p 462/463. Reprinted by permission from Motor Crash Estimating Guides C by the Hearst Corp. 1977.

FIGURE 2-3. 1976 CHEVETTE, SUBCOMPACT, FRONT AND REAR BUMPERS (SHEET 2 of 2)

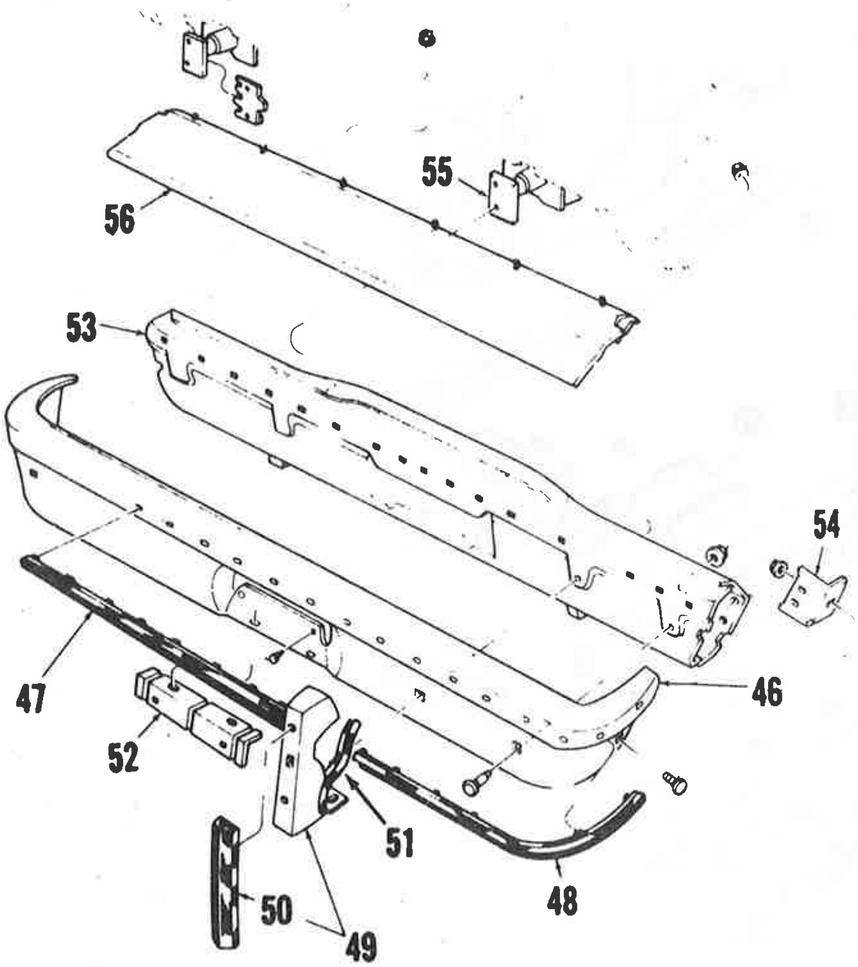


		REPLACEMENT COST($)
21.	Face bar, wo/guards & pads, 74-75...	97.10
	1976....	97.10
	w/guards & pads, 74-75...	90.75
	1976....	97.10
	w/guards, wo/pads, 74-75...	97.10
	1976....	97.10
22.	Pad, center........................	6.85
23.	side R-L......................	6.20
24.	Guard & pad, R-L..................	18.05
25.	pad..............................	2.25
26.	insulator, each (improvise)........	
27.	License mounting bracket...........	2.20
28.	Reinforcement......................	83.50
29.	brace, R-L, 1974-75...............	1.80
30.	Shield, bmpr opng, R-L.............	3.40
31.	Isolator (absorber) 1974...........	34.10
	75-76.........	34.10
32.	Gravel deflector...................	35.90

FRONT BUMPER

Source: Reference 2-4, p 525/526. Reprinted by permission from Motor Crash Estimating Guides C by the Hearst Corp. 1977.

FIGURE 2-4. 1976 MAVERICK, COMPACT, FRONT AND REAR BUMPERS (SHEET 1 of 2)

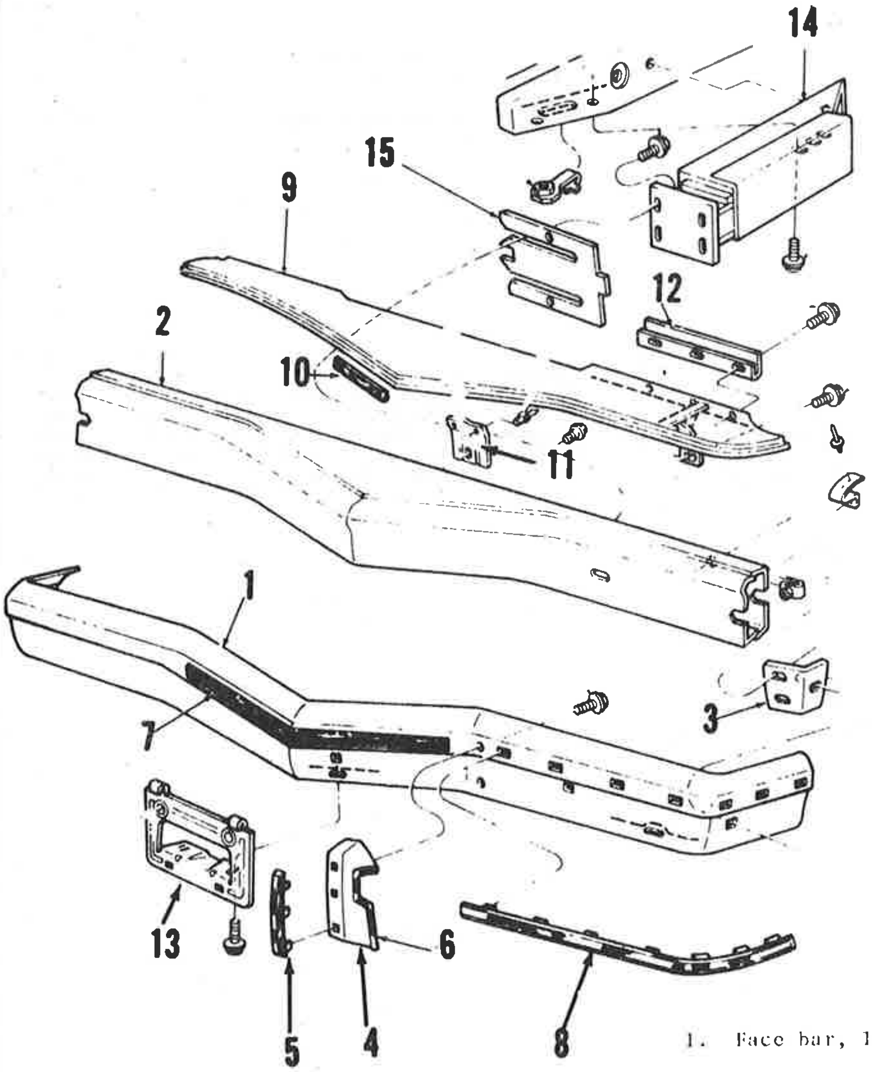


			REPLACEMENT COST ($)
46.	Face bar, wo/guards & pads,	74-75...	83.10
		1976....	83.10
	w/guards & pads,	1974....	83.10
		1975....	83.10
		1976....	83.10
47.	Pad, center..........................		6.85
48.	side, R-L........................		5.25
49.	Guard & pad, R-L....................		18.05
50.	pad.................................		2.25
51.	insulator, each (improvise)........		
52.	License mounting bracket............		3.55
53.	Reinforcement, 1974-75..............		85.85
	1976................		85.85
54.	bracket, R-L, 1974.................		2.00
55.	Isolator (absorber), 1974-75........		32.35
	1976............		32.35
56.	Stone deflector, center.............		28.70
	side, R-L...........		15.60

REAR BUMPER

Source: Reference 2-4, p 525/526. Reprinted by permission from Motor Crash Estimating Guides C by the Hearst Corp. 1977.

FIGURE 2-4. 1976 MAVERICK, COMPACT, FRONT AND REAR BUMPERS (SHEET 2 of 2)



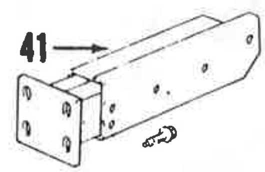
		REPLACEMENT COST ($)
1.	Face bar, 1974, wo/guards & pads....	97.70
	w/guards, wo/pads...	97.70
	w/guards & pads.....	97.70
	75-76, wo/guards & pads....	107.25
	w/guards, wo/pads...	107.25
	w/guards & pads.....	107.25
2.	Reinforcement......................	114.35
3.	brace, to bumper end..............	3.00
4.	Guard & cushion....................	23.25
5.	cushion only................	2.25
6.	insulator, each (74)..............	.95
7.	Rubber cushion, center.............	6.85
8.	side, R-L...........	6.85
9.	Stone deflector, side..............	10.40
	center............	6.80
10.	insulator.........................	.38
	support, R-L......................	3.35
11.	bracket, each......................	.67
12.	Sight shield.......................	1.50
13.	License plate mounting brkt, 1974...	2.30
	75-76...	2.35
14.	Isolator (absorber)................	38.05
15.	spacer............................	1.55

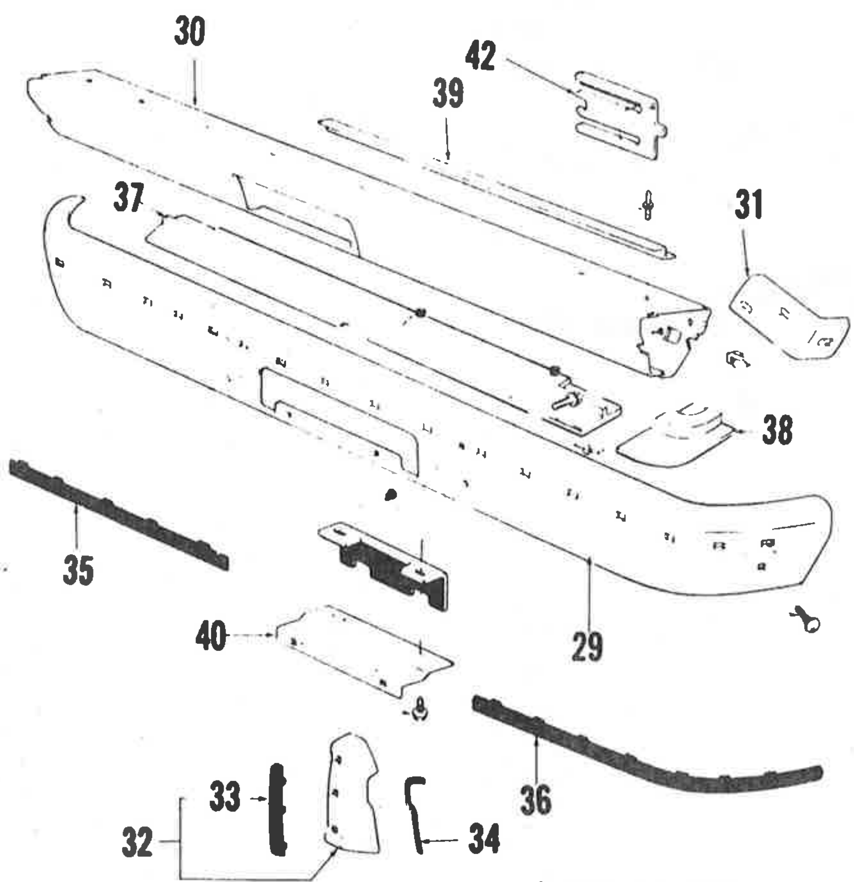
FRONT BUMPER

Source: Reference 2-4, p 582/583. Reprinted by permission from Motor Crash Estimating Guides C by the Hearst Corp. 1977.

FIGURE 2-5. 1976 TORINO, INTERMEDIATE, FRONT AND REAR BUMPERS (SHEET 1 of 2)

		REPLACEMENT COST ($)
	Face bar, wo/guards or pads.........	85.20
	w/guards, wo/pads, 74-75..	85.20
	1976...	85.20
	w/guards & pads...........	85.20
30.	Reinforcement, 74-75...............	98.65
	1976.................	98.65
31.	bracket to face bar, exc............	2.55
	from 7/7/75..............	5.80
32.	Guard & pad.......................	15.55
33.	cushion only.............	2.25
34.	insulator, not used	
35.	Rubber cushion, center.............	6.85
36.	side.................	5.25
37.	Stone deflector, center............	37.20
38.	side...............	10.40
39.	support, each.......................	1.35
	Shield, bumper opng, exc............	.85
	from 4/74...............	.85
40.	License plate mtg brkt..............	2.30
41.	Isolator exc........................	39.40
	from 1/5/76...............	39.40
42.	spacer..............................	1.50

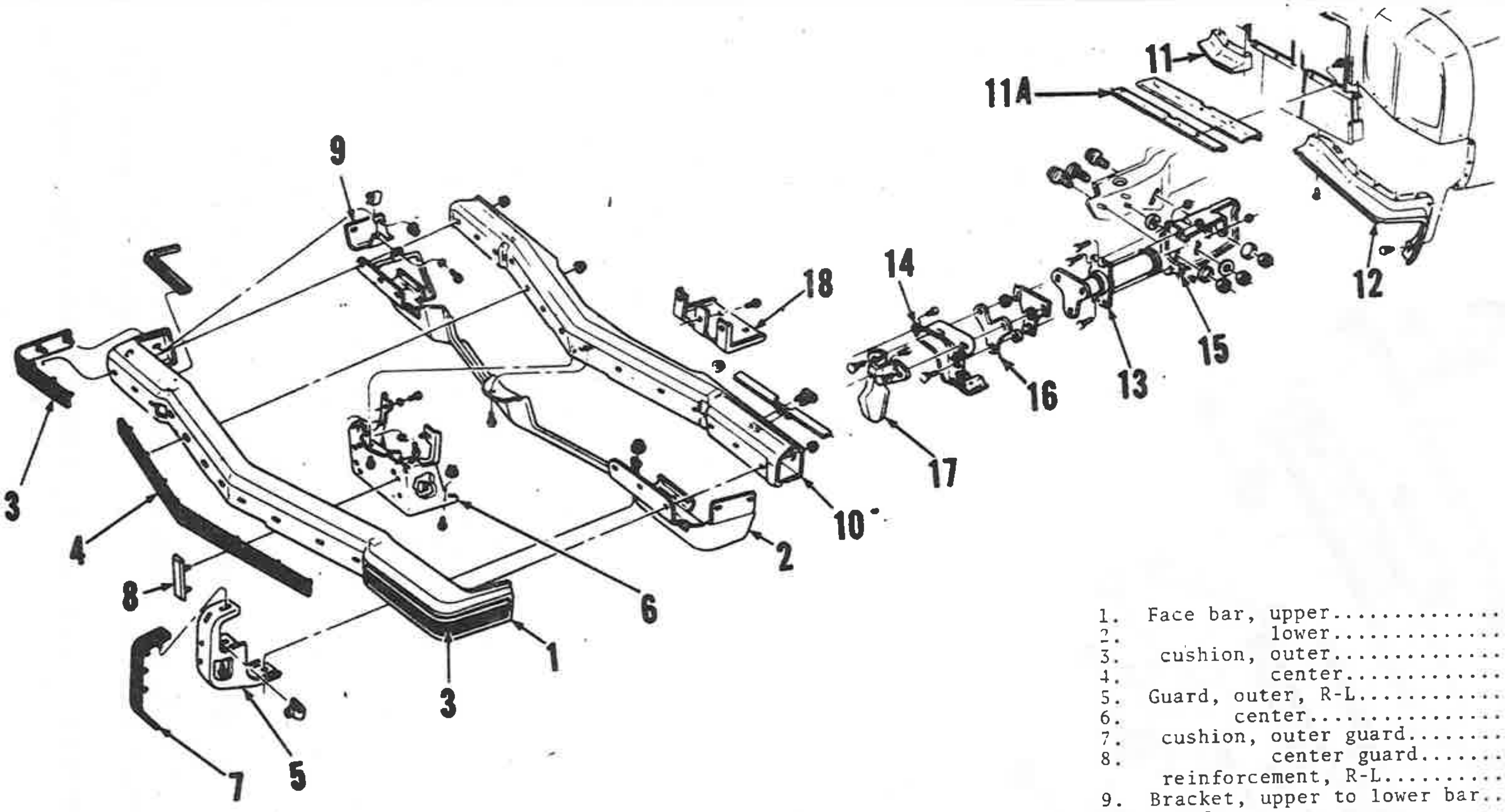




REAR BUMPER

Source: Reference 2-4, p 582/583. Reprinted by permission from Motor Crash Estimating Guides C by the Hearst Corp. 1977.

FIGURE 2-5. 1976 TORINO, INTERMEDIATE, FRONT AND REAR BUMPERS (SHEET 2 of 2)

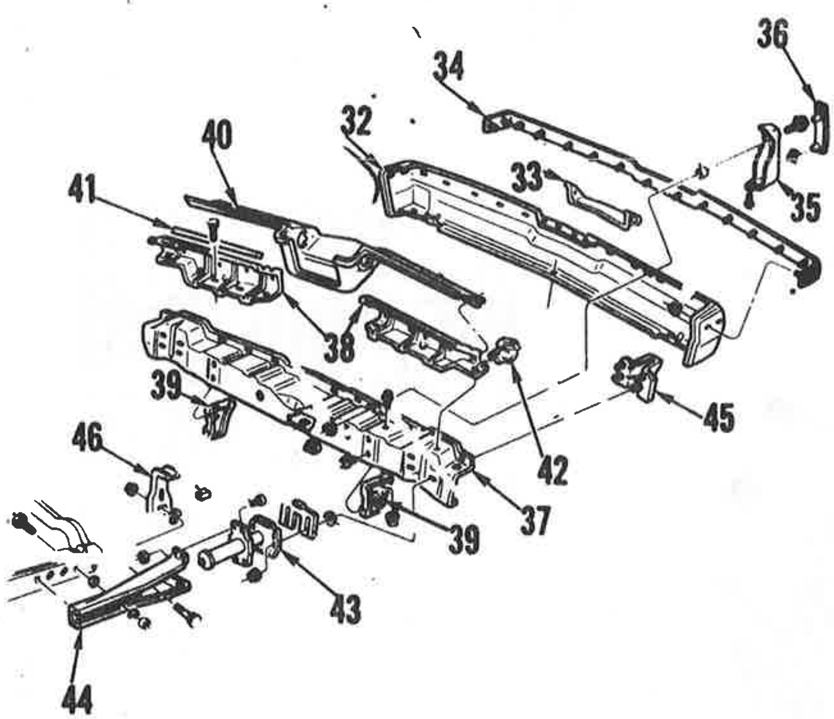


		REPLACEMENT COST(S)
1.	Face bar, upper	113.00
2.	lower	108.00
3.	cushion, outer	6.85
4.	center	11.10
5.	Guard, outer, R-L	33.25
6.	center	30.25
7.	cushion, outer guard	3.90
8.	center guard	2.55
	reinforcement, R-L	33.50
9.	Bracket, upper to lower bar	9.75
10.	Reinforcement	82.00
11.	Filler, center	7.10
	outer	7.90
11A.	support	4.00
	License plate bracket	1.95
13.	Energy absorber	21.20
14.	bracket, front	9.75
15.	rear to frame	8.45
16.	locator plate	.38
17.	reinforcement to bumper	6.00
18.	Impulse detector support	3.45

FRONT BUMPER

Source: Reference 2-3, p 528/529. Reprinted by permission from Motor Crash Estimating Guides C by the Hearst Corp. 1977.

FIGURE 2-6. 1975 OLDSMOBILE, FULL-SIZE, FRONT AND REAR BUMPER (SHEET 1 of 2)



		REPLACEMENT COST($)
32.	Face bar............................	
33.	Moulding, center....................	7.95
34.	Cushion.............................	32.65
35.	Guard...............................	17.15
36.	cushion...........................	4.70
37.	Reinforcement.......................	91.25
38.	support to bumper.................	1.60
39.	Filler to rear body.................	16.10
40.	support, R-L......................	1.60
41.	shim..............................	.32
42.	Support, qtr extn filler............	.42
43.	Energy absorber.....................	21.20
44.	bracket to frame, R-L.............	18.75
45.	mounting plate....................	9.45
46.	Restrictor..........................	1.15
	pad...............................	.27

REAR BUMPER

Source: Reference 2-3, p 528/529. Reprinted by permission from Motor Crash Estimating Guides C by the Hearst Corp. 1977

FIGURE 2-6. 1975 OLDSMOBILE, FULL-SIZE, FRONT AND REAR BUMPER (SHEET 2 of 2)

TABLE 2-2. 1974 STEEL BUMPER WEIGHT (lbs)

MANUFACTURER	VEHICLE MODEL	FRONT	REAR	TOTAL	CURB WEIGHT
AMERICAN MOTORS CORP.	GREMLIN	73.9	60.5	134.4	2739
	HORNET	66	60.3	126.3	2827
	MATADOR 4 DR.	111.5	84.8	196.3	3647
	MATADOR 2 DR.	92.4	71.5	163.9	3659
	AMBASSADOR	120.2	84.8	205.0	4079
FORD MOTOR COMPANY	PINTO	77.3	72.8	150.1	2443
	MAVERICK	87.6	71.1	158.7	2852
	TORINO	109.9	123.2	233.1	3954
	LTD	128.9	115.9	244.8	4302
	LINCOLN CONTINENTAL	129.1	166.2	295.3	5195
CHRYSLER CORP.	PLYMOUTH VALIANT	80.3	80.3	160.6	3115
	DODGE DART	85	84	170.0	3135
	DODGE CORONET	81	81	162.0	3610
	PLYMOUTH SATELLITE	95	95	190.0	3535
	PLYMOUTH FURY	101	101	202.0	4315
	DODGE POLARA	110	110	220	4300
	CHRYSLER NEW YORKER	109	109	218	4560

NOTE: Data for General Motors Corp. models not available.

Source: Reference 2-2.

TABLE 2-3. WEIGHT DISTRIBUTION FOR BUMPER SYSTEMS

MANUFACTURER	VEHICLE MODEL	BUMPER LOCATION AND YEAR	FACE BAR WEIGHT (Lbs)	REINFORCEMENT BAR WEIGHT (lbs)	WEIGHT OF E.A. UNITS (lbs)	BUMPER SYSTEM WEIGHT (lbs)	FRACTION* OF TOTAL WEIGHT CONSIDERED
AMERICAN MOTORS CORP.	GREMLIN	1973 FRONT	12.97	10.75	14.50	52.67	.726
		1973 REAR	13.18	-	-	28.08	.468
		1974 FRONT	22.78	23.35	14.50	73.93	.82
		1974 REAR	22.78	23.35	-	60.53	.71
	HORNET 2 DR. HATCHBACK	1973 FRONT	19.54	18.20	14.50	65.19	.803
		1973 REAR	13.18	-	-	28.08	.468
		1974 FRONT	18.47	18.93	14.50	66.40	.782
		1974 REAR	22.78	23.35	6.80	60.33	.878
	MATADOR 4 DR. SEDAN	1973 FRONT	16.30	16.00	5.60	53.50	.709
		1973 REAR	21.50	-	-	38.12	.55
		1974 FRONT	29.98	47.65	14.50	111.47	.826
		1974 REAR	23.45	34.45	7.24	84.82	.768
	MATADOR 2 DR. SEDAN	1974 FRONT	22.58	33.50	14.50	92.36	.765
		1974 REAR	21.16	31.38	7.00	71.56	.831
	AMBASSADOR 4 DR. SEDAR	1973 FRONT	26.22	16.40	14.50	77.87	.734
		1973 REAR	19.36	-	-	35.98	.538
		1974 FRONT	29.98	47.65	14.50	120.17	.765
		1974 REAR	23.45	34.45	7.24	84.82	.768
CHRYSLER CORP.	PLYMOUTH VALIANT	1974 FRONT	22	35.5	20.8	80.3	.975
	DODGE DART	1974 FRONT	24.7	34.6	23.7	85	.975
	DODGE CORONET	1974 FRONT	28	31.6	21	81	.98
	PLYMOUTH SATELLITE	1974 FRONT	28.5	36.1	18	95	.87
	PLYMOUTH FURY	1974 FRONT	33.5	44.9	20.6	101	.98
	DODGE POLARA/MONACO	1974 FRONT	36	51.1	21.4	110	.98
	CHRYSLER NEW YORKER	1974 FRONT	37.6	47.7	22.5	109	.985
FORD MOTOR COMPANY	PINTO	1973 FRONT	7.5	8.5	21.2	44.26	.84
		1973 REAR	8.65	-	-	14.99	.577
		1974 FRONT	17.83	30.48	23.20	77.28	.925
		1974 REAR	19.85	32.82	14.10	72.80	.916
	MAVERICK	1973 FRONT	16.50	26.70	26.18	73.28	.946
		1973 REAR	11.50	-	-	14.32	.804
		1974 FRONT	22.72	30.86	25.92	87.56	.907
		1974 REAR	22.60	33.43	12.00	71.12	.96
	TORINO	1973 FRONT	27.25	47.10	34.04	124.96	.867
		1973 REAR	25.80	-	-	48.02	.537
		1974 FRONT	24.75	45.39	34.03	109.86	.95
		1974 REAR	27.45	49.96	39.10	123.23	.945
	LTD	1973 FRONT	27.60	51.44	39.00	122.28	.965
		1973 REAR	25.10	36.84	25.00	94.64	.917
		1974 FRONT	27.60	46.10	39.40	128.94	.876
		1974 REAR	25.10	44.10	36.70	115.93	.914
	LINCOLN CONTINENTAL	1974 FRONT	29.27	35.06	39.40	129.08	.805
		1974 REAR	62.17	58.04	40.20	166.18	.986

*The sum of face bar, reinforcement bar and energy absorber weight divided by the bumper systems weight.

NOTE: Data for General Motors Corp. models not available

Source: Reference 2-2.

During the period from 1971 to 1974, the total incremental average vehicle weight increase resulting from the improved bumper systems has been: subcompacts - 90 pounds; compacts - 121 pounds; intermediates - 166 pounds; and full size - 152 pounds.[2-5] These weight increases resulted only from the bumper modifications; when combined with other government-required design modifications which also increase vehicle weight, the effect becomes even more significant. This trend to increasing weight could, if continued, penalize fuel economy such that the operating costs over the life of the vehicle could reduce the cost effectiveness of the bumper systems. A program oriented toward weight reduction of bumper systems, could also result in weight decreases in areas such as the suspension system, frame, brakes, etc.

Additional estimated system weights of currently used systems are illustrated in Figure 2-7. The extrapolated bumper system weights are based on the system weight being proportional to the vehicle weight. This figure shows the conventional steel bumper designs as having a large potential for weight and cost reduction. The Chevette and VW Rabbit show low bumper system weights. Both of these bumpers are one piece steel units with two shock absorbers. The VW bumper is less styled and has a slightly more weight efficient section. This shows that weight reduction can be made at the expense of styling. The replacement cost for the VW bumper and Chevette bumper are also very low compared with other bumpers. The retail purchase cost of the painted VW bumper is $32, and the cost of the chromed version is $56.

Weight reduction can be accomplished in several ways ranging from a more frugal use of existing materials to material substitutions. Material substitution appears to offer the best prospect for weight reduction. Use of aluminum, thermoplastics, urethanes, etc., in place of steel, would result in significant weight savings. Previous studies by ALCOA indicate that the replacement of some bumper components currently made of steel with aluminum could reduce the weight of the system significantly. Additionally, aluminum has the advantage of being easily extruded into a variety of shapes.

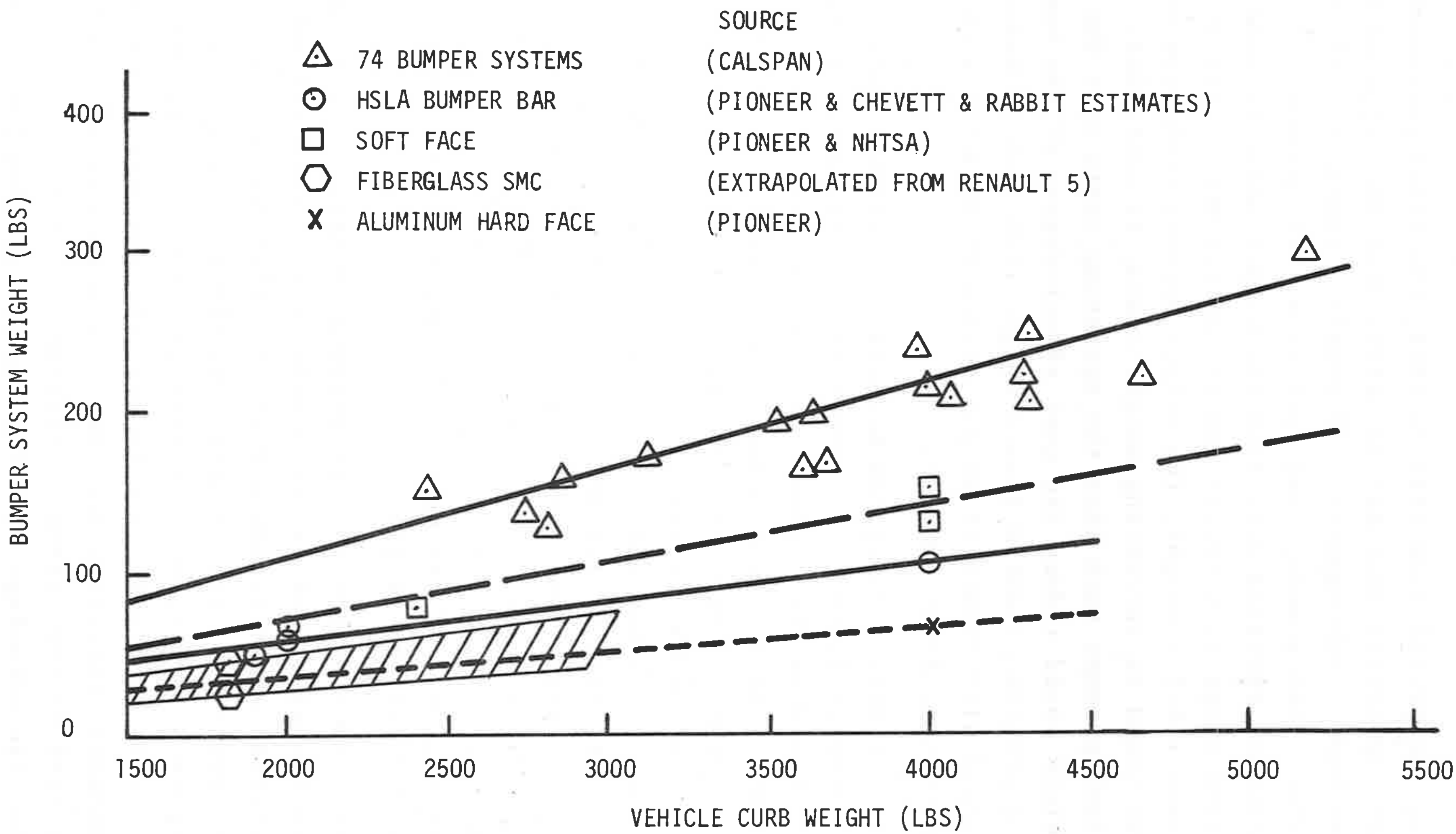


FIGURE 2-7. TOTAL SYSTEM WEIGHT FOR FRONT AND REAR 5 MPH PROTECTION

2.3 ALTERNATIVE BUMPER SYSTEMS

The overall objective of this section is to describe an approach for conducting comprehensive study of promising low-speed automobile damage reduction systems. It includes descriptions of the parts of alternative damage reduction systems so that accurate manufacturing, assembly and replacement costs can be estimated. The cost estimates are compared with the costs of current systems and can be used in performing a cost benefit analysis of each of these designs. Three promising systems have been chosen as good candidates for more extensive study. They are: 1) the soft face design; 2) the aluminum design with soft components (hybrid); and 3) the high strength steel design (hard). Advantages and disadvantages of each are shown in Table 2-4.

2.3.1 Soft Face Design

Microcellular urethane foam offers lightweight and excellent energy absorption characteristics. It is easily molded. Urethane foams vary in density depending on whether they are essentially open cell or closed cell. For use in energy absorption applications, the density range is from 20 to 55 lb/ft^3. When compared to the present steel systems, urethane is less than one-tenth the weight and, therefore, represents a considerable weight saving. The use of this material for front and rear bumper systems could result in a weight saving on the order of 125 pounds for an intermediate size vehicle. Davidson Rubber Division of the McCord Corporation is doing extensive research in this area.

"All soft" (microcellular urethane) assemblies installed on a portion of the New York Taxi fleet appear to offer a promising future in bumper protection systems. The basic design covers the entire front of the vehicle and also offers corner protection. Behind the entire bumper is a block of urethane foam which serves as the energy absorber. To further enhance this urethane front, the material can be painted so that it matches the exact color of the vehicle (elastomeric paint), thereby appeasing the style-conscious American. It is believed by the manufacturers that, at higher speeds, the urethane front will remain undamaged, and the

TABLE 2-4. ADVANTAGES AND DISADVANTAGES OF PROMISING DAMAGE REDUCTION SYSTEMS

SYSTEM	ADVANTAGES	DISADVANTAGES	VEHICLE CHANGES REQUIRED	LEAD TIME PROBLEMS	PROBLEM IN INCREASING REQUIREMENTS
Conventional Steel System	Presently available.	weight	none	none	major; 1) increase absorber stroke or 2) redesign vehicle frame
Soft Face Designs	less possibility of damage, better design for higher speeds, light weight easy repair when necessary	large material vol. req'd. mass production techniques lacking	major redesign of front & rear	large	minor
Advanced Aluminum Design	lightweight	easy to deform, high energy req'd for production & welding	minor	very small	same as conventional
High Strength Steel Design	lightweight 250% increase in yield strength	high cost, protective coating req'd	minor	very small	same as conventional

vehicle itself will be damaged. The design appears to be very promising and has been explored by several domestic manufacturers as well as the foreign manufacturers.

2.3.2 Aluminum Design with Soft Components

The use of aluminum over the current steel systems results in a further weight reduction of the bumper bar. This weight reduction may reduce vibration problems and improve fuel economy. Further bumper system weight reduction may make possible additional weight savings in other vehicle systems. This would provide an increased weight savings and permit an increased performance level or cheaper, less efficient energy absorbers.

As vehicle weight and/or performance decreases, the metal thickness may be reduced in the bumper bar. This makes a shell buckling mode more important. Because an aluminum section can be extruded with a more perfect section shape and thicker walls at appropriate places, shell buckling can be reduced. This would indicate that aluminum might have a better advantage for lighter cars than for heavier cars.

The price of an aluminum bumper would reflect the higher price of aluminum than steel and the higher fabrication cost of aluminum. The compromise for aluminum bumpers is a weight reduction at a higher bumper cost. Depending on the value placed on weight reduction, material costs, and availability, an aluminum bumper may or may not be more cost effective than a high strength steel bumper.

A hybrid design utilizing aluminum and urethane also shows promise and should be explored along with the all aluminum design. Section 2.3.4 discusses this hybrid system but with steel rather than aluminum.

2.3.3 High Strength Steel Design

Using high strength, low alloy steel for bumper systems in lieu of the present steel, shows considerable promise in that reductions in both weight and cost are possible as shown in Appendix C. The basic design remains as the existing design but employs a material of superior impact characteristics. This system is further discussed in Section 2.3.4.

2.3.4 Pioneer Study

Pioneer Engineering and Manufacturing Company, Warren, Michigan under contract to the DOT,* has acquired in-depth weight and cost data for several representative bumper systems, from "all hard" to "all soft." The cost and weight data of these systems is presented in detail in Appendix C to give an indication of the depth of analyses expected during the design phase of these promising bumper systems.

Figures 2-8, 2-9, and 2-10 present the three basic concepts that were evaluated under the Pioneer contract, the "All Hard," the "All Soft" and the "Hybrid." As can be seen, the "Hybrid" combines the soft fascia with a steel bumper plate and hydraulic energy absorbers, the "All Soft" system contains soft fascia urethane energy absorbers.

A total of sic bumper systems were studied. They included an "All Soft" (System 3), a "Hybrid" (System 4) and four variations of the "All Hard" Systems (Systems 1, 2, 5, and 6). Table 2-5 is a cost summary for the six systems. The "All Hard" systems are:

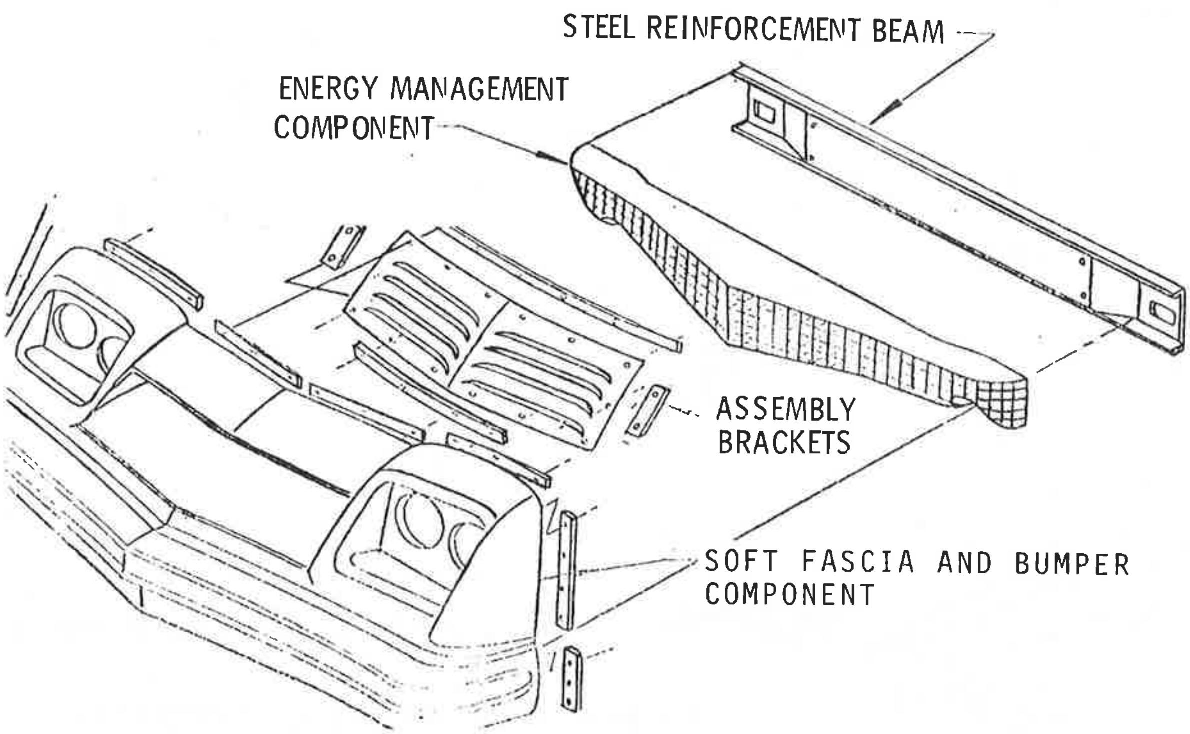
a. A current production system with a plated steel bumper, a backup bar assembly, hydraulic energy absorbers, and a die cast grille and headlamp housing assembly (System 1).

b. The same system as above except with ABS (acrylonitritebutadiene-styrene) material being substituted for the die cast grille and headlamp housing (System 2).

c. The same system as System 2 except with a high strength low alloy steel bumper face plate substituted for the current production bumper face plate and backup bar assembly (System 5).

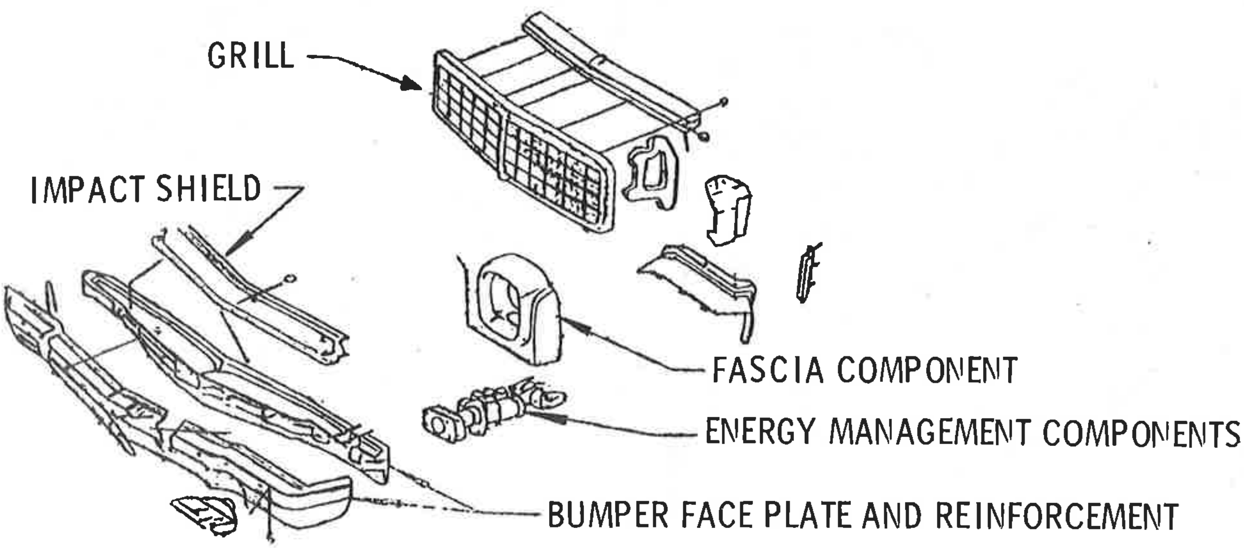
d. The same system as System 2 except with a high strength aluminum alloy (7046) substituted for the current production bumper assembly (System 6).

*Contract No. DOT/TSC-1045.



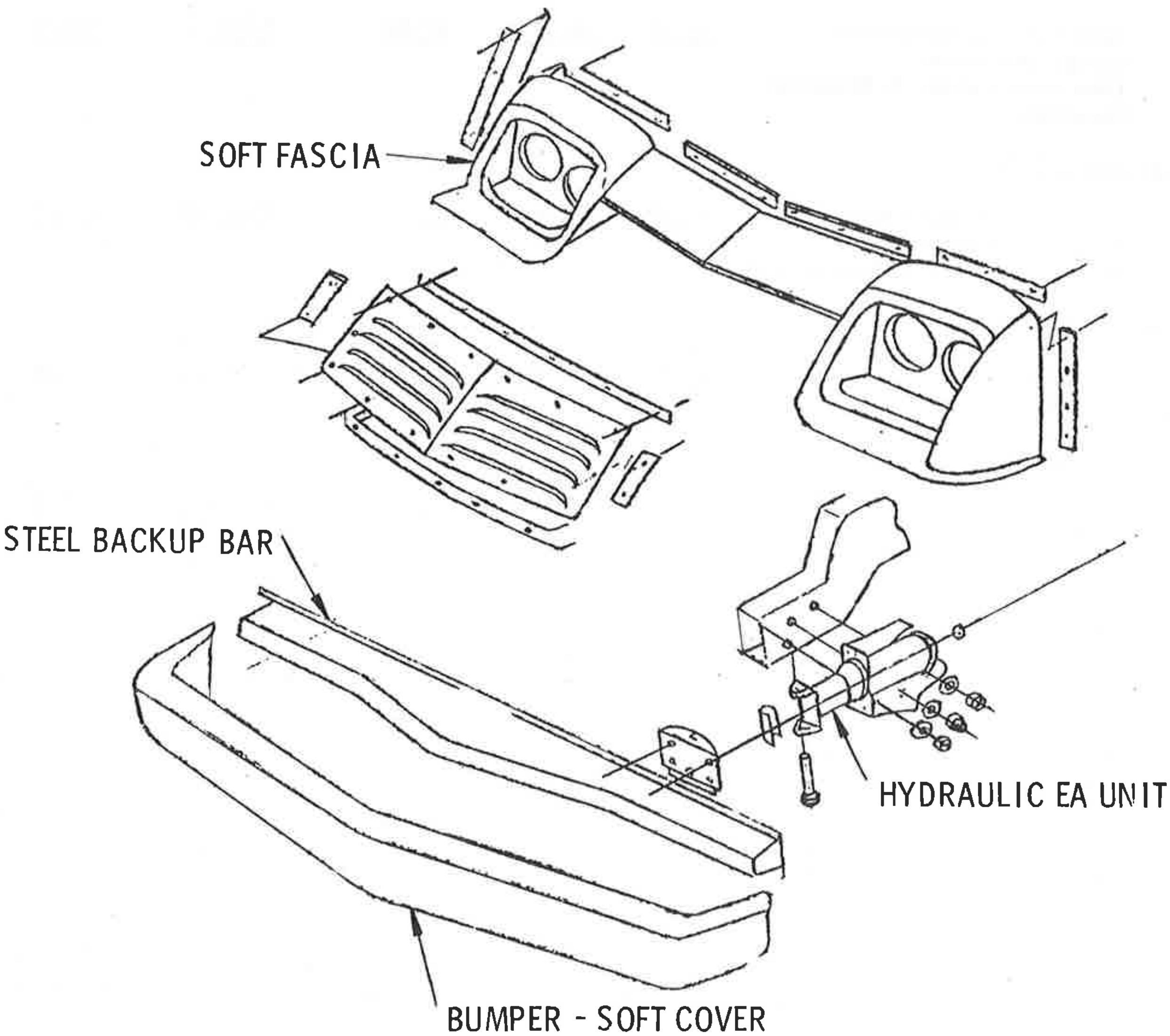
Source: Reference 2-6

FIGURE 2-8. THE "ALL SOFT" BUMPER SYSTEM



Source: Reference 2-6

FIGURE 2-9. THE "ALL HARD" BUMPER SYSTEM



Source: Reference 2-6

FIGURE 2-10. THE "HYBRID" BUMPER SYSTEM

TABLE 2-5. PRODUCTION COST ESTIMATES SUMMARY* SOFT VS. HARD, 5 MPH BUMPER SYSTEMS

	Matl. ($)	Labor & Burden ($)	Total Part Cost ($)	Die Model & Tooling Cost ($000)	Weight (Lbs.)
System No. 1					
Hard Fascia, Hydraulic Energy Absorbers (Die Cast Grille & Headlamp Housing)	41.12	19.72	60.84	2,252.7	148.4
System No. 2					
Hard Fascia, Hydraulic Energy Absorbers (ABS Grille & Headlamp Hsg.)	32.47	14.58	47.05	2,273.5	129.9
System No. 3					
Soft Fascia, Soft Energy Absorber	31.73	10.90	42.63	2,061.2	92.0
System No. 4					
Hybrid Soft Face Soft Fascia, Hydraulic Energy Absorbers	49.79	16.18	65.97	4,204.5	145.5
System No. 5					
Same as System No. 2 Using a HSLA Steel Bumper Face Plate	21.59	13.24	34.83	2,035.0	75.9
System No. 6					
Same as System No. 2 Using an Aluminum - 7046 Face Plate	23.00	13.51	36.51	2,195.0	54.6

*Intermediate size automobile - 4,000 lbs.

Source: Reference 2-6

Detailed studies were not made on the rear bumper system. Cost and weight differentials for these components, however, would be similar to those on the front bumper systems for comparable parts.

2.3.5 Three Alternative Bumper Systems

The three alternative bumper systems described in the preceding sections will form the basis for the comprehensive study. It is recommended that in the comprehensive study the three bumper systems be studied in detail, and that actual engineering designs be made of each of the concepts. Each design should be analyzed for adaptability to the four vehicle weight classes (sub-compact, compact, intermediate, and full size).

The design data package for each bumper concept should show weight, design, and stress calculations for the various elements, and should also include overall layout drawings to show the installations on typical vehicles. The layout drawings should also show the envelope of the front and rear of the vehicle, location of the frame, radiator, etc., critical dimensions, and major interfaces with typical existing vehicle designs. Areas to be investigated during this study are the integration of the face bar with the reinforcement bar; typical face and reinforcement bar cross-sections and relative stiffness-to-weight ratios; overall shape of the face bar; the effect of separation of the bumper system from the styling to simplify the face bar shape; and commonality of parts (absorbers, fasteners, brackets) among the four vehicle weight classes.

After the three promising damage reduction system designs have been established, a manufacturing data package should be provided. This package should consist of engineering drawings, bills of material, process sheets, and specifications for the parts required. Each part should be adequately described by a drawing or specification in sufficient detail so that it can be accurately costed. The material, source of supply, manufacturing process, finishing details, and appropriate tolerances should be specified for each of the bumper system parts. This information would be used to determine the manufacturing cost estimates for the three bumper systems. The parts used in each system should be separately costed to identify the material cost, processing cost, finishing cost, costs for tooling, and costs for machinery and labor to install the part on the vehicle. The estimates should be based on producing the parts in suitable quantities for each of the design concepts and for the appropriate vehicle classes. The cost breakdown of parts should be studied so as to permit an evaluation of cost trade-offs that may be available from the use of common parts throughout some or all of the weight classes, such as the same or similar face bar cross-sections or the same energy absorber (for the metal bumper designs). Lead times needed to incorporate the use of the new designs should also be estimated and become part of this study. An example of the level of detail expected for this cost analysis is shown in Appendix C.

In summary, pertinent comments relative to the many current designs which were reviewed have been presented in this section.

It was shown from previous work by Pioneer that there was a great advantage in changing the basic material used for the bumper (face bar and/or reinforcement). The estimated costs and weights were reduced considerably by substituting high strength, low alloy (HSLA) steel or aluminum for the conventional mild steel bumper systems.

The use of aluminum over high-strength low-alloy steel can result in even further weight reduction of the bumper bar. This weight reduction can result in reducing vibration problems due to heavy overhang over the front suspension.

As vehicle weight is reduced, it may be possible to utilize lighter weight, one piece bumper design for several of the vehicle classes. This may be true if aluminum extrusions with high section modulus designs can be utilized so as to reduce the manufacturing costs. This method of manufacture should be investigated during the comprehensive design study.

The price of an aluminum bumper probably would reflect the higher price of the material and the possibly higher fabrication cost of aluminum. The compromise for aluminum bumpers is a weight reduction at a higher initial bumper cost since there may be a saving in the overall life cycle costs. Only an extensive analysis will indicate the relative savings. Another area where there may be savings in the bumper system is in the selection of the suitable energy absorber. A number of different types are available. These vary from the simple rubber buckling column and rubber shear spring to the shock absorber, liquid spring type. Theoretically, the buckling type would be able to absorb the maximum amount of energy for the same stroke as compared to an absorber having a linear spring rate. The buckling column type may be relatively simple and inexpensive, but not practical to use due to packaging problems. The other absorber types, such as the Ford PGM (Polygel Mitigator) and the GMC oil shock absorber may be better choices even though they may cost more. They are fairly compact, are less sensitive to temperature extremes (as compared to most rubber elastomers) and can be sized easily for each particular vehicle class.

For the "Soft Face" concept combinations, urethane foam material appears to be a good candidate absorber coupled with either the HSLA or aluminum backup bar. This system probably will have a higher initial cost, but it appears to be a cost effective design. In general, it most likely will suffer less damage in a collision since the grille, headlamp enclosures and other parts normally damaged are all flexible and resilient. The cost analysis will reveal the relative life cycle cost as compared to the "All Hard" systems.

2.4 STATE-OF-THE-ART CONCEPTS

The increased emphasis on bumper design and technology has instigated considerable research in this area by other than the automotive manufacturers. These new ideas have come from those industries which hope to find a new market or to preserve the existing market for the technology they represent, and to provide fresh ideas to bumper applications. Materials suppliers such as the steel, plastics, and aluminum industries have brought forth their thoughts on bumper design. A few of the most innovative are described briefly.

1. Steel Cable Bumper Decelerator (U.S.Steel)[2-7] (Figure 2-11)

A steel cable is anchored to the rear portion of the bumper outboard of the frame, passes over the ends of the frame and connects to the energy absorber, a disc brake system.

2. Air Cushion Bumper (Safety Dynamics)[2-8] (Figure 2-12)

The cushion yields under impact and compresses the internal air, thereby absorbing the impact. The bumper structure is a closed, airtight chamber into which some of the air is forced during impact. The check valve then closes to restrict the return flow, and to control rebound.

3. Plastic Bumper

This concept is the most sophisticated, and probably requires the most development. It is, basically, a one-piece plastic bumper or front end in which the deformation of the bumper itself provides for the energy absorption. Such a system is currently being used for the Renault Mini Car.[2-9] It is questionable how successful this concept may be on a large car. Pontiac is currently looking into the concept in their Phoenix Program.[2-10] The estimated weight of eight pounds for this system shows a large potential for weight reduction. It is doubtful that the concept is usable for higher performance requirements or heavier vehicles because of the stroke inefficiency and higher energy management requirements. This concept looks especially attractive for lower speed systems for smaller cars. The all-plastic bumper will probably require more lead time than most of the other systems. In addition to the large amount of development needed, styling, structural and packaging changes may be required. This makes this system attractive for an all-new-car.

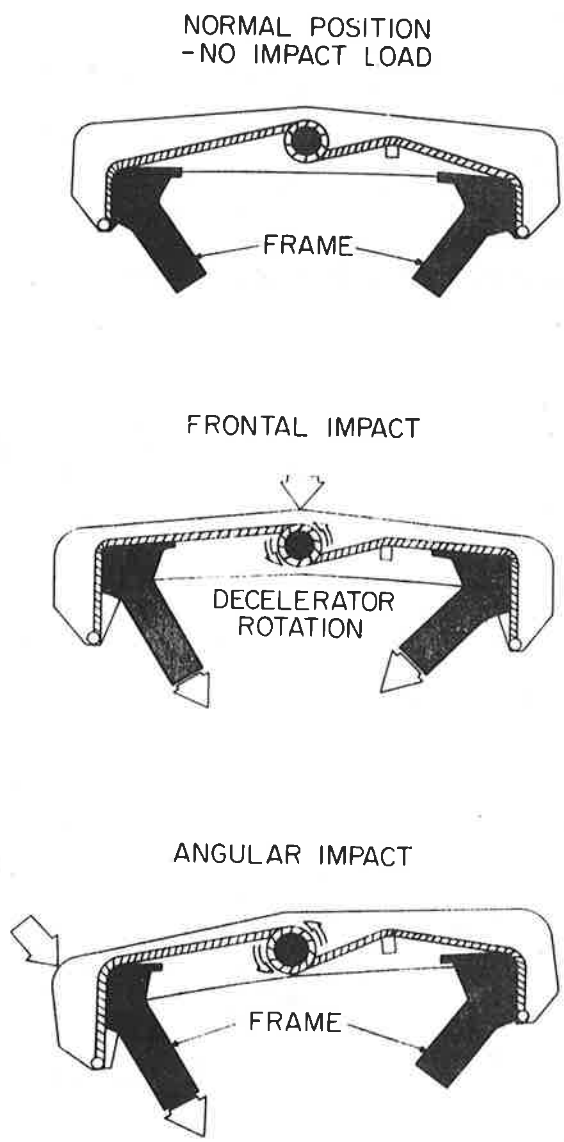


FIGURE 2-11. STEEL CABLE BUMPER DECELERATOR

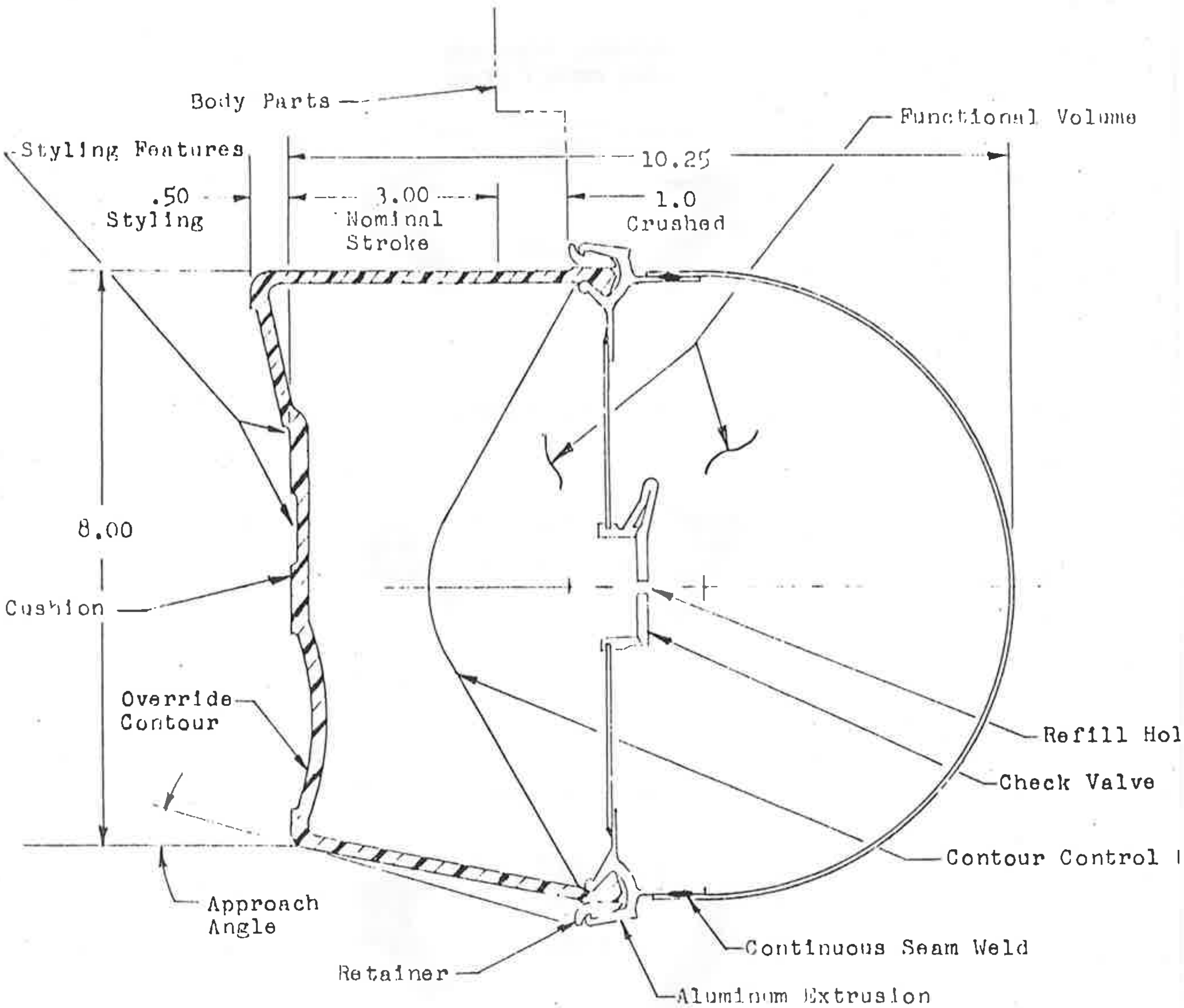


FIGURE 2-12. AIR CUSHION BUMPER

3. DESCRIPTION OF THE NULL CASES

3.1 GENERAL

The null cases allow a cost/benefit analysis to be performed on the differences between new bumper systems and the current systems. Descriptions of the null cases in following paragraphs include parameters of the new car fleet, aspects of the crash environment that are the basis for crash reduction benefits, repair costs for the reference bumper systems, and other aspects of car operation that are the basis for changes in operating costs.

The null cases are taken to be model years 1971 through 1975, or a subset of these when data are not available for all years. To present this information for more than a single year serves several useful purposes. First, these years span the period before and after bumper regulations became effective. Second, no one model year has all required data, so, missing data may be supplied from adjacent years if it appears that major changes have not occurred. Third, increased statistical validity may be obtained by combining data from several years.

In performing an actual cost/benefit analysis of new bumpers, a single reference model year should be chosen. The choice of year depends on the purpose and context of the analysis. If some of the essential information is missing for the chosen year, other null cases may be used to fill the gaps.

3.2 NEW CAR FLEET PARAMETERS

Tables 3-1 through 3-3 give certain data for model years 1971 through 1975 for each of four classes -- subcompact, compact, intermediate, and full size. The latter includes standard and luxury cars. Table 3-1 gives the number of new cars entering the fleet; Table 3-2 gives their average list prices. Imports and domestically manufactured vehicles are averaged together.

In addition, fuel economy figures are available for the 1975 model year from the TSC Motor Vehicle Production Data Bank. The average EPA composite cycle fuel economies follow.

TABLE 3-1. NUMBER[1] OF NEW CARS, 1971-1975
(Thousands)

Year	Subcompact	Compact	Intermediate	Full Size[2]	Total
1971*	2082	1663	1916	4302	9964
1972*	2231	1720	2214	4443	10608
1973*	2642	2106	2498	4231	11478
1974*	2264	1644	2284	2606	8798
1975**	1964	1917	2076	1993	7950

* Source: Reference 3-1, Tables B-39 through B-42.

** Source: Reference 3-2.

[1] 1971-1974, new car registrations; 1975, new car production for U.S. sale.

[2] 1971-1974 figures include same small size luxury models.

TABLE 3-2. AVERAGE CURB WEIGHTS[1] OF NEW CARS, 1971-1975
(Curb Weights in Lbs.)

Year	Subcompact	Compact	Intermediate	Full Size[2]
1971*	2166	3098	3680	4407
1972*	2212	3099	3800	4471
1973*	2329	3186	4006	4573
1974*	2497	3300	4058	4652
1975**	2526	3506	4263	4912

*** Source: Reference 3-3, Table A1-12.**

**** Source: Reference 3-2.**

[1]1975 values are inertia weights minus 300 pounds.

[2]1971-1974 figures include some small size luxury models.

TABLE 3-3. AVERAGE LIST PRICES OF NEW CARS, 1971-1975

Year	Subcompact	Compact	Intermediate	Full Size[1]
1971*	$2359	$3065	$3771	$4865
1972*	2515	3016	3722	4925
1973*	2778	3211	3951	5157
1974*	3319	3632	4180	5596
1975**	3800	4454	5068	6303

* Source: Reference 3-3, Tables A1-20 and A1-21.

** Source: Reference 3-2.

[1] 1971-1974 figures include some small size luxury models.

Subcompact	22.6 MPG
Compact	16.6
Intermediate	14.4
Full Size	13.0

3.3 THE CRASH ENVIRONMENT

From investigations of repaired and unrepaired crashes, the Ford Motor Company has estimated that an average car has 5.5 crashes over its lifetime; of these, 3.0 remain unrepaired, and 2.5 are repaired. Table 3-4 shows the distribution of these crashes by impact area and repair.

TABLE 3-4. LIFETIME CRASH DISTRIBUTION BY IMPACT AREA

	Front	Sides	Rear	Total
Unrepaired	19%	19%	17%	55%
Repaired	17%	15%	13%	45%
Total	36%	34%	30%	100%

The probability of damage in the first year or two is around 40-45%, and is equally distributed between repaired and unrepaired vehicles. Table 3-5 shows relative agreement between Ford Motor Company estimates and State Farm Insurance Company estimates of per-year damage.

TABLE 3-5. DAMAGE FREQUENCY PER YEAR

	MY 1973[1] in 1973	MY 1973[2] in 1974	MY 1974[1] in 1974
Unrepaired	.247	.24	.192
Repaired	.219	.205	.195
Total	.466	.445	.387

[1]Source: Reference 3-4, p 19.

[2]Gene Gardner, State Farm Research Department, Personal Communication. Insured vehicles only.

A more detailed breakdown of damage distribution by impact area is provided by Ford surveys for 1974 model year vehicles in their first year of service, as shown in Table 3-6. A breakdown that distinguishes among market classes, by State Farm Insurance Company for damage claims through insurance, comprises Table 3-7.

TABLE 3-6. CRASH DAMAGE DISTRIBUTION, 1974 MODEL YEAR VEHICLES, BY IMPACT AREA

	Front Center	Front Corners	Sides	Rear Center	Rear Corners	Total
Unrepaired	12.7	24.3	35.5	7.4	20.1	100
Repaired	15.9	21.1	43.8	7.1	12.1	100

Source: Reference 3-4, pages 7 and 12.

TABLE 3-7. CRASH DAMAGE DISTRIBUTION BY MARKET CLASS, INSURED DAMAGE CLAIMS

Market Class	% Involvement[1]	Distribution by Impact Point[2]						
		Front Center	Front Corners	Right Side	Left Side	Rear Center	Rear Corners	Total
Subcompact	33.4%	14.7%	23.0%	12.0%	15.6%	17.1%	15.8%	100%
Compact	19.6	16.7	23.9	15.4	18.1	16.9	14.0	100
Intermediate	27.8	12.9	22.7	19.1	18.3	12.7	13.2	100
Full Size	15.3	9.0	22.1	20.6	19.1	11.1	16.9	100
Total[3]	100.0	11.8	23.0	16.9	17.9	14.1	15.0	100

[1] 1974 model year in 1974; Gene Gardner, State Farm Research Dept., private Comm.

[2] 1973 model year in 1973. Source: Reference 3-5, Page 4.

[3] Includes 3.9% involvements by vehicles in "other" market classes.

It must be emphasized that the above estimates of the magnitude and type of crashes are based on scattered and incomplete survey and, thus, have doubtful reliability for national estimates. Section 6 gives the assessment of this data base, and Section 8 shows how to remedy the deficiencies.

3.4 REFERENCE BUMPER SYSTEM REPAIR COSTS

Two factors combine to give reference bumper system repair costs -- the speed distribution of accidents, and the cost to repair an automobile involved in a crash at a given speed. The best current estimate of the speed distribution of crashes is shown in Figure 3-1, which shows separate cumulative curves for front and rear crashes. Thus, 80% of all front crashes and almost 90% of all rear crashes occur at less than five miles per hour, meaning that accident consequences at low speeds may critically affect a benefit/cost analysis of bumper standards.

Figures 3-2 through 3-5 give the repair cost as a function of crash speed for front into barrier, subcompact and full size cars, and rear into barrier, subcompact and full size cars, respectively. These figures are based on crash test data of the Insurance Institute for Highway Safety for 1969-1975 model year autos.[3-6, 3-7]

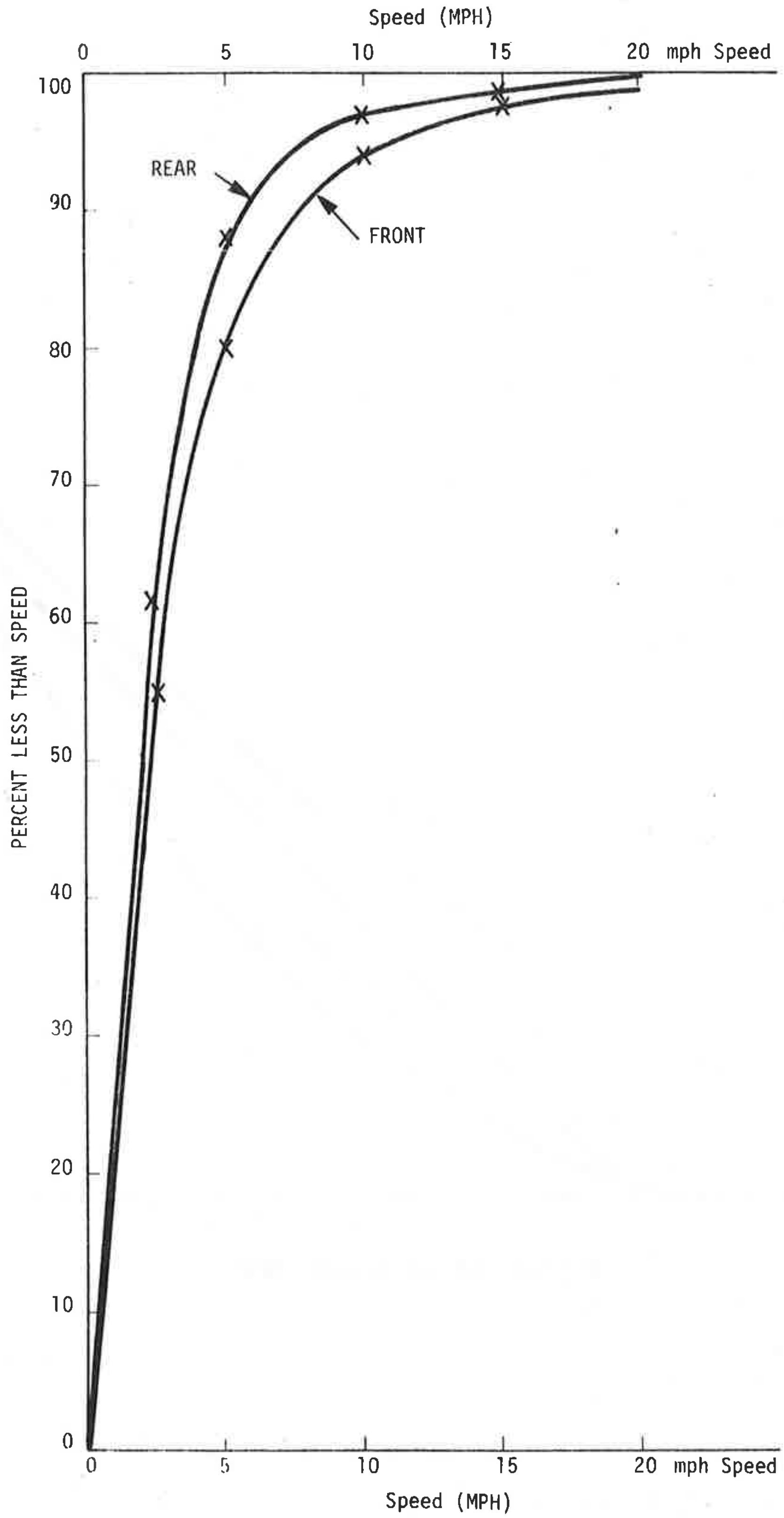
Quadratic curves have been statistically fitted to the data for 1969-1972 models; the sample sizes proved to be large enough so that the parameters of these curves were statistically significant. More recent models had insufficient data points for adequate statistical analysis, therefore, curve fitting was employed.

3.5 BUMPER WEIGHT EFFECT ON OPERATING COSTS

3.5.1 Body Weight and Bumper Weight

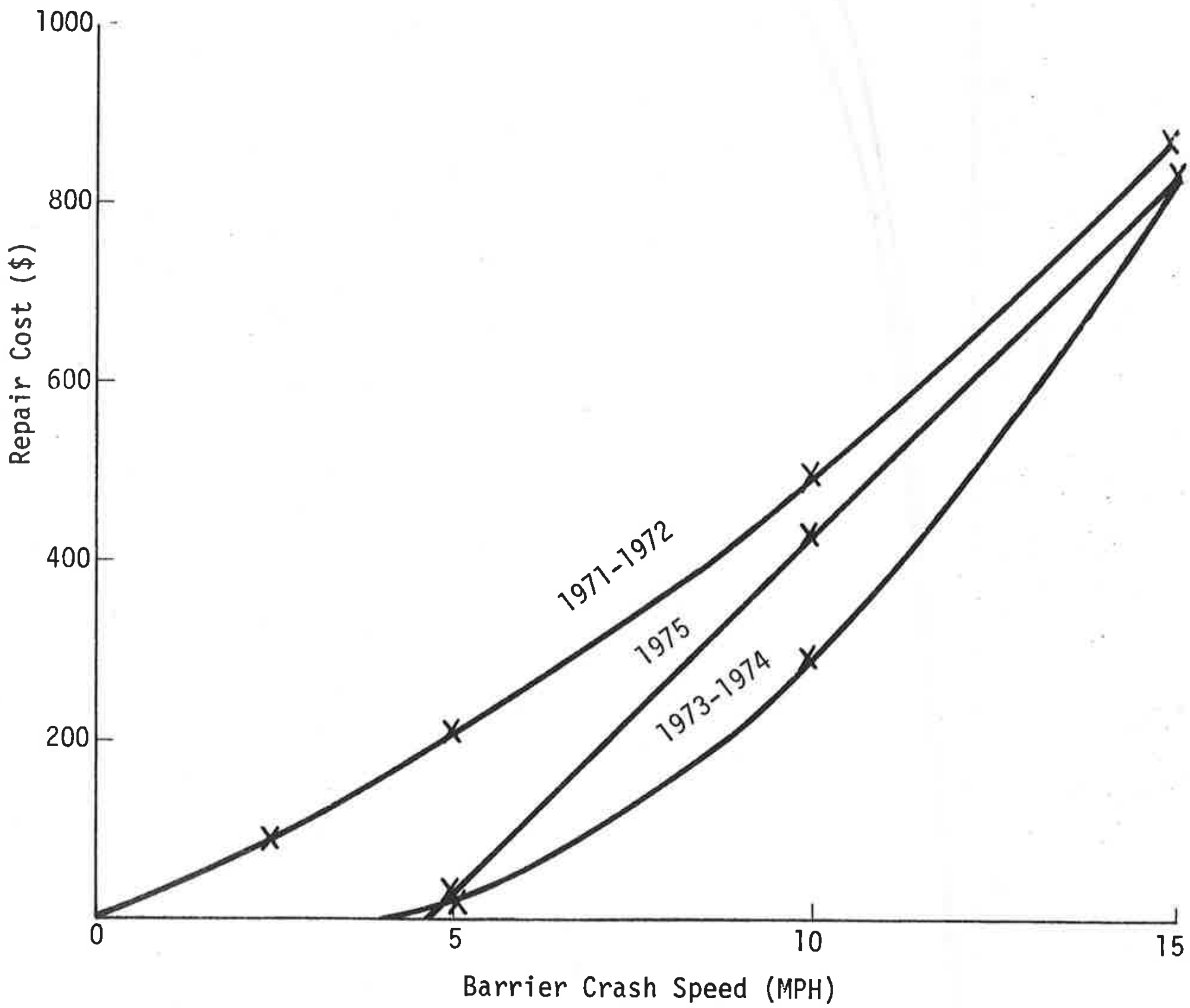
The bumper weight has an effect on car body weight, directly and with a multipler effect. Any increase (or decrease) in bumper weight is magnified by the need for the vehicle design changes to support that weight. When this relationship is worked out, as in the Motor Vehicle Goals Report,* it is found that every pound

*Source: Reference 3-9, p 5B-3



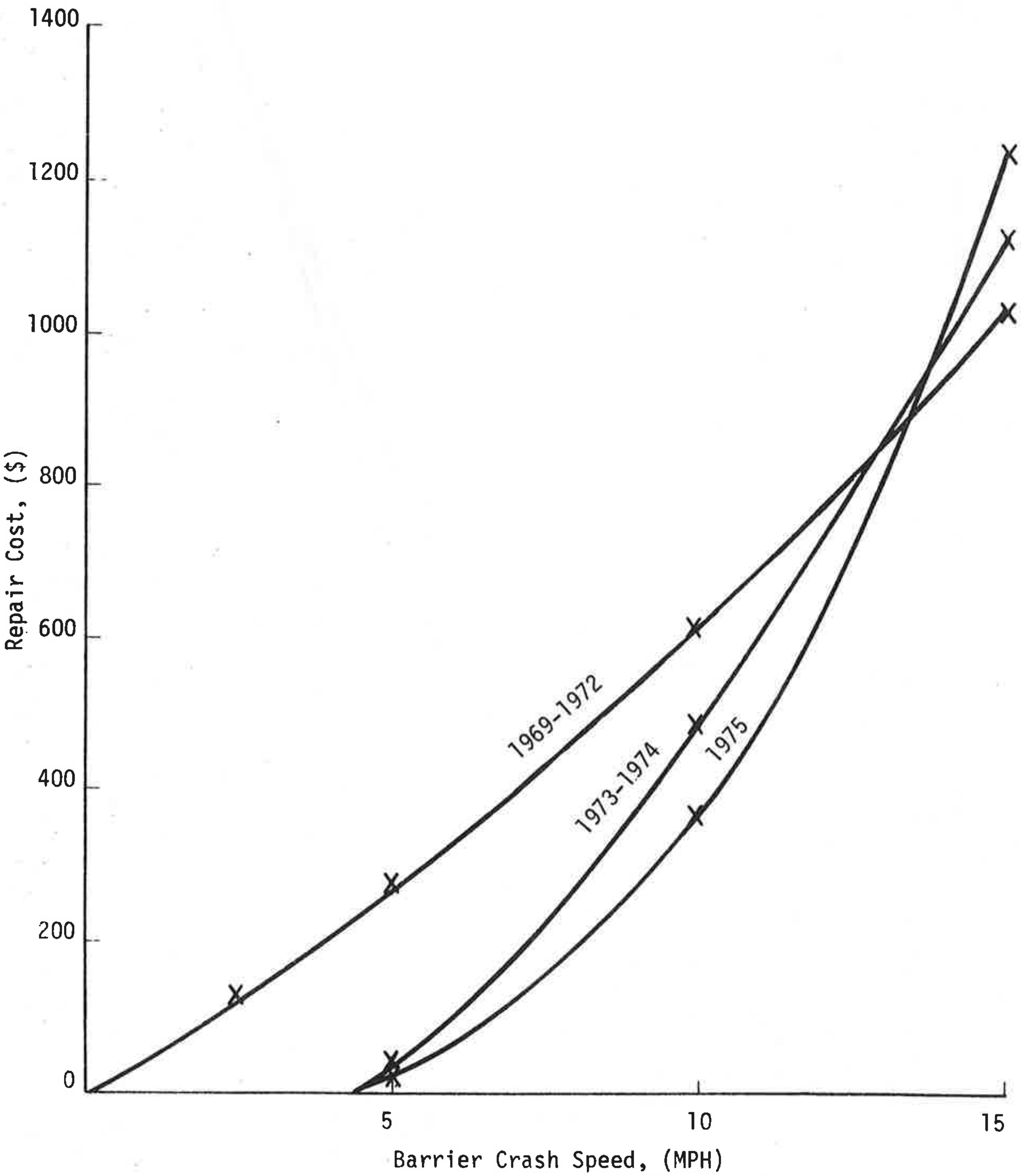
Source: Reference 3-8

FIGURE 3-1. CUMULATIVE DISTRIBUTION OF CRASHES BY SPEED



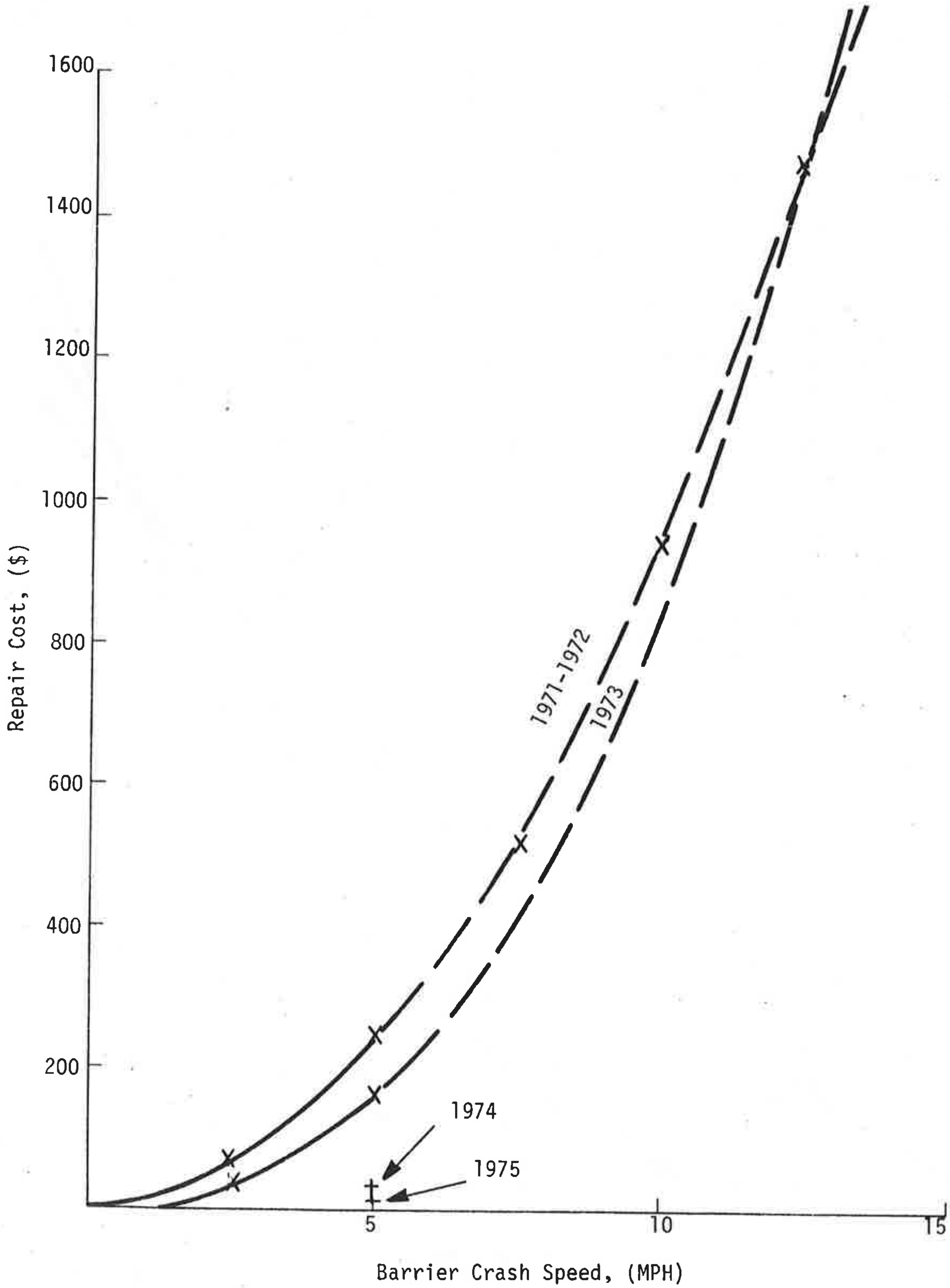
Source: References 3-6 and 3-7

FIGURE 3-2. REPAIR COST AS A FUNCTION OF CRASH SPEED FRONT INTO BARRIER - COMPACT CARS



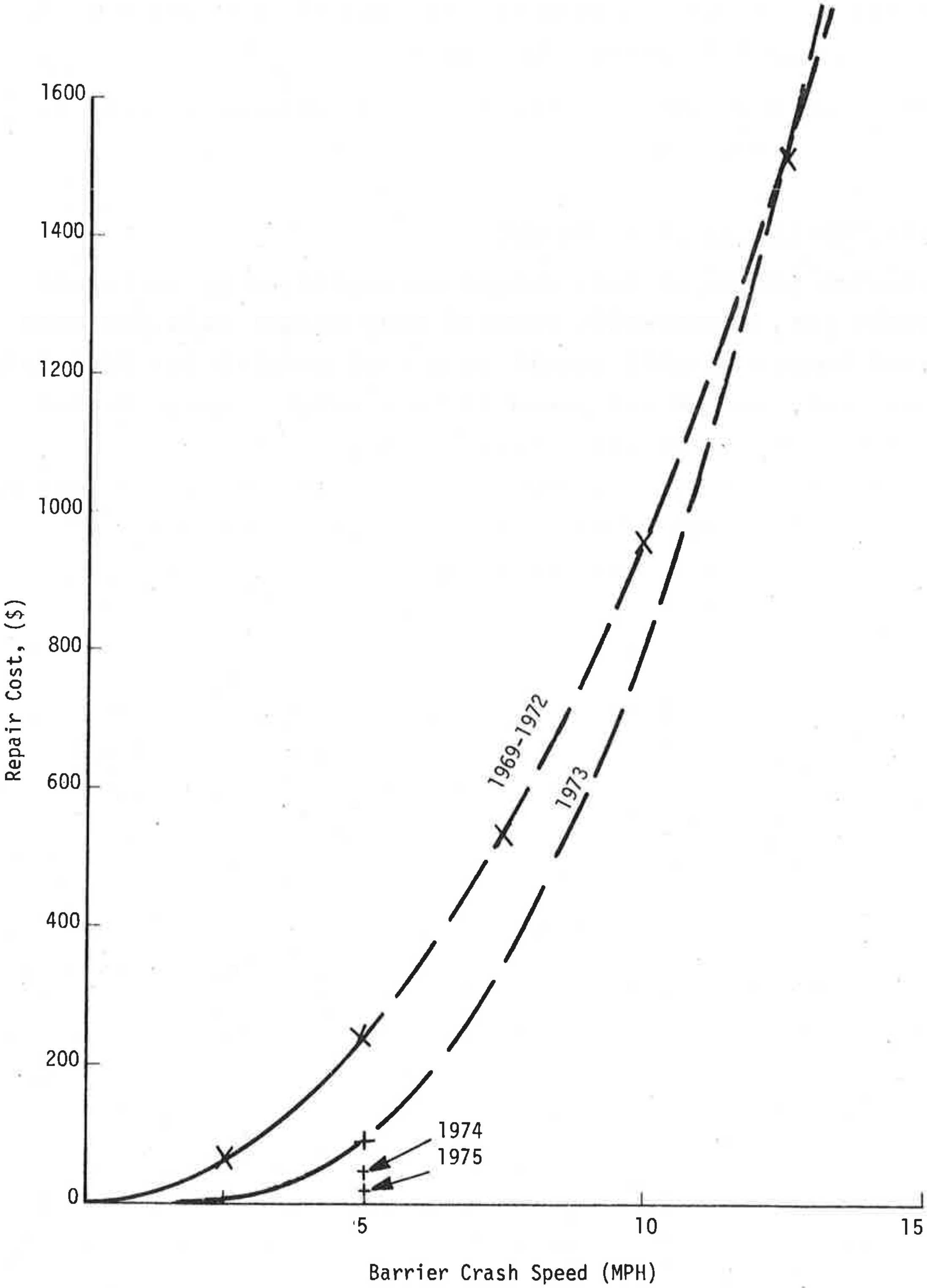
Source: References 3-6 and 3-7

FIGURE 3-3. REPAIR COST AS A FUNCTION OF CRASH SPEED FRONT INTO BARRIER - FULL SIZE CARS



Source: References 3-6 and 3-7

FIGURE 3-4. REPAIR COST AS A FUNCTION OF CRASH SPEED REAR INTO BARRIER - SUBCOMPACT CARS



Source: References 3-6 and 3-7

FIGURE 3-5. REPAIR COST AS A FUNCTION OF CRASH SPEED REAR INTO BARRIER - FULL SIZE CARS change in the bumper system weight results in a change of approximately 1.5 pounds in curb weight (and inertia weight) for domestic cars, and 1.35 pounds for imports.

Bumper system weights for the base and improved systems have been discussed in Section 2.

3.5.2 Fuel Penalty vs. Body Weight

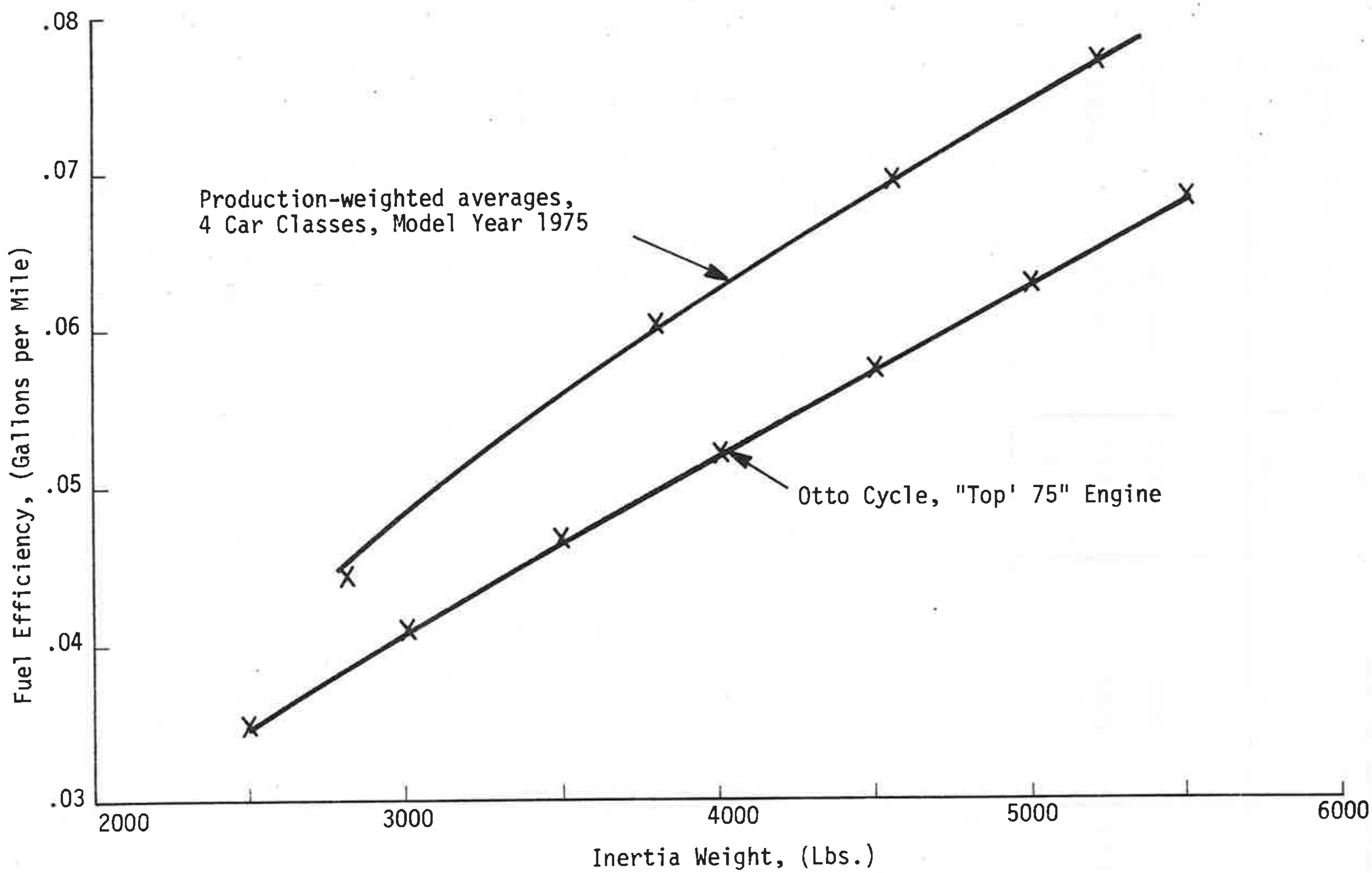
Additional pounds of body weight necessitated by increased bumper weight (or, conversely, reduced body weight made possible by decreased bumper weight) result in a fuel penalty (or savings). The fuel use rate change per pound of body weight change depends on the base weight of the car. Figure 3-6 gives the fuel efficiency in gallons per mile as a function of inertia weight for two different cases: 1) The weighted averages of actual model year 1975 production; and 2) cars equipped with the best Otto cycle engines in 1975, hereafter called "Top '75." The latter is a likely characteristic of production in the near future.

Changes in gallons per mile as a function of body weight changes necessitated by bumper changes are predicted by moving along these curves, assuming that production of the different car sizes can be merged into a continuum. This is likely true of the "Top '75" engine curve since all vehicles are assumed to have a constant horsepower to weight ratio of 0.03. However, in the actual model year 1975 production, larger sized cars had a greater average horsepower to weight ratio than smaller sized cars, so if changes in body weight preserve the horsepower to weight ratio characteristics of each size class, it would be incorrect to move along that curve.

Table 3-8 compares the change in gallons per mile per 100 additional pounds for 1975 model year average cars as indicated from the graph of Figure 3-6, with that predicted by the Task Force Report formula (Eq. 3-1):*

$$\text{gallons/mile} = \frac{1}{6060} WT^{.88} \left(\frac{HP}{WT}\right)^{.40} \qquad \text{(Eq. 3-1)}$$

*Reference 3-9, p 5-3



Sources: Reference 3-2; and Reference 3-9, p 5-3.

FIGURE 3-6. FUEL EFFICIENCY VS. VEHICLE WEIGHT

TABLE 3-8. FUEL PENALTY/100 LB BODY WEIGHT CHANGE, 1975 MODEL YEAR PRODUCTION

	Avg. Inertia WT	Avg. HP/WT	Δ Gallons/Mile/100 lb.	
			Eq. 3-1	Graph, Fig. 3-6
Subcompact	2826	.0293	.00136	.0016
Compact	3806	.0291	.00131	.0013
Intermediate	4563	.0337	.00136	.0012
Full Size	5212	.0338	.00134	.0012

Equation (3-1) shows a surprisingly constant fuel-weight penalty when horsepower=to-weight ratios characteristic of each car class are used. The graphically determined fuel-weight penalty is highest for the subcompact and decreases to a constant value for the heavier cars. For the Otto Cycle "Top '75" Engine, the fuel-weight penalty in the same units decreases from 0.00119 for a 2500 pound car to 0.00105 for a 5500 pound car, which can be shown by Figure 3-6.

3.5.3 Lifetime Maintenance Penalty vs. Body Weight

Part of the maintenance cost increases with car weight; this includes tires, antifreeze, brakes, universals, and bearings. Figure 3-7 shows lifetime maintenance cost versus body weight for current and future configurations. Additional maintenance ranges from 45¢/lb of body weight for large cars of current configuration, to 60¢/lb for small cars of innovative design with an Otto cycle engine.

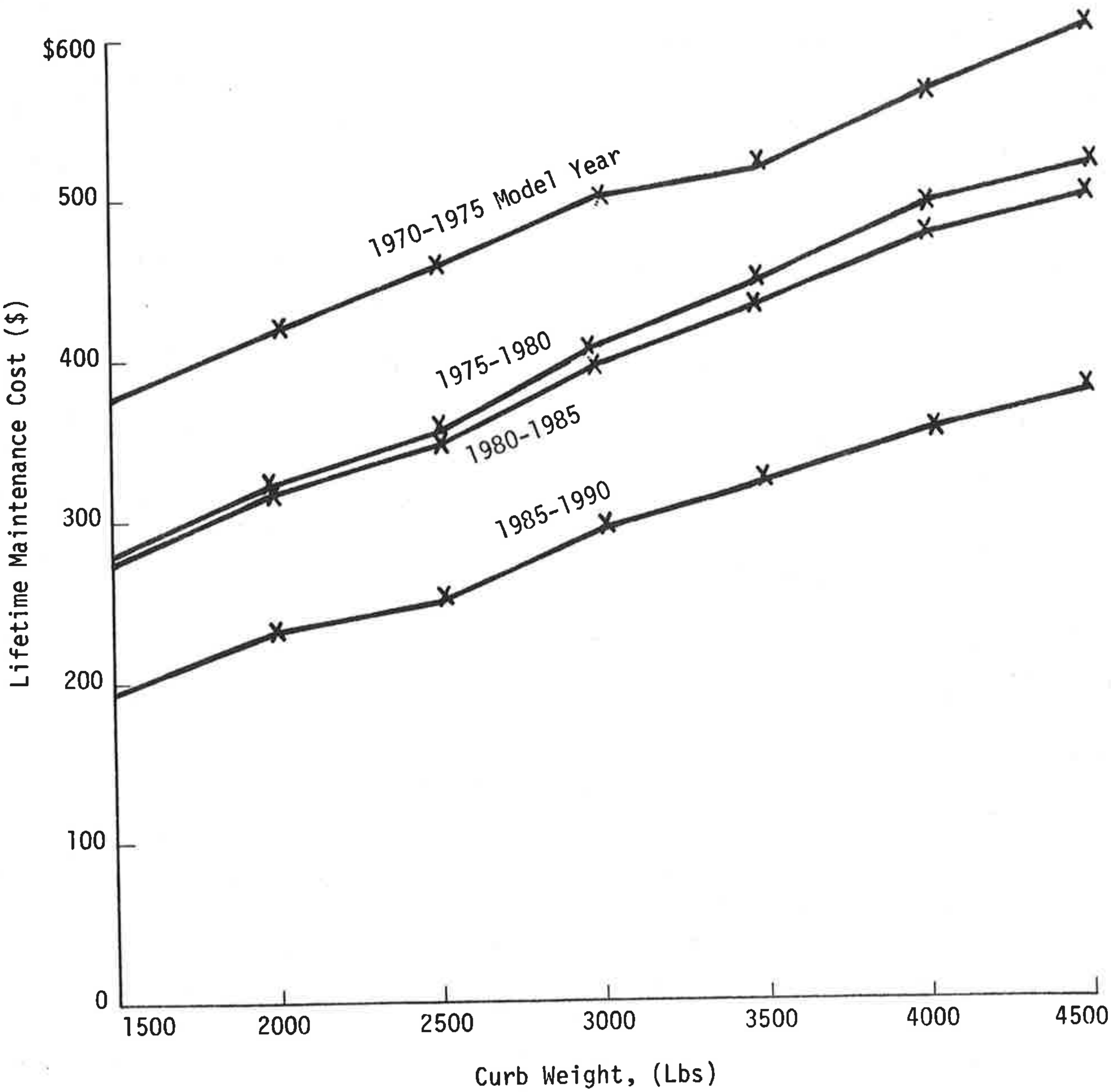


FIGURE 3-7. LIFETIME MAINTENANCE COST VS. CURB WEIGHT

4. DEVELOPMENT OF ALTERNATIVE REQUIREMENTS

4.1 APPROACH TO DEFINING OPTIMUM SPEED

In developing an alternative to the existing motor vehicle safety standard (MVSS) 215, for bumper systems, the fundamental objective must first be defined. As specified in Title 1 of the Motor Vehicle Information and Cost Savings Act, the objective is to provide a bumper system that will offer "the maximum feasible reduction of costs to the public and to the consumer." The present MVSS 215 requires that the vehicle be equipped with bumpers designed for no damage at impacts of 5 mph on front and rear bumpers, and 3 mph on front and rear corners of the vehicle's bumper system. It is quite possible that this existing standard does not meet the objectives, and that some other standard or conditions would fully satisfy the objective. Assuming that the existing standard does not satisfy the objective, the development of an alternative standard must then be considered. In developing such an alternative standard, it is quite possible that approaches other than defining a speed should be considered, since stating that the bumper must withstand a specific impact speed does not assure that the goal will be met as the bumper cost may far exceed any benefits that would accrue. Careful consideration should be given in the comprehensive study to other approaches for specifying the bumper standard. For purposes of this study, the possibility of determining the optimum speed for a particular type of bumper system will be explored. This optimum speed will be defined as that speed which provides the consumer and the public with the largest positive net benefit. Ideally, in approaching this problem, a series of costs and benefits for a variety of conditions would be provided. These conditions could then be plotted as benefit and cost curves. Figure 4-1 shows two hypothetical curves representing the costs and benefits of a particular type of system designed for no damage at impact speeds of X_1, X_2, X_3, X_4 and X_5. For each bumper design speed, the total costs of that bumper system and the dollar value of the benefits which would accrue can be plotted. From Figure 4-1, it can be seen that the

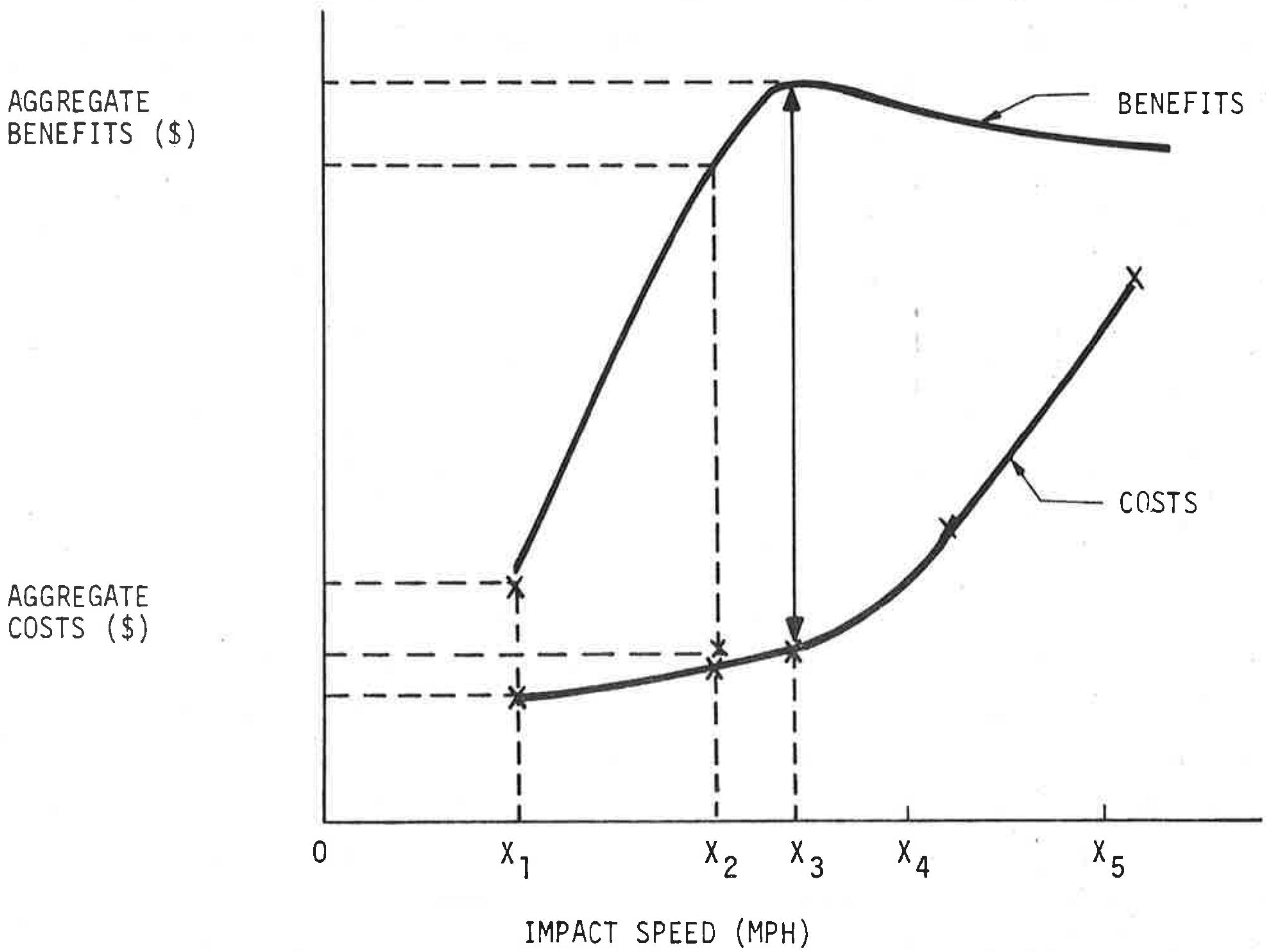


FIGURE 4-1. BENEFIT AND COST CURVES FOR SPECIFIC BUMPER DESIGN SPEEDS (HYPOTHETICAL)

greatest benefit to the consumer and the public, from this hypothetical type of bumper system, is achieved at approximately X_3 mph. If this technique could be employed for bumper systems of various designs and for various vehicle sizes, a family of curves would be created which would allow the selection of a speed at which a particular system would provide the greatest benefit. This approach determines the optimum standard speed for that particular bumper system.

Another case is that where a specific bumper system is designed for no damage at only one speed, and damage may result at other speeds. Note that the previous discussion referred to a specific bumper design concept, but the cost curve was generated from estimates of the cost of bumpers of that design but for different impact speeds and no damage, i.e., four different cost estimates. In the present case, a bumper is designed for only one speed, say 5 mph, and the cost is constant as shown in Figure 4-2 (replacement cost is considered a negative benefit). Despite the fact that this bumper system is designed for one speed, benefits will accrue at speeds other than the design speed. In this hypothetical case, Figure 4-2 shows the largest net benefits to be at X_3 mph. Although the bumper is designed for no damage at X_2 mph, the amount of damage sustained at X_3 mph is limited, and the replacement cost is far offset by the actual benefits obtained.

This method of determining the optimum speed by plotting curves of speed versus the benefits to accrue from a particular bumper system and the costs associated with that bumper system has major problems. The accuracy of estimating the benefits and costs when working in the very low speed range of zero to ten miles per hour is a problem. Additionally, when estimating costs to manufacture or replace a bumper system, a firm design on which to base the costs is necessary. The following paragraphs of this section further explore the problems associated with determining the optimum speed, and recommend a possible method which is, un-

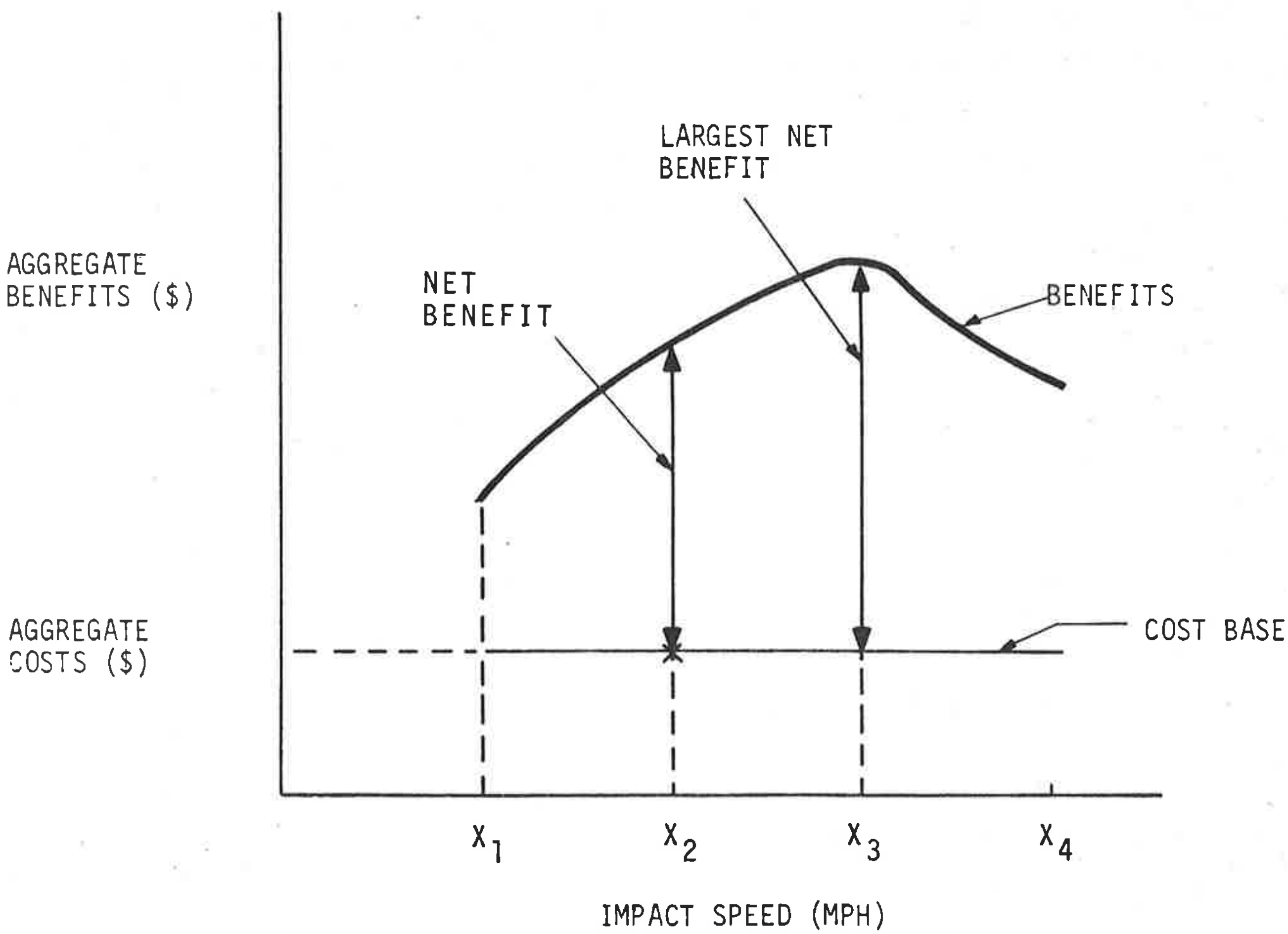


FIGURE 4-2. BENEFIT AND COST CURVES FOR BUMPER DESIGNED FOR NO DAMAGE AT A SPEED OF X_2 MPH (HYPOTHETICAL)

unfortunately, quite involved. An extensive rework of the existing data and a sensitivity analysis of the assumptions employed are needed to make the method more useable.

4.2 DESIGN OF ALTERNATIVE BUMPER SYSTEMS

This section discusses alternative bumper systems for impact speeds above or below the present standard. The design of bumper systems to accommodate various design speeds may be accomplished by methods such as material substitution, new bumper design, or vehicle design changes. The degree to which the new bumper system will be changed from an existing design is dependent on many factors; among these are vehicle size, basic vehicle design, vehicle performance, and the past experience of the manufacturer. For purposes of this discussion, only the current steel bumper systems shall be considered as candidates for use in designing bumper systems for speeds other than the present MVSS 215. Aside from changing the vehicle structure to absorb more of the energy from the impact, the option of changing the bumper system energy absorber stroke or efficiency remains. However, these two options for new bumper designs to accommodate new impact speeds pose problems.

Utilizing the approach of changing the bumper energy absorber stroke will pose no major problems when changing to a lower design speed but will create definite problems when increasing the stroke to accommodate higher design speeds. It should be noted that if the design speed is reduced, it is possible that reduction of stroke would not be the most efficient means of achieving this lower impact speed requirement. Increases in the bumper design impact speed could pose many problems, because increases in the energy absorber stroke, if not compensated for, will increase the overall vehicle length and could create operational problems. Examples of operational problems resulting from the longer bumper overhang are increased vehicle vibration; problems in towing; problems in jacking the vehicle for tire change; and problems of ramp clearance for the vehicle. Additional problems associated with increased energy absorber stroke and subsequent increased vehicle length are those of styling, parking, and shipping of vehicles. Problems of the type mentioned above will vary among vehicles and can only be predicted with precision by the vehicle designers.

On the other hand, assuming that changing the vehicle energy absorber stroke or efficiency is not appropriate, it becomes necessary to modify the basic vehicle structure to manage the energy of impact. This approach is more difficult but, perhaps, more realistic, as changes in the bumper system and supporting structure may require additional changes in the vehicle suspension system, brakes, tires, frame size, etc. Again, as noted, when the vehicle energy absorber stroke is changed, the magnitude of the problems associated with changing the basic vehicle structure can only be clearly defined by the vehicle designer. Many of the changes required to design and adapt the new candidate systems will require inputs based on the manufacturer's past experience, and tests on the design under consideration.

Detailed vehicle design data of the type mentioned above coupled with the necessary experience is not available, and, henceforth, estimates of costs and weights associated with the candidate systems could only be based on best engineering judgement.

4.3 COST ELEMENTS

As discussed in the previous section, the actual design and its associated details can only be specified when the complete vehicle design data is available. Without a firm design, the cost estimates will be based on a best engineering judgement which could be quite inaccurate. The costs which must be included in any estimate of cost to the consumer or public are incremental initial cost to the vehicle purchaser; any change in operating cost; and the incremental replacement cost associated with the bumper system. The initial cost to the vehicle purchaser is comprised of the labor, tooling, material, assembly, and mark-up costs associated with the particular bumper system. Vehicle life-time operating costs would be estimated on a vehicle life cycle of, for example, 100,000 miles, and would be based on any change in vehicle weight resulting from the bumper system and the costs associated with the bumper system changes as it affects fuel economy, brakes, and tires. As an example, any substantial increase in vehicle weight (100 pounds) will increase the total lifetime operating cost of the vehicle, as fuel economy will decrease, and both brake and tire wear will increase. Bumper system replacement cost, derived for the new accident frequency, cannot be estimated with sufficient accuracy because of the large variations in the degree to which replacement consists of a total bumper system replacement or merely a portion of the bumper system.

Reviewing the cost elements, it can be seen that without a firm design, which clearly spells out what vehicle changes must be made, we cannot, with any degree of accuracy, estimate the cost and weight changes associated with that particular bumper system. Section 5 assesses the available cost methods and recommends a suitable cost estimating technique which, when employed in conjunction with a sensitivity analysis of all the cost elements, will provide bounds for the cost estimates on a specific vehicle design.

4.4 BENEFITS

The determination of the benefits curves of Figures 4-1 and 4-2 requires that for each speed, all the benefits that will accrue from a particular bumper system be determined. In determining the benefits, both the primary and secondary benefits to accrue from the bumper system must be considered. Primary benefits are based on the insurance claims (property damage and collision) eliminated, any cost reduction that might be present above the bumper system design speed, owner-repaired and unrepaired accidents, and unreported claims. Secondary benefits are based on elements such as reduced administrative costs to insurance companies, insurance premium reductions, vehicle demand shifts, impact on auto repair industry, societal impacts, etc. The estimation of both primary and secondary benefits as pertains to a particular bumper system design cannot be accomplished with sufficient accuracy for construction of a benefit curve from which an optimum speed may be determined. Review of the benefit methodology of Reference 4-1 indicates that this methodology provides only an inexact approach to the problem with many assumptions upon which a sensitivity analysis is needed. In this methodology, the approach discussed in the following paragraphs was used.

Estimates of the primary benefits to accrue from the bumper system were based on the insurance claims eliminated by the bumper system, the accident cost reduction that might be present for accidents above the bumper system design speed, owner repaired and unrepaired accidents, and increased bumper replacement costs. Both 2-1/2 mph and 5 mph bumper systems were considered in the analysis. Several sources of claim data were used to arrive at the final primary benefits. As an example, the Insurance Institute for Highway Safety (IIHS) tests indicated that at 5 mph, in a frontal barrier crash, the damage to a pre-bumper standard vehicle was estimated to be $250, and for a 5 mph rear barrier crash, the damage was estimated to be $300. Therefore, it was assumed from these tests that all frontal accidents below $250 and all rear accidents below $300 are potentially protected by the 5 mph bumper system. These assumptions along with percent estimates of the vehicle impact locations and actual claim data were then used to determine the percent claim reduction by vehicle location (front, front corner, etc.) brought about by the bumper standard. The claim data used was collision claim data obtained from the Highway Loss Data Institute (HLDI). Property damage claim reduction was also estimated from the HLDI collision data as no absolute damage claim data exists.

The property damage claim frequency was estimated from the collision claim frequency, and the relationship between collision and property damage claims observed in the State Farm data (two collision claims to every property damage claim). As another example of the inexact nature of Reference 4-1, it was also assumed that for speeds above the bumper design speed, the standard would reduce the damage costs from accidents. From the IIHS tests, the value of $650 was assumed to represent the upper limit at which one would find some reduced damage as a result of the standard. Utilizing the HLDI claim data, over the range from $250 to $650, and impact location data, the percentage of all claims which might be affected was estimated.

Estimated average cost reduction in a frontal crash was assumed to be $200, and estimated average cost reduction in a rear-end crash was assumed to be $100. This information would then allow an estimate of the overall benefit to be obtained from the bumper above the design speed of the bumper system.

Additionally, the changes associated with the replacement costs were incorporated into the benefits. In this study, they were used as a negative benefit. Owner-repaired and unrepaired accidents again were based on figures of $250 and $650.

In general, it can be said that the damage cost estimates provided to determine the claim reduction, cost reduction, etc., were based on assumed estimates of the cost of an accident.

Estimation of benefits is a complex procedure, as it requires piecing together the universe of accidents, measured in terms of frequency, cost, and point of impact, from a number of disparate sources. Since no reliable accident data are available relating impact speed and cost of damage, damage estimates were derived from test crashes and were compared to damage costs of real-world accidents, to develop an assumed impact speed.

4.5 RECOMMENDATIONS

Paragraphs 4.3 and 4.4 highlighted the problems associated with estimating the costs and benefits for a bumper system. The basic problem is, quite simply, the large number of variables involved in the formulation of total cost and benefit figures, and the uncertainty as to which estimates or assumptions are the most accurate.

Reviewing Reference 4-1, it can be seen that the costs and benefits associated with the model years 1973, 1974, 1975 and 1976 were as follows:

Model Year	Cost	Benefits
1973	$ 97	$148
1974	$202	$207
1975	$221	$228
1976	$269	$269

The top dollar value of costs and benefits is $269, a point at which the cost/benefit ratio is one. This is quite low when the various elements which make up these estimates are considered. It is quite possible that any of these estimates may not be sufficiently accurate to guarantee that an optimum speed has been ascertained. It is recommended that the comprehensive study perform a sensitivity analysis on all the cost and benefit parameters associated with Reference 4-1 in an effort to place upper and lower bounds on the costs and benefits which would accrue from several impact speeds. Additionally, careful consideration should be given to the criteria for defining optimum speeds.

It should, however, be borne in mind that from the theoretical standpoint, if an optimum speed for a particular bumper system could be determined, there is no guarantee that a manufacturer's design for mass production would be cost beneficial.

5. COST METHODOLOGIES

5.1 INTRODUCTION

5.1.1 Relation to Report

This section discusses costs emanating from changes in design, materials, labor, tooling, and capital equipment for the manufacture of cost-beneficial bumpers to meet a given design speed. These elements of manufacturing cost have a bearing, to varying degrees, on all parameters in the cost/benefit analysis. The discussion of the methodology for determining costs consists of a discussion of assumptions, definitions, data results, level of precision, and limitations. The first cost methodology to be considered is the underlying framework for the costs used in the original TSC report.[5-1] Then, an alternative cost methodology will be discussed in terms of what it can add. Available data will be discussed, as well as plans for obtaining additional data. This discussion will be related back to the impact of the costs on all the parameters of the cost/benefit analysis. The relation of this section to Section 7 on cost-price relationships will also be discussed.

5.1.2 Definitions

The term "cost" can be used in many senses, therefore, it is worthwhile discussing what it includes and does not include.

a. For the purposes of incremental cost analysis, it is easier to discuss the effect of changes in various parameters and to assess whether these changes result in an increase or a decrease in cost when all the "deltas" or changes (either plus or minus) are added together; the result is the net change.

In this section, where costs are increases in manufacturing cost, initial purchase price, fuel consumption, taxes (sales and excise); and finance charges, "costs" will be discussed using the terminology of the original TSC report.[5-1] Increases in replacement costs will be discussed as well, even though Reference 5-1 designates them as "negative benefits." Replacement cost is closely related to manufacturing cost and initial purchase price, so, it is most easily handled in this section. In addition to the above costs, several other cost areas are included. These fall into the category of marketability and are, thus, related to manufacturing cost; purchase price; and owner operating, maintenance, repair, and replacement costs. Cost factors affecting marketability include appearance, durability, damageability, maintainability, repairability, and replaceability. These cost factors cannot be as quantified in all cases, but, where possible, a method will be explored.

b. The first element of cost is the manufacturing cost. This is composed of the cost of the materials the manufacturer buys which end up in the bumper (i.e., direct costs). If the manufacturer buys a finished component such as an hydraulic energy absorber from a supplier, the entire cost of the absorber is a direct materials cost for that manufacturer, but, for the purpose of this effort, it is assumed that the bumper is disassembled down to the parts and semi-finished materials (i.e., nuts, bolts, and sheet steel) before a direct materials cost is computed. This point will be discussed further later.

The second element of cost is direct labor cost, the cost of employing workers who work directly in making the parts, subassemblies, and the final assembly of the bumper system.

The third element is tooling cost, the cost of the special tools (dies, jigs, fixtures, tool bits, etc.) needed for a particular bumper design. This is generally given in thousands of dollars and then divided by the volume produced to give the tooling cost/piece.

The fourth element of cost is the factory burden which includes indirect materials, such as cutting oil and electricity; indirect labor, such as front loader operators and inventory control workers; and a proportion of factory overhead for a given size establishment which can be variable or fixed depending upon its nature. The cost of capital equipment is included here. In addition to manufacturing cost, the mark-ups from manufacturing cost, corporate selling price, and dealer selling price are included. The cost to the consumer varies, but manufacturer's suggested retail price is probably a good indicator of consumer initial purchase cost. (See cost-price relationships section.)

5.2 COST METHODOLOGY

5.2.1 Framework for Analysis

The objective of this paragraph is to develop the framework for a cost methodology. In order to meet this objective, it is necessary to construct an analytical framework which will enable the cost methodology of the original TSC work to be described in such a way that it can be easily compared to alternative methodologies. The analytical framework that seems to be the most useful follows the stages that a costing procedure would follow:

1. The design of the costing methodology,
2. The use of the costing methodology to determine cost data,
3. The use of cost data to evaluate alternatives.

All three stages are necessary, because a cost methodology by itself cannot be evaluated without a context. It is only when the cost methodology is considered together with the cost data (either generated for the purpose or gathered from available sources) and the alternatives being evaluated that the cost methodology itself can be evaluated.

5.2.2 Design of Costing Methodology

The design of a costing methodology, which is the first stage of the analytical framework, begins with the statement of the objective of the study. In stating the objective of the study, the key elements are apparent. The purpose of the costing methodology is to provide a means of assessing the range of changes in consumer costs which will result from choosing a particular combination of impact speeds, angles of approach, and damage tolerances for the bumper design. Alternative bumper systems which "shift" the damage distribution are to be costed in terms of their effect on consumer costs.

Keeping the objective of the study and the purpose of the costing effort in mind, the first step in the costing methodology is to define precisely what is being costed, for two reasons: 1) because every piece of hardware, no matter what its size, costs something; and 2) because existing cost data cannot be compared accurately unless the definition of exactly what has been costed has been examined. Furthermore, it is also important to consider the definition of what is being costed in terms of its function. For example, if a soft fascia bumper system replaces the grille as well as the bumper, its cost should be compared to the cost of the conventional bumper plus the conventional grille. This point will be discussed subsequently in conjunction with the material on the standard costing techniques of the automotive industry.

The second step in the costing methodology is to determine the terms in which the costing is to be done. The terms are determined by identifying the parameters which determine consumer costs. On a general level, the parameters include manufacturing cost, initial purchase price, taxes, finance charges, fuel consumption, fuel price, accident frequency, accident damage, insurance premiums, insurance deductibles, owner maintenance, repair and replacement costs, unrepaired damage, and lost time due to accidents. All of the parameters influence consumer costs to some extent, and should be examined when the terms in which the costing is to be done are fully defined.

A bumper system capable of meeting a particular bumper standard will cause a net increase in consumer cost via some of the parameters, and a net decrease in consumer cost via the others. For the purpose of this study, it is assumed that the parameters can be classified as "cost" parameters and "benefit" parameters without undue confusion. The "cost" parameters will be the focus of this section. They include manufacturing cost, initial purchase price, taxes, finance charges, fuel consumption, fuel cost, and owner maintenance, repair, and replacement costs.

The "benefit" parameters will be discussed in detail in Section 6, but to some extent in this section when second- or higher-order effects due to changes in cost parameters are possible. The determination can be made that the terms for costing should be: 1) manufacturing cost; 2) initial purchase price; 3) weight; 4) replacement cost; 5) maintainability; and 6) repairability.

The terms of costing each of these parameters should also be considered, taking into account the likelihood of changes in each due to alternative standards. Manufacturing costs are of paramount importance because they influence initial purchase price and replacement costs. Weight, maintainability and repairability will be reflected to some extent in manufacturing costs.

The area of manufacturing cost is at the center of many discussions of cost/benefit analysis of policy options. In some cases, "cost-effective" solutions can be found which actually reduce the cost of a vehicle. It should be noted that the area of greatest difference between the cost methodology of the original TSC study[5-1] and the standard cost estimating methodology is the question of manufacturing cost.

The third step in the costing methodology is to define the extent to which alternative designs, materials, or levels of technology are to be included. The primary factors to be considered include: 1) the designs and materials available, either in prototype or in production; and 2) the timespan of the study. If the timespan of the study is short, for instance one or two years, the level of technology will not shift noticeably, and most likely, only prototype or production designs and materials need to be considered. If the timespan of the study is longer, changes in the level of technology need to be considered, either historically or projected forward.

The fourth step in the costing methodology is to determine the appropriate level of precision for the data to determine changes in each parameter. One problem that is always present is the inconsistencies in data availability or data that can be generated. In some cases, great precision is possible; in other areas, it is much more difficult. Overall consistency may not be a good guideline. To the extent that changes in a particular parameter can have an influence on the consumer costs, devoting effort to determining the extent of changes in that parameter can have merit even when changes in other parameters remain imprecisely quantified. In the bumper work, it may be that more precision can be obtained in one area, i.e., changes in manufacturing cost, while no further precision can be obtained in other areas, i.e., determining the associated change in initial purchase price or replacement cost. A more pragmatic approach dictates that issues be determined on a rational, quantifiable basis wherever possible, and that in areas where uncertainties defy rational analysis, issues be determined using an alternative means, such as subjectively assessed weighting factors. At the same time, judgment must be used to assure that the precision of the data in one area is not misapplied. This will be discussed later.

The fifth step in the costing methodology involves the choice of an appropriate approach to the costing. The approach can be either incremental, with reference to an appropriate point of departure, or total, meaning that a more extensive costing effort is employed. An incremental approach is generally easier, but it requires that the definitions of what is being costed do not change in any fundamental way; that the timespan of interest is not too long; and that the level of technology does not change significantly. All of these considerations are a matter of judgment. A "total" approach is the only solution when the incremental approach fails, but the question of just how extensive the "total" approach will be depends upon the same kinds of factors. For instance, costing bumpers using a "total" approach would mean determining the entire manufacturing cost of alternative bumper systems, rather than looking at the increase in manufacturing cost from one year to the next. Attention must be given to factors that are not normally considered, such as variations in production volumes that could entail cost reductions in subsequent years, or changes in the economic structure that could cause unusual increases in the cost of a particular material. The more the number of alternative designs and materials being considered increases, the more the timespan being considered lengthens, and the more the way is opened for changes in the level of technology or the underlying economic structure, the less likely it is that a detailed level of precision will be applicable. When the range of possibilities becomes very large, it is perhaps more appropriate to argue the issues on the basis of changes in more fundamental quantities affecting manufacturing cost, such as labor, materials and machines. This point will be further explored in the last section.

At this point, the steps in designing a cost methodology have been laid out. The design stage has been discussed in great detail. The remaining two stages can be treated more briefly, because they are normally more obvious.

5.2.3 Use of Costing Methodology to Determine Cost Data

The second stage, the use of the costing methodology to determine the cost data, is the time-consuming stage. Available data that fits the costing methodology needs to be retrieved. New data needs to be generated in as cost-efficient a manner as possible. The important point is that assumptions will have to be made to get around problems in the cost data. The assumptions should be made with the guidelines of the costing methodology in mind. The parameters affected by assumptions should be tested in formal sensitivity analyses.

5.2.4 Use of Cost Data to Evaluate Alternatives

The third stage, the use of the cost data to evaluate alternatives, determines the outcome of the work. The level of confidence in results will vary with the nature of the parameters, the cost data, and the assumptions. Weighting factors can be used to allow a means of expressing the effect of changes in parameters that can only be evaluated subjectively.

5.3 ANALYSIS OF ORIGINAL TSC REPORT[5-1]

5.3.1 Methodology of Original TSC Report

In this section, the analytical framework will be used to discuss the cost methodology of the original TSC report.

The original TSC report concluded that the bumper standards in effect for 1973, 1974 and 1975 were cost-beneficial to the consumer, with 1976 being marginal, relative to bumper systems of 1971. The report is explicit about its assumptions, the available data, and way in which changes in the parameters were assessed.

The five steps included in the discussion of the cost methodology design will be discussed in order.

1) Definition of what is to be costed:

The TSC report considers bumper systems from production vehicles of four size classes for the years 1973-1976 in reference to the base year of 1971. The bumper system consists of two bumpers, one on the front and one on the rear, each bolted to the frame of the vehicle. In 1971, the design consisted of a face-bar, a reinforcement bar, nuts, and bolts. The 1973 design added two energy absorbers to the front bumpers. The 1974 design added two energy absorbers to the rear bumper. The 1975 design added four corner brackets with nuts, and bolts (two to each bumper). The 1976 design added two additional corner brackets to each bumper so that the bumper was protected against corner impacts at heights of 16 and 20 inches above the ground. In each case, the design is improved incrementally.

2) Determination of the terms in which the costing is to be done:

The TSC Report includes cost data for the following parameters: incremental unit cost, average replacement cost, fuel economy penalty per 100 pound vehicle weight change, increased operating cost in fuel dollars per 100,000 miles, and incremental taxes and finance charges. The choice was made not to address manufacturing cost directly, and not to address the relation between manufacturing cost and initial purchase price, or manufacturing cost and replacement cost. Alternative estimates of incremental unit cost from three sources are given: from TSC, from the automotive manufacturers, and from Rath and Strong under contract to TSC.

3) Definition of the extent to which alternative designs, materials, and levels of technology are to be included:

The TSC report considers only bumper systems that are of conventional design with the addition of incremental improvements to meet the escalating standards. Energy absorbers are included, but they are self-contained units of relatively simple design. The addition of energy absorbing units did not constitute a change in level of technology, because they could be produced using standard manufacturing and assembly techniques. No alternative materials were considered; only conventional steel.

4) Determination of appropriate level of precision:

The TSC report attempts to maintain the same relative level of precision throughout the study, and an attempt is made to arrive at quantified results for all parameters without using weighting factors in subjective assessments.

5) Definition of approach:

In the TSC Report, the approach was incremental, which was appropriate because no extreme changes in design, materials, or level of technology were being considered.

5.3.2 Evaluation of the TSC Report

It is evident from the preceding discussion that the TSC Report is based on a cost methodology that appears quite limited in scope in comparison to how the study might be approached today. The range of bumpers in production has expanded to include new materials, new designs, and new techniques. New materials include aluminum, HSLA steel, and plastics. New designs include the integrated design where the bumper and grille are incorporated in the front end, or the design where additional filler panels are used to integrate the bumper with the body. The new technology includes production techniques for the new materials, especially plastic. Prototype soft energy absorbers are available.

The TSC Report is, however, consistent and thorough in its analysis, and there is no reason to believe a priori that the results of the study would change if it were redone.

Due to the emphasis on improving emissions, and fuel economy as well as safety, the pace of implementation of technological changes in automobile designs and manufacturing techniques has been rapid in the past years. Bumpers are good candidates for materials substitution, because they are not part of the load-bearing structure and because they have generally increased in weight over the past few years.

As a result of efforts in all areas, more data is available on manufacturing costs, and there is more interest in the relation of manufacturing costs to purchase price and replacement cost.

The next paragraph discusses a manufacturing cost methodology.

5.4 MANUFACTURING COST ESTIMATING PROCEDURE

5.4.1 Introduction

In this paragraph, a second cost estimating procedure, of more extensive scope than the cost methodology discussed in the previous paragraph, will be discussed. The cost estimating procedure is a cost methodology for determining manufacturing cost. As was pointed out in the previous paragraph, the manufacturing cost parameter is the primary cost parameter. It is a major determinant of initial purchase price and of replacement cost.

It is typical of the automotive industry, or of any high volume production industry, to do cost estimates at the level of hundredths of a cent. A cost difference of $.01 per vehicle translates into $3500.00 per year with a production volume of 350,000 vehicles per year. Clearly, a manufacturer will want to be able to perceive annual cost differences more finely than in $3500 increments. For this reason, tenths and hundredths of a cent are typically carried on the books. Thus, using a manufacturing cost estimating procedure that is typical of high-volume production manufacturers means dealing with a level of precision that is several orders of magnitude more precise than the kinds of cost estimates used in the original TSC report.

One disadvantage in using this type of cost estimating is that the results will be misapplied in situations where the assumptions of the cost work have been changed. It is necessary that assumptions of standard production volumes, standard manufacturing equipment and tooling, and standard rates for the costs of labor, material, and factory burden be realized. There are many areas where standard questions of business uncertainty intervene. At the same time, differences between plants and differences between manufacturers make it impossible to use one set of assumptions for all of these situations. Therefore, either because of uncertainties that cannot be resolved in advance or because of differences at the plant level which the data is not yet sufficient to describe, the level of precision generated using standard manufacturing cost estimating can only be used to give representative costs, which may or may not accurately depict the cost reality in advance.

One advantage of doing manufacturing cost work at this level of precision is that the discrimination of differences between alternatives in the same range of costs is possible. In this sense, the industry's attitude toward costing is better represented, and the way is opened for an intelligent discussion of cost trade offs.

A second advantage is that it may not be possible to achieve a consistent level of precision throughout a cost study. Some areas require subjective assessments that cannot be precisely quantified. Decisions between alternatives must be made even with this lack of precision. It is helpful in these cases to have some detailed cost work to illustrate the kinds of trade-offs in manufacturing cost that must be made, even though once manufacturing costs are factioned into other equations, the precision will be lost.

The manufacturing cost methodology to be discussed in this paragraph is based upon the cost estimation procedure used by Pioneer Manufacturing and Engineering Company of Warren, Michigan. The cost estimation procedure is based on years of experience in costing automotive parts and vehicles. The discussion will be divided into three sections:

1) a discussion of the Pioneer methodology in terms of its basic analytical framework,

2) examples of bumper costs arrived at by this methodology used in another study and,

3) a discussion of how the manufacturing cost methodology could contribute to the bumper study.

5.4.2 Pioneer's Manufacturing Cost

5.4.2.1 Design of Cost Methodology - The objective of most cost studies which use the cost methodology of Pioneer is to assess the variable cost or the manufacturing cost of a new automotive design or a change in automatic design which will be produced in a high volume mass production environment. The key elements here are the design and the high-volume environment. The purpose of the cost methodology is to determine changes in variable cost or manufacturing cost within the context of the high-volue mass-production operations of the automotive manufacturing industry. As mentioned previously, high-volume production runs mean that cost differences of fractions of a cent become significant. The constraint of this type of precision influences the cost methodology at each stage.

From the design point of view, the cost methodology used by Pioneer is precisely structured. The methodology has been used for years, and refinements have been made gradually. The basic parameters do not change, but the estimating coefficients are updated each year. Certain coefficients are application-dependent, and these will vary depending upon the objective of the study. Certain coefficients are manufacturer-dependent, and these will vary depending upon the characteristics of the manufacturer in question. The rest of the paragraph will discuss the five steps of the cost methodology. The basic parameters will be explained, and examples of the changes that can occur in the estimating coefficients of the parameters will be given.

1) Definition of what is to be costed:

The Pioneer costing methodology can be used to determine the variable cost or the manufacturing cost of any part, subassembly, assembly, system, or complete vehicle for which a detailed design is available. An assembly, such as a bumper system, cannot be costed in the abstract. The definition of what is to be costed must include a detailed design showing the design of each part, its relation to the entire assembly, and the tolerances to be maintained. The material (or alternative materials) must be specified. The desired production volume must be specified. The material, the required production volume, and the size of the part will determine the manufacturing process (or processes) that are likely to be most cost-effective.

2) Definition of the terms in which the costing is to be done:

The Pioneer costing methodology is a bottom-up approach to costing which requires that an item to be costed be costed in terms of its parts. Each part will be costed in terms of its variable costs and its tooling cost. In some cases, manufacturing cost is required as well. In one particular application, other corporate costs and dealer mark-ups were calculated to give consumer cost, but the methodology of these cost elements was determined by a sub-contractor, and is not part of Pioneer's standard cost estimating procedure being discussed in this section.[5-2]

a) Variable Cost

The variable cost is calculated in terms of direct materials cost, direct labor cost, and the cost of variable burden (which is the variable factory overhead). The determination of the variable burden rates is one of Pioneer's areas of expertise. The variable burden is allocated to a part on the basis of its machine occupancy time. The following section is a statement from the Final Report of contract DOT-HS-5-01081 describing how variable costs are determined by Pioneer:

> "The variable costs of production of automotive components are those incremental costs associated with that component. The major categorical contributors to variable costs are direct labor, direct materials, and variable burden. Other minor contributors to variable cost such as setup costs, where applicable, are included in the variable burden rate.
>
> Direct labor costs are determined as an average rate depending on the worker classification required to perform the tasks identified in the process study (e.g., punch press operator, drill press operator, machinist). Average labor rates are determined from Union records, Department of Labor statistics, or a combination thereof. Labor fringe benefits and standard allowance for less than 100 percent labor efficiency are included in the average labor rate.
>
> The process study identifies the type of machinery used to perform the task at hand and the rate at which that machinery operates. With these data, the direct labor charge for the given task is calculated, and that partial cost is assigned to the direct labor costs for that component. Total direct labor cost per component part is a summation of costs taken over all tasks or operations required in the production process.
>
> Direct material costs are those costs associated with the purchase of all material required in the production process. Accordingly, direct material costs include the cost of not only the material in the finished component, but also that of the material scrapped minus salvage price, due to material removal.
>
> Variable burden costs are estimated charges that attempt to account for all other expenses due to the production process that vary directly with the production volume and contribute to the cost of sales. Examples of sources of such expenses include, but are

> not limited to, perishable tools (e.g., drill bits, spot welding tips), fuel and power requirements, and direct supervision and clerical. The total of all expenses that vary with the production quantity is estimated, based on a production planning volume. The sum of these expenses is then apportioned to each component on some logical scheme. The amount of apportionment is known as a variable burden rate.
>
> Several methods of applying variable burden have been popularly accepted in the past as well as during current times. Total costs that are apportioned on the number of pieces produced, or material usage, misrepresent true costs whenever parts of different sizes or complexities are produced. Costs apportioned on direct labor misrepresent true costs in a highly automated production process.
>
> This study utilizes a burden rate applied on occupancy time in a given machine, or station, performing a task during the production process. Burden rates are calculated on the basis of a combination of machine or station complexity, cycle time, area occupied, and other considerations that more realistically reflect the true rate of apportionment of total variable expenses."

Direct material costs are the most straightforward element of variable cost because they can be calculated from published material. Direct labor costs, which are industry averages for each task in the process study, will vary with the manufacturing processes chosen for the manufacture of each part. They are affected to some extent by the pace of technological change in manufacturing techniques. Variable burden rates are a subject of much debate. Not only is the method of allocation a problem, but also, the nature and extent of the expenses included varies from one plant to another. Establishing these rates according to a routine procedure, such as is followed at Pioneer, helps reduce arbitrary fluctuations.

b) Tooling Cost

The tooling cost is caluclated in terms of the cost to make the die model (usually wood or plastic) and the cost to make the dies themselves which will then be set-up in the presses. Normally, a left and a right of any part will be made with the same die. The cost of the tooling is given in thousands of dollars, which must then be allocated to the number of parts to be produced with that tooling. Where the part is to be used for one model year and a planned annual volume of 350,000 vehicles, the number of parts to be produced with that tooling will be 700,000. When the dies wear down, the edges are rebuilt. In this way, the useful lifetime of a die-set can be extended. The following excerpt from the Final Report of Contract DOT-HS-5-01081 describes how tooling costs are determined by Pioneer:

> "Tooling cost in this study is determined by apportioning the total expense for special tooling to manufacture a component over the entire life production volume of that component. The following sample calculation will serve to explain the technique:
>
> The front floor pan, a component of the front floor assembly in the underbody (UPG 01A01) as an example, has an estimated expense for special tooling of $940,000. This includes all costs incurred to produce the necessary die model and all metal forming dies and fixtures required to produce this part. This part is planned for three years. New designs after three years will require a different part. 350,000 units are planned per year which result in a total lifetime production of 1,050,000 units. Dividing the total tooling expense of $940,000 by 1,050,000 results in $0.8952 per unit."

Some manufacturers include the cost of tooling (as amortization of special tooling) in the factory cost of a part. The Pioneer cost methodology keeps it as a separate cost category, which would allow for flexibility in amortization schedules.

c) <u>Fixed Cost</u>

The fixed cost is not always included in a study. The determination of fixed costs is largely a matter of accounting policy and, thus, will vary greatly from one manufacturer to the next. Furthermore, purchased components entail no fixed cost, although a 10% vendor mark-up is added to the calculated variable cost. The decision as to whether to make a part or purchase it from a supplier is a complex process involving many factors. In the final report of HS-5-101081[5-1], the fixed costs were calculated in the following way:

"The portion of total manufacturing costs, known as fixed cost, is the accumulation of costs incurred in the manufacturing of a product that does not vary regardless of the volume. Major categorical contributors to fixed cost are indirect labor, indirect materials, and fixed burden.

Indirect labor costs are determined by apportioning the total estimated wages for indirect labor over the planned production volume. Indirect labor is comprised of, but not limited to, supervisory and management, clerical, janitorial, plant production, etc. The total cost of such labor is not affected by variations in the production rate. Total estimated labor costs are a function of specific manufacturing plant's manning requirements.

d) Indirect Material

Indirect material costs are determined by apportioning the total estimated costs for all material necessary for the proper functioning of the manufacturing plant and not related to the finished product over the planned production volume. Indirect materials are comprised of, but not limited to, stationery and office supplies, janitorial supplies, maintenance supplies, first aid and medical supplies, etc.

e) Fixed Burden

Fixed burden is determined by apportioning the remaining estimated expenses related to the operation of a manufacturing plant over the planned production volume. All such expenses are conveniently accumulated categorically as burden. Such expenses are comprised of, but not limited to, property taxes, insurance costs, depreciation charges on buildings and capital equipment, etc.

Indirect labor, indirect material and fixed burden collectively contribute to a fixed burden rate. As with the variable burden rate, fixed burden is applied on a basis of occupancy time in a machine or station. The application of the burden rate for the proper time intervals results in the fixed cost contribution to the total component cost.

This material is included mainly for the sake of completeness. The variations between manufacturers make it necessary to consider Pioneer's estimation of fixed costs as an approximation only. The fixed costs are also highly variable from year to year depending upon corporate finances and accounting policies.

Throughout this material, the importance of planning volume has been stressed. Planned production volumes should be viewed as one of the terms in which the costing will be done. It will be necessary to select typical volumes, because actual volumes will vary with the manufacturer's sales and marketing strategies. Planned volumes are important for another reason as well: the selection of the manufacturing process to be used depends upon the planned volume. Different manufacturing processes are cost-effective in different output ranges. The factors involved here are complex and constitute one area of special expertise of the automotive industry.

3) <u>Definition of the Extent to Which Alternative Designs, Materials, and Levels of Technology are to be Included:</u>

The Pioneer methodology uses the current level of technology. Alternative materials are included in Pioneer's work when they become sufficiently cost-effective to be potentially appropriate for high-volume automotive applications. Alternative designs are always being costed or developed. The point to be made here is that the Pioneer cost methodology can be used to determine costs of any new design or material, but estimates of the cost of high-volume manufacturing processing cannot be made until actual production experience exists. There is no way to predict high-volume manufacturing processing costs without using a current production item as a basis for comparison. The excerpt in Table 5-1 from Pioneer's Work under contract DOT-TSC-1045 describes this problem.

Furthermore, the fact that Pioneer updates its cost data for materials, labor, and burden each year means that studies done one year with one cost structure are not directly comparable to studies done in another year. Even when the data is corrected for inflation, changes in the underlying level of technology cannot be factored out.

TABLE 5-1. PREFACE TO PIONEER REPORT

Historically, the major portion of body components have been made from steel. Decorative parts such as grilles, headlamp bezels, door handles, etc., have been produced from other materials. However, these decorative components comprise a relatively small part of the total number and mass of body components. As a consequence, the many facets of automobile body design and fabrication know-how are based on the use of steel, and this knowledge has evolved over a period of 70 years or more.
Cost data on these steel components are quite accurate because of this vast experience and the records that have been generated over the many years of producing automobiles. Cost of new steel parts can be predicted with a high degree of confidence because of this historical data.
The cost of parts to be made from candidate lightweight materials cannot be projected with the same degree of confidence as steel because of the lack of historical data. Costs associated with handling, fabrication, fastening, finishing, employee training, etc., are inherently vague because there are many unforeseen problems that develop when a new material is put into production. Several manufacturers of candidate lightweight materials would not forecast piece costs in production because of these problems.
The effort in this task, therefore, was concentrated in those areas where lightweight materials are being used and there is some historical data.

4) Determination of the Appropriate Level of Precision:

The Pioneer cost methodology is based on the preparation of a detailed operation sheet for each part. The preparation sheet includes the calculation of the material cost, the labor cost, and the burden cost for variable manufacturing cost of that part. The associated tooling cost calculation is also included. Costs are calculated in hundredths of a cent. The level of precision is necessary to allow for reasonable precision in predicting aggregated annual model year costs. The level of precision used is typical of the automotive industry. The results of the costing do not predict what costs will be for a particular manufacturer, but they do provide a reasonable, standardized method of providing cost data that can be used as a means of making the cost-effectiveness of design alternatives.

5) Definition of Approach:

The approach of the Pioneer cost methodology is to cost as much of the item as is desired. The changes in only one portion of an assembly may be costed. Then, the approach can be incremental relative to the cost of the rest of the assembly which can be assumed not to change. If a new design for the entire assembly is being costed, then the approach can be reviewed as fundamental, and the entire cost structure for that part can be re-optimized. In one sense, the choice of approach replicates a manufacturer's decision to cost on the basis of "on-the-shelf" sub-components, or to cost on the basis of manufacturing certain sub-components in-house which could result in a cost savings if the new design is more cost-effective to produce. Pioneer has the expertise to supply cost data for bumper systems using a wide-range of materials and designs, with the understanding that high-volume production processing cost estimates can only be given where actual production process data exists. The entire bumper system (or possibly the entire front-end) would be costed in each case. The results would only be valid for the current level of technology, but could be repeated in a subsequent year to determine whether changes in technology had altered the cost structure significantly enough to affect the results for bumper systems.

The factors that have been discussed summarize the Pioneer cost methodology from the design point of view.

5.4.2.2 Use of Pioneer Costing Methodology to Determine Cost Data

The objective of this paragraph is to show how the cost methodology, whose design was discussed in the previous paragraph, is used to determine cost data. It will be necessary to discuss the definitions of the elements of variable cost in more detail in order to indicate how the cost data is generated. An example of an Operations sheet from the Estimating Department at Pioneer will be discussed to illustrate the details of the estimation procedure calculations. Examples of costs of bumper systems costed by Pioneer will be presented.

Further definition of materials and processes is not an arbitrary exercise; in fact, it is indicative of the way the process of change goes on in the automotive industry. The manufacturers compete continuously in the area of design improvements to reduce costs. It is the job of the manufacturing engineers and the product engineers to determine the most cost-efficient solution for each part, and for the collection of parts that make up the complete design. The problem of finding the "optimal" design in terms of its being most cost-beneficial to the company (and to the consumer as well) is continually being re-examined. Usually, the process is evolutionary, proceeding by incremental changes from one design to the next. At times, an "all-new" design is introduced. The all-new design can occur at any level from the component level to the vehicle level. (Obviously, it occurs less frequently at the more aggregated levels because the amount of effort required is much larger.) Often, the optimization process will entail having several alternatives "costed out," and the decision regarding the alternatives will be based on the results of the costing study.

To return to the problem of the terms for further defining the material and process of a part or assembly, the two areas can be considered separately once the distinction between them is made clear. Broadly speaking, the material is what is purchased from a supplier, and the process is whatever manufacturing operations are performed in-house. The decision regarding what parts of a particular assembly or subsystem or vehicle are to be made in-house or purchased from a supplier constitutes the essence of manufacturing strategy. Each manufacturer will attempt to maximize his opportunity for profit by producing the parts in-house which give him a competitive adantage, i.e., parts for which his fixed costs will be low compared to his competitors. The demarcation line between the two is different for each manufacturer, and, furthermore, the demarcation line will shift each year as the manufacturers change their part sourcing to maximize their competitive position. In terms of assessing what the variable cost of a part or assembly is, where the demarcation line is established makes a difference to the extent that parts which are designated for purchase from a supplier will be marked up by 10 percent to cover the supplier's profit. Otherwise, the variable cost estimation procedure is the same. (If fixed costs are being included in the study, no fixed costs will be shown for purchased parts.)

Next, the definition of the "material" from which the part is to be made will be discussed. Various levels of definition are possible. At the most basic level, the materials in a vehicle are described as: steel, iron, aluminum, plastic, rubber, glass, zinc, copper, brass, lead, composites, asbestos, cardboard, and fabric. These materials can be further specified in terms of their "grade" (which means adjectives such as hot-rolled, cold-rolled, galvanized, aluminized, etc. for metals, and polyethylene, nylon, polypropylene, phenolic, etc. for plastic); "form" (which means adjectives such as fastener, casting, forging, bar, sheet, wire, powder metal, tubing, plate, and rod); and "gage". For the cost methodology used by Pioneer, the input material must be specified in a manner sufficiently detailed to enable a purchase price to be estimated for that material purchased in quantity.

Next, consider the definition of the "process" to be used in manufacturing the part. At a basic level, the manufacturing processes include: stamping, casting, forging, machining, extruding, forming, and molding. Each basic process includes a series of steps which must be determined in detail for each part. For instance, a stamping process, generally includes blanking, welding, notching, trimming, and bending. The detailed operations for each part depend upon its design. Blanking normally requires one station on the line. Spot welding normally requires one station. Stamping may require a number of stations depending upon the complexity of the design. The particular combination of stamping operations, including notching, bending, trimming, etc., to be carried out by each station will be specified. The dies for the press at each station will be designed to accomplish these operations and will be costed accordingly.

Using the more detailed definitions of what is being costed, as described above, the cost data can then be generated. The procedure will be illustrated by an example from the Pioneer costing of the 1975 Pinto which was performed under contract to NHTSA. The Operations Sheet for the "B" Pillar Upper of the Pinto is presented in Table 5-2. The "B" Pillar Upper is a stamped steel part. The input material to be purchased is coiled steel. The processes to be used are blanking, spot welding, three stamping operations, and inspect and pack, for a total of six operations. Each operation is described in detail on the operations sheet, including details such as the speed of the blanking operation, the number of spotwelds, the number of workable stations in each die and what they are, and the tonnage of each press. For each operation, the number of workers performing the operation and the number of pieces processed per hour are given. The description of each operation is then costed out, based on the equipment occupancy time, the skill category of labor required to do the work, the burden rate for running that particular type of equipment, and the tooling cost for making the necessary dies and fixtures.

In the example of the Pinto pillar, the direct materials cost is $.2926 per pillar. A one percent scrap allowance for rejected parts is added to this figure to give $.2955 per pillar.

TABLE 5-2. ESTIMATING DEPARTMENT OPERATION SHEET

OPER	OPERATION DESCRIPTION	TYPE OF EQUIPMENT	M/P	PCS/HR. / MINS/pc	LABOR COST $ / LABOR $ RATE	OCC. HOURS /min		BURDEN RATE $/hr	BURDEN COST $	VAR COST $ / MFG COST	DIE MODEL $ (000)	TOOLING $ (000)
10	Roll sweep & cutoff @ 65'/min			2000	.00349		V	12.31	.00616	.0096		
				.03	.1163	.0005	M					8.5
							V					
							M					
20	Spot weld flange - 1 hit			400	.01744		V	12.31	.03078	.0482	Fixt	10.0
				.15	.1163	.0025	M				only	1R/1L
							V					
							M					
30	4-Sta - Notch -trimside -D/bend			300	.02256		V	9.08	.03024	.0528	3.0	21.7
	PRC key slot & control notch lower end			.20	.1128	.00333	M					1R/1L
							V					
							M					
40	3-Sts - Notch -Shuttle notch -notch			350	.01934		V	9.08	.02597	.0453		8.25
	upr end			.17143	.1128	.00286	M					1R/1L
							V					
							M					
50	3-Sta - Shuttle notch - Restrike -			350	.01934		V	9.08	.02597	.0453		9.3
	PRC key slot upr end			.17143	.1128	.00286	M					1R/1L
							V					
							M					
60	Inspect & pack			800	.00346		V	9.08	.01135	.0198	5.0	
				.075	.1128	.00125	M					
							V					
							M					
							V					
							M					

SHT	COIL	GAGE	QUAL	MAT'L		PCS	ROUGH WGT
	X	.053		CR CQ	5.42 x 23.375	1	1.902 #
		Actual Wt			= 1.52# ea. op 3.04#/Car		

COST PER LB. .15386 MAT'L COST .2926

SKETCH – REMARKS

Carton = .0080

TOTAL VAR. LABOR & BURD.		.2210
TOTAL MFG. LABOR & BURD.		
MATERIAL		.2926
SCRAP	1%	.0029
SET-UP		
OTHER		.0080
MARK-UP %	10%	.0524
TOTAL VAR. COST		.5769
TOTAL TRANS. COST		

DIE MODEL total: 8.0 TOOLING total: 57.75

KEY ☐

NON KEY ☐

VOL. 1750 pc/day

UPG

PART NO "75" PINTO

PART NAME "B" PILLAR UPPER

The direct labor cost and the variable burden cost are calculated based on the equipment occupancy times for the six operations, which vary from .0005 hours (1.8 secs) for blanking to .00333 hours (12 secs) for the most complicated stamping operation. The direct labor rates are around $7.00/hour. The variable burden rates are $12.31/hour for blanking and welding, and $9.08 for stamping. Thus, the variable costs of the processing operations range between $.0096 and $.0528 for each operation, and the total for the six operations is $.2210. The cost of the carton is $.0080 per pillar. At this point, the variable cost per pillar is $0.5245. A 10 percent mark up is added to this to cover the vendor's profit. Thus the total variable cost per pillar is $.5769. There are two pillars per vehicle, so the variable cost per vehicle is $1.1538. This figure does not include tooling cost. The tooling cost is $8,000 for die models and $57,750 for die tooling and fixtures. These figures are for the tooling for both a right and a left pillar. Assuming that the tooling is amortized over three years with an annual production volume of 350,000 vehicles, the allocation of tooling cost per vehicle would be approximately $.06 per vehicle. (This calculation neglects return on investment.)

In summary, the cost of the Pinto pillars is approximately $1.20, of which 50 percent is direct materials cost, 15 percent is direct labor cost, 20 percent is variable burden cost, 5 percent is the cost of tooling and 10 percent is the vendor's profit. The proportions of costs are interesting in themselves for the insight that they offer regarding the nature of the cost structure of automotive parts. The concept of value added should be mentioned here, because the vendors profit of 10 percent is not an insignificant amount of the variable cost of the part. The actual vendor selling price might incorporate the cost of the tooling and other fixed overheads, but in the Pinto study, costs were organized in this fashion on purpose. The importance of the example is not the costs per se, but the illustration of the way in which the cost methodology of Pioneer is applied. In particular, the methodology is precisely but not rigidly structured. Changes in assumptions regarding volumes or the demarcation line between suppliers and original equipment manufacturers can readily be incorporated. The standardized procedures for arriving at labor rates and burden rates provide a means for possible projections of costs in terms of changes in these rates. The level of technology is reflected in the relationship of these two rates, the occupancy times, and the tooling expenses. The greatest advantage of this methodology is that it provides a means of distinguishing cost differences when the items being costed are similar. A later section will discuss the usefulness of this methodology relative to the determination of an optimal bumper standard, but first, some results for bumper systems costed by Pioneer will be presented.

5.4.2.3 Costs of Bumper Systems Determined by the Pioneer Methodology

The objective of this paragraph is to present some examples of bumper systems that have been costed by Pioneer. The bumper system for the 1975 Chevelle was costed as part of the Final Report in Contract DOT-HS-5-01081. This work included fixed costs as well as variable costs. A series of bumpers was costed as part of the work on lightweight materials under Contract DOT-TSC-1045. The Chevelle bumper system is an important example, because it shows costs for detailed parts of the bumper system, and it illustrates the next level of aggregation after the operations sheets have been prepared. The lightweight materials study's bumpers are important as an example of the range of costs associated with bumpers made from alternative materials. It is particularly important to notice how the percentage of cost due to different cost elements shifts, i.e., the percent for tooling vs. the percent for direct materials, etc.

Table 5-3 shows detailed costs of the front bumper for Chevelle.

Table 5-4 shows detailed costs of the rear bumper for Chevelle.

The lightweight materials study considered bumpers as part of the front end. Thus, the bumper systems costed here include

TABLE 5-3. COSTS OF FRONT BUMPER FOR 1975 CHEVELLE

Item BUMPERS	Req'd Per Vehicle	Material	Weight	Total Tooling ($000)	Years Amort.	COST PER VEHICLE Variable	Fixed	MFG.	Tooling	Gin Cost + Profit	Dealer Markup	Consumer Costs	COST PER POUND OF VEHICLE Variable	Fixed	MFG.	Tooling	Consumer Costs
36001 - FRONT BUMPER TOTALS			107.13	937.3	1	34.0100	4.4165	38.4265	1.9027	3.6081	11.6796	55.6172	0.3175	0.0412	0.3587	0.0178	0.5192
Facebar - Front Bumper	1	Steel + Nickel + Chrome	35.90	312.5	1	14.3448	1.9357	16.2805	0.5900	1.5364	4.9735	23.6333	0.3996	0.0539	0.4535	0.0249	0.6597
Panel - Front Bumper Reinforcement Front	1	Stamped HS Steel	38.90	171.3	1	7.7290	1.0566	8.7859	0.4534	0.8297	2.6859	12.7593	0.1987	0.0271	0.2258	0.0126	0.3258
Reinforcement - Front Bumper Reinforcement Center	1	Stamped HS Steel	6.00	37.1	1	1.3857	0.1107	1.4964	0.1060	0.1433	0.4641	2.2098	0.2310	0.0184	0.2494	0.0177	0.3683
Reinforcement - Front Bumper Reinforcement Outboard	2	Stamped HS Steel	5.00	19.5	1	0.8452	0.0289	0.8740	0.0557	0.0832	0.2692	1.2921	0.1690	0.0058	0.1748	0.0111	0.2564
Assembly of Front Bumper Reinforcement	1	--	--	20.0	1	1.0141	0.0225	1.1026	0.0571	0.1037	0.3359	1.5993	0.0118	0.0011	0.0129	0.0007	0.0156
SUBTOTAL: Front Bumper Reinforcement Assembly	--	--	85.80	560.4	1	25.3191	3.2203	28.5394	1.6011	2.6965	8.7285	41.5645	0.2951	0.0375	0.3326	0.0157	0.4844
Assembly - Front Bumper Energy Absorber	2	Steel + Plastic + Rubber	15.30	385.7	6	6.6752	1.0860	7.7612	0.1837	0.7108	2.3009	10.9566	0.4364	0.0709	0.5073	0.0120	0.7161
Plate - Front Bumper Stud	2	Stamped HS Steel	--	12.4	1	0.2396	0.0714	0.3110	0.0354	0.0310	0.1003	0.4777	--	--	--	--	--
Stud - Front Bumper Mounting	8	Steel	--	--		0.4000	0.0000	0.4000	--	0.0355	0.1153	0.5516	--	--	--	--	--
Assembly of Front Bumper Stud Plate	2	--	1.26	0.8	1	0.0738	0.0082	0.0820	0.0023	0.0076	0.0244	0.1163	0.0586	0.0065	0.0651	0.0018	0.0923
SUBTOTAL: Front Bumper Stud Plate Assembly	--	--	1.26	13.2	--	0.7134	0.0796	0.7930	0.0377	0.0743	0.2406	1.1456	0.5662	0.0632	0.6294	0.0299	0.9092
Bracket - Front Bumper License Plate Mounting	1	Stamped Steel	2.81	28.0	1	0.5183	0.0319	0.5502	0.0800	0.0564	0.1825	0.8691	0.1844	0.0114	0.1959	0.0285	0.3093
Fasteners	--	Steel	1.96	--		0.7840	0.0000	0.7840	--	0.0701	0.2271	1.0812	0.4000	0.0000	0.4000	--	0.5516

TABLE 5-4. COSTS OF REAR BUMPER FOR 1975 CHEVELLE

Item BUMPERS	Req'd Per Vehicle	Material	Weight	Total Tooling ($000)	Years Amort.	COST PER VEHICLE							COST PER POUND OF VEHICLE				
						Variable	Fixed	MFG.	Tooling	Oth Cost + Profit	Dealer Markup	Consumer Costs	Variable	Fixed	MFG.	Tooling	Consumer Costs
3G02 - REAR BUMPER TOTALS			90.75	857.9		31.0690	4.4431	35.5121	1.5329	3.3142	10.7284	51.0877	0.3424	0.0490	0.3913	0.0169	0.5629
Facebar - Rear Bumper	1	Steel + Nickel + Chrome	24.50	228.9	1	10.6059	1.7755	12.3814	0.6540	1.1662	3.7751	17.9767	0.4329	0.0725	0.5054	0.0267	0.7337
Panel - Rear Bumper Reinforcement Upper	1	Stamped HS Steel	24.50	103.7	1	5.[illegible]	0.7650	6.3504	0.2963	0.5949	1.9255	9.1704	0.2251	0.0312	0.2593	0.0121	0.3743
Panel - Rear Bumper Reinforcement Lower	1	Stamped HS Steel	23.00	85.6	1	5.3185	0.6120	5.9305	0.2446	0.5525	1.7883	8.5159	0.2312	0.0266	0.2578	0.0106	0.3703
Gusset - Rear Bumper Reinforcement	5	Stamped Steel	1.60	8.0	1	0.4665	0.0480	0.5145	0.0229	0.0451	0.1556	0.7411	0.2916	0.0302	0.3216	0.0143	0.4632
Assembly of Rear Bumper Reinforcement	1	--	--	32.8	1	1.2241	0.1180	1.3421	0.0937	0.1285	0.4158	1.9801	0.0166	0.0016	0.0182	0.0013	0.0269
SUBTOTAL: Rear Bumper Reinforcement Assembly	--	--	73.60	459.0	--	23.2034	3.3185	26.5219	1.3114	2.4901	8.0607	38.3841	0.3153	0.0451	0.3604	0.0178	0.5215
Assembly - Rear Bumper Energy Absorber	2	Steel + [illegible] + [illegible]	14.30	385.7	6	6.5162	1.0450	7.5612	0.1838	0.6929	2.2430	10.6809	0.4557	0.0731	0.5288	0.0129	0.7469
Plate - Rear Bumper Stud	2	Stamped HS Steel	--	12.4	1	0.2396	0.0714	0.3110	0.0354	0.0310	0.1003	0.4777	--	--	--	--	--
Stud - Rear Bumper Mounting	8	Steel	--	--	--	0.4000	0.0000	0.4000	--	0.0355	0.1158	0.5516	--	--	--	--	--
Assembly of Rear Bumper Stud Plate	2	--	1.26	0.8	1	0.0738	0.0092	0.0830	0.0023	0.0076	0.0244	0.1163	0.0586	0.0065	0.0651	0.0018	0.0923
SUBTOTAL: Rear Bumper Stud Plate Assembly	--	--	1.26	13.2	--	0.7134	0.0795	0.7930	0.0377	0.0743	0.2406	1.1456	0.5662	0.0632	0.6294	0.0299	0.9092
Fasteners	--	Steel	1.59	--	--	0.6360	0.0000	0.6360	--	0.0569	0.1842	0.8771	0.4000	0.0000	0.4000	--	0.5516

more parts and will cost proportionately more. The definition is necessary, because the soft front ends make it possible to perform the same function with fewer parts. Cost estimates of four of the six systems are given in Table 5-5. In comparing these four systems, note that materials vary, but labor and burden are nearly constant, as is tooling. The complete costing data is given in Appendix C.

5.4.2.4 Effect of Manufacturing Costs on Other Cost Parameters

The previous paragraph discussed manufacturing cost in terms of weight, variable cost, tooling cost, and fixed cost. It was shown how estimates of variable cost and tooling cost could be made from detailed knowledge of a bumper system. The weight could be calculated in the process. The fixed cost structure would vary among manufacturers, and thus, could not be as reliably estimated. Perhaps bounds could be established. The purpose of this paragraph is to relate the results of the previous paragraph to the remaining cost parameters, including intial purchase price, fuel consumption, replacement costs, and maintainability and repairability.

The relation between manufacturing cost and initial purchase price is discussed in Section 7. If the design of the bumper system changes, with or without a change in manufacturing cost, the initial purchase price may be affected. If the bumper system has different consumer attributes or different perceived consumer value, the change will be more significant. Appearance, maintainability, and damageability, are the kinds of attributes that affect the consumer.

The relation between manufacturing cost and fuel consumption depends, basically, upon the manufacturing weight. A weight increase increases fuel consumption, and vice-versa. The relationship is well-discussed in the original TSC report.[5-1] An additional weighting factor must now be included because of the emphasis on fuel economy. This will make the penalty for increasing weight more stiff. Bumpers are generally viewed as a component which lends itself to weight reduction. For this reason,

TABLE 5-5. VARIABLE COST ESTIMATES FOR FOUR FRONT BUMPER SYSTEMS

PIONEER SYSTEM NUMBER*	DESCRIPTION	WEIGHT (lbs)	DIRECT MATERIAL ($)	DIRECT LABOR & VARIABLE BURDEN ($)	DIE MODELS & TOOLING ($000)
1	Production Steel Bumper	148.4	41	19	2252
2	Same with ABS Grille	129.9	32	14	2273
3	Same with HLSA Face Plate	75.9	21	13	2035
6	Same with aluminum 7046 face plate	54.6	23	13	2195

* See Appendix C

bumper systems that increase weight will no longer be good candidates. Within the range of bumper system designs that decrease weight relative to the base case, the cost trade-off of increased manufacturing cost versus decreased operating cost must be examined.

The relation between manufacturing costs and replacement costs is similar to the relation between manufacturing costs and initial purchase price except that the markups are not necessarily the same. In general, it can be assumed that the historical relationships would not be changed unless factors such as replacement frequency as a function of design were altered. For instance, if the new bumper system involved bumpers of the same design for front and rear, the replacement costs might decrease to the extent the lower inventory costs are a factor in replacement costs.

The relation between manufacturing cost and maintainability and repairability depends upon the characteristics of the bumper design. If a bumper is chosen that cannot be hammered out when dented slightly (at whatever speed), the maintenance and repair costs of that bumper might increase.

All of the interactions mentioned here should be examined in relation to each bumper design. The changes in the other cost parameters that might occur should be included in the cost/benefit analysis. If no changes are projected to occur, the cost decisions could be made on the changes in the elements of manufacturing cost alone.

6. ASSESSMENT OF AVAILABLE BENEFIT DATA AND METHODOLOGY

6.1 GENERAL

A cost/benefit analysis of proposed low speed damage reduction systems is required for their evaluation. The schematics of the cost/benefit analysis are shown in Figure 6-1. The analysis will weigh the incremental benefits of the new damage reduction systems against their incremental cost increase over current systems. The major benefits expected from new damage reduction systems are the reduction in lifetime crash damage costs. Additional benefits may occur from a reduction in insurance administration costs (fewer claims), and in time that the vehicle is not available for use. These benefits are offset by initial and lifetime operating cost increases due to increased bumper complexity, more costly materials, and increased weight.*

This section assesses the methodology and information for determining the benefits side of the cost-benefit analysis. The adequacy of current determinations of damage cost reduction is addressed first, followed by a similar discussion of all other cost changes.

6.2 DAMAGE REDUCTION BENEFITS

6.2.1 Information Requirements

The expected damage cost reduction for each bumper type is the expected lifetime dollar damage for cars equipped with innovative bumper types subtracted from the lifetime dollar damage for cars equipped with reference systems. Since different bumpers

*The classification of benefits and costs shown in Figure 6-1 is motivated by the assumption that, when candidate bumper systems are compared to the reference system, damage costs will decrease but capital and operating costs may increase. In fact, as Figure 6-1 notes, any of these cost components may change in a positive or negative manner. This does not affect the cost/benefit methodology.

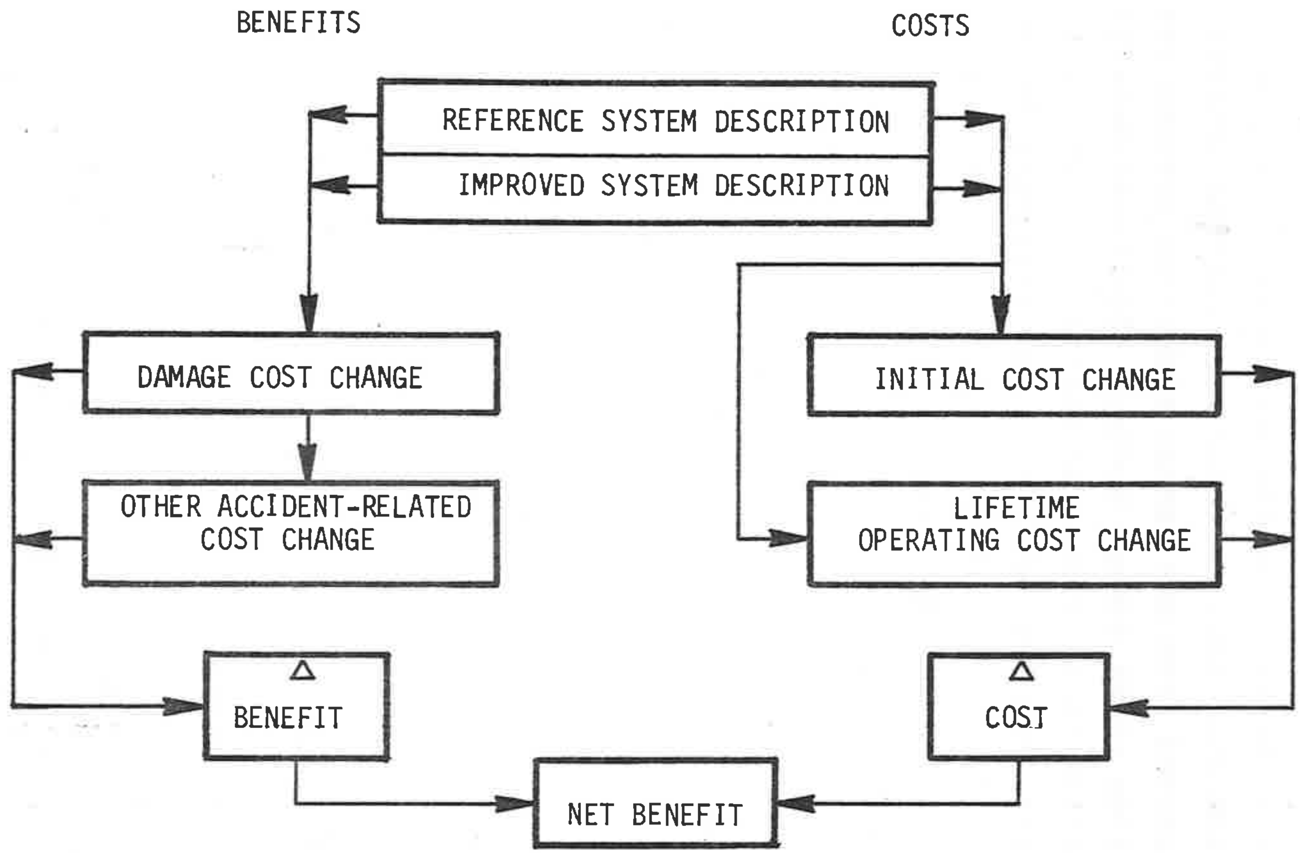


FIGURE 6-1. COST-BENEFIT ANALYSIS OUTLINE FOR DAMAGE REDUCTION SYSTEMS

may be appropriate for different car sizes, the damage expected with any bumper system must be estimated separately for each car size class. Four car sizes will be used here that correspond as closely as possible to the manufacturer's classification.

It is convenient to separate the information required for calculating the expected lifetime damage into the following three types:

Type 1. The expected number of crashes* per vehicle per year of exposure, by the car size class.

Type 2. The distribution of crashes by speed.

Type 3. The dollar damage suffered in a crash as a function of speed, for each car size and each bumper type.

These information types are obtained separately for each impact area. For the purposes of the damage cost analysis, the following six impact areas are sufficient: 1) Square front; 2) front corners; 3) left side; 4) right side; 5) square rear; and 6) rear corners.

Broadly speaking, these three quantities are multiplied together and the result integrated over all speeds to give the dollar damage expected per vehicle year for each car size, each bumper type, and each impact area. Type 2 information, the distribution of crashes by speed for each impact area, must be modified under conditions of a changing fleet mix to translate the closing speed in a car-to-car collision into a barrier equivalent velocity of impact. Summing over the life of the car gives expected lifetime dollar damage for each car size and each bumper type, which makes possible a comparison of the effectiveness of different bumper systems.

Potential data sources for this information is included in following paragraphs. Type 1 information could come from surveys of repaired and unrepaired damage, insurance company records, or fleet records; this will be discussed below. Direct observations

*A crash is here defined as an incident that would cause damage to reference year vehicles.

of crash speeds cannot be obtained in practice; hence, Type 2 information must be indirectly derived. This can be done by observing the distribution of crashes by dollar damage for different car sizes for reference year vehicles, and combining this with Type 3 information for cars with bumper types similar to those on reference year vehicles. It is assumed that the speed distribution of crashes remains constant over time; hence, the above distribution, obtained for the reference year, is used also in future years.

Data for the information now replacing Type 2, namely the crash distribution by dollar damage, comes from the same sources as Type 1 information. Type 3 information is obtained from a physical and mathematical damage analysis of potential bumper systems. This analysis may include a test program that installs new and existing bumpers on cars and crashes them in a controlled fashion so as to simulate real-world crash environments.

A discussion follows that assesses existing data on the crash frequency and the distribution of crashes by dollar damage for reference year vehicles. The damage cost estimate is completed by combining this with Type 3 information that is developed by a damageability analysis. Section 9 discusses this latter subject.

6.2.2 Adequacy of Existing Data on Crash Frequency and Dollar Damage Distribution

There are three general sources for this data: automobile company surveys, insurance company surveys, and fleet records. After reviewing this data, there were problems found with all three sources.

1) Automobile Company Surveys

The purpose of the automobile company surveys is to measure the damage-resisting properties of new cars to show changes from one model year to the next, especially in relation to FMVSS 215 requirements as they took effect.

(a) General Motors[6-1] has a continuing survey of body repair shops in Fort Wayne, Indiana, a closed geographical area, to obtain damage frequency estimates for repaired damage and the distribution of dollar repair costs. They also survey an employee parking lot in Michigan for estimates of unrepaired damage frequency and the cost to repair. A third survey being conducted examines all repairs on claims through their subsidiary, General Motors Insurance, to aid efforts to improve the resistance of GM cars to damage in all kinds of accidents.

Although these surveys are adequate for General Motors' primary objective of understanding year-to-year changes in car damageability, and give a feeling for the magnitude of the accident problem, they are inadequate for government planning purposes. Single-city surveys of repaired and unrepaired damage cannot be generalized. Also, Ford Motor Company[6-2] has shown that from one-fourth to three-fourths of all repaired damage is not claimed for insurance; this limits the usefulness of insurance records.

(b) Ford Motor Company[6-2,6-3] examined body repairs by Ford and Lincoln-Mercury dealers in 21 different geographical areas, and parking lots for unrepaired damage in 11 different geographical areas. Based on the distribution of repair costs,and using barrier test data from the Insurance Institute for Highway Safety (IIHS) showing repair cost as a function of impact speed, they estimated the speed distribution of crashes for front and rear modes, and repaired and unrepaired damage types. This was done for calendar year 1970-1974.

This survey had geographical distribution, but given the wide variation in unrepaired damage frequency among different areas that was discovered in the State Farm survey (discussed below), it is unlikely that this survey would present an accurate nationwide representation of unrepaired damage. In addition, dealer-run body shops are in a distinct minority and are not likely to be representative of the whole.

(c) Chrysler and American Motors representatives were contacted by TSC and said they had developed no independent data addressing vehicle damage.

2) Insurance Company Surveys

The primary purpose of the insurance company surveys described below was to understand how damage claims are influenced by a changing crash environment and changing vehicle designs. However, they have also shown some interest in unrepaired damage

(a) State Farm[6-4] has a continuing survey of damage compensated through insurance. The repairs are tabulated by impact point, repair cost, and car size class. This has the advantage of large sample size and extensive geographical coverage. However, as discussed previously, the large percentage of repaired damage that is not covered by insurance particularly for low speed accidents, invalidates the use of this data by itself, although it may be used in conjunction with other data as shown in Section 8.

(b) The Highway Loss Data Institute (HLDI)[6-5] has a continuing survey of damage compensated through collision or first party insurance that includes eight insurance companies. This is even more comprehensive geographically than the State Farm data bank; however, it covers even a smaller percentage of repaired damage, hence must also be complemented by other data.

(c) State Farm and IIHS[6-6] conducted a survey of unrepaired damage in 1974 in seven different metropolitan areas. The methodology was similar to that of the Ford survey discussed above. Due to the wide variation from one metropolitan area to another (unrepaired damage incidences for 1972 model year cars in 1974 varied from 19% to 65%), such a small and non-random sample of geographical areas cannot be trusted to give an accurate nationwide picture.

3) Fleet Data

Fleet operators are primarily concerned with liability in the event of an accident, and, particularly, injury-producing accidents. Vehicle damage, in particular minor damage, is not given much attention once these liability concerns are disposed of.

(a) Government Fleets Accident reports are submitted for the GSA fleet, and for the part of the fleet used by DOT. The reports, however, concentrate on personal injury, and minor property damage accidents are almost certainly underreported.

(b) Rental Car Fleets. These have been ignored due to their non-typical driver use; people drive them "hard", and usually will not be as careful in low-speed driving conditions as they would with their own cars.

(c) Police and Taxi Fleets. These have also been ignored due to their specialized uses and distinct driver characteristics.

(d) Corporate Fleets. Corporate fleets with passenger car vehicles and wide geographical distribution, and which collect accident information have not been found.

Section 8 justifies and describes, in detail, measures that will assist in remedying these deficiencies in data from existing sources.

6.3 BENEFITS FROM REDUCING OTHER CRASH-RELATED COSTS

Three types of crash-related consumer costs, other than damage cost, are significant (being valued at greater than $100 million per year). These are the variable portion of insurance administration, civil court litigation costs not included in insurance administration, and miscellaneous vehicle-related costs.

Insurance administration has a fixed part, and a part that varies with changes in the number and severity of claims. This variable part has been estimated at $2.9 billion in 1971.[6-7] However, only part of this is related to auto damage. In 1974, auto damage premiums were 38% of the total of all automobile insurance premiums.[6-8] Applying this factor to total variable administration gives $1.1 billion that results from auto damage.

Miscellaneous vehicle-related accident costs includes loss of vehicle use, accommodations while away from home, telephone calls, replacing damaged clothing, and vehicle repair arrangements. These totaled $800 million in 1971.[6-7] The cost of providing civil courts for automobile litigation, plus attorney's fees and other claimants' expenses not included in insurance administration, was $1.4 billion in 1971.[6-7] However, of this, only 5 to 10 percent is associated with property damage claims, giving $70 to $140 million.

A simplifying assumption makes it possible to key insurance administration to crash damage. This assumption is, if variable insurance administration charges per crash are proportional to the severity of the crash, a given percentage of change in crash damage would result in the same percentage change in the former. The error of this assumption stems from the fact that many small crashes and crashes of old cars are not reflected in insurance claims; however, given the relative magnitudes of crash damage and insurance administration ($7 billion[6-7] vs. $1.1 billion; the conclusion of a cost/benefit analysis is unlikely to change. However, the error causes the insurance administration percentage change to be overestimated.

The same assumption can be used for the other two cost categories. It is accurate for miscellaneous vehicle-related costs except for replacing damaged clothing, which is unaffected by improved bumper systems since the interior kinematics of car occupants in crashes is unrelated to bumpers. Hence, replacing damaged clothing should be backed out of the analysis. Applying the same assumption to legal costs would again overestimate the percentage change, but on a small quantity hence producing little error.

The conclusion concerning other crash-related costs is that no new methodology and little new data is needed for a cost/benefit analysis.

7. COST-PRICE RELATIONSHIPS

7.1 GENERAL

This section assesses the different cost-price models that have been developed for the automobile industry, including new-car production and aftermarket. Since there are no constant cost-price relationships within the automobile industry, engineering costs cannot be converted into prices by one simple transformation equation. Thus, in order to estimate changes in the consumer's cost of buying and maintaining a car, a model is needed which estimates price changes due to given cost changes resulting from revised bumper standards. Cost-price models are an important analytical method required to perform the cost-benefit analysis of the Low Speed Automobile Damage Reduction Study.

The historical pricing behavior of the industry, which in economic terms is an oligopoly, is considered first. An oligopoly may be defined as a situation in which a few large sellers supply the entire market for a product. Some of the classical economic theories of oligopoly pricing will then be considered, followed by a discussion of some more recent work on pricing policies for the automobile industry. Finally, a recommended course of action for the comprehensive study, in regard to cost-price relationships, will be presented.

7.2 PRICING BEHAVIOR OF THE AUTOMOBILE INDUSTRY

In the new car market, U.S. automobile manufacturers are fairly price conscious. In general, the actual selling price for comparable models, comparably equipped, is roughly the same for all four manufacturers. However, although it might appear to be highly competitive,[7-1] the market does not involve competition in the strict economic sense. General Motors is de facto price leader in the industry. The other domestic manufacturers are no more than passive followers of General Motors' pricing policy.[7-2,7-3]

Because of its size, General Motors has the greatest economies of scale and is able to produce automobiles at the lowest cost of any manufacturer (GM's share of the market has generally been between 40% and 50% since World War II).[7-4] GM can set its prices for a desired return on investment while the other manufacturers must generally accept a lower rate of return in order to be price competitive.[7-2]

Wholesale prices are the key prices to the manufacturer since they determine the amount of revenue derived per car.[7-5] It is generally accepted that GM's principal technique in setting prices is the target return method, with maintenance of market share as a collateral consideration.[7-6] The wholesale price is based on the anticipated cost of a vehicle at a specified level of output (typically 80% of the firm's capacity output) and the profit margin required to yield the desired return on investment (typically 15% to 20% on an after tax basis).[7-3] The planned level of output, or standard volume, is a key parameter in this process. The actual cost per vehicle varies with output level, and actual profits are highly sensitive to deviations from the standard volume.

Wholesale prices determine the Manufacturers' Suggested Retail Price or "sticker" price. The "sticker" price includes the wholesale price, the dealer's markup (largely determined by the manufacturer), excise taxes and preparation charges. The "sticker" price is the highly publicized basic price for a stripped version of the model in question. The "sticker" price is almost never the actual selling price. To this are added transportation charges and any "options" which the dealer can sell. Finally, the dealer subtracts his trade-in allowance or special "deal" from the price. This "deal" has been found to vary widely among dealers for the same car and to vary widely within the same dealership, depending upon what dealers think the market will bear.[7-5]

The "sticker" price is psychologically important as a determinant of demand,[7-7] although it is an imperfect measure of the price actually paid for the automobile. Manufacturers seem to take the importance of the sticker price into account when setting dealer markups. Dealer markups on higher priced models, where the demand is less sensitive to price, tend to be higher than those on low price models (markups range from about 17% for economy models to 25% for full sized cars.[7-5]

There is little published information on the aftermarket.[7-2] Furthermore, this area is more complex since there are several parts markets, each with its own level of demand, number of manufacturers, degree of competition, etc., depending on the nature of the part in question. For example, the market for parts such as ignition parts, filters, or mufflers is highly competitive, with a number of independent manufacturers competing with the major auto assemblers. However, the market for parts such as body stampings and trim is controlled by the new-car manufacturers. Other parts markets fall somewhere between these extremes in the number of manufacturers, degree of competition, and resulting pricing policies.

In summary, GM sets new car prices for the industry based on its unit costs at a specified level of output and a desired return on investment. The highly visible "sticker" price is a very important demand determinant from the industry's point of view, although it is seldom the actual price paid by the consumer. Considering the diverse nature of the many parts markets, little can be said about the cost-price relationships in the aftermarket in general. Furthermore, little can be said definitely about the nature of the cost-price relationships of any particular segment of the aftermarket at the present time.

7.3 CLASSICAL MODELS OF OLIGOPOLY PRICING

The price and volume of production of the automobile industry is determined by a few companies. In the terms of economic theory, the automobile industry is an oligopoly. The purpose of an economic theory of oligopoly is to explain price and output and the equilibrium relation between price and cost in the same way that these relationships are explained for monopoly, monopolistic competition, and pure competition. Unfortunately, there is no one satisfactory theory of price and output under oligopoly. Instead, there are a number of theories and models, none of which is theoretically satisfactory or applicable to a real-world situation. These models indicate that price and output under oligopoly approach those of pure monopoly, pure competition, or are somewhere in between, although the models cannot say precisely where.

A detailed review of these models is not warranted and can be found in any standard text on price theory.[7-8] However, a few remarks may be worthwhile in order to give some feel for the quality of most of the available economic models.

The models are generally based on the assumptions of identical costs for all firms, homogenous products, and full information on total industry demand. Individual models further assure that the industry acts to minimize the industry's total profits, or that individual firms act to maximize sales without considering the actions of competing firms. None of these assumptions replicates the actual situation in the industry, and, thus, none of the economic models of oligopoly pricing would appear to be useful for the purposes of comprehensive study.

7.4 PRICING IN THE MOTOR VEHICLE GOALS STUDY

Perhaps one of the primary reasons why economists have failed to develop a satisfactory, workable model of an oligopolistic industry is that they have attempted to do too much at once. In attempting to define the cost-price-output relationships for an oligopolisitic industry, the models are forced to incorporate overly simplistic and unrealistic assumptions.

A more realistic approach was taken by Eckstein and Fromm[7-9] when they attempted to isolate the pricing problem itself. Using aggregate industrial statistics on U.S. manufacturing prices, they tried to determine whether the supply-demand, competitive pricing mechanism, target return mechanism, or cost-plus oligopolistic pricing mechanism predominated in U.S. industry. While their results were inconclusive, their models of oligopolistic pricing are of interest. They expressed target return pricing as follows:

$$p = \frac{\pi K}{X^N} + ULC^N + UMC^N \qquad \text{(Eq. 7-1)}$$

where π is the target rate of return;

K is the firm's capital stock;

X^N is standard output;

ULC^N is standard unit labor cost; and

UMC^N is standard unit material cost.

This formulation is appealing since it replicates the historical behavior of GM in the establishment of wholesale auto prices.

Equation (7-1) was tested on actual industry data in another study,[7-10] and it was found that it did not adequately explain pricing behavior. However, the model was tested on Ford Motor Company data, a firm which does not use target-return pricing, but which generally follows GM's lead in establishing prices.

The Eckstein-Fromm formulation forms the basis for the model proposed for use by the INTERAGENCY TASK FORCE ON MOTOR VEHICLE GOALS BEYOND 1980.[7-4] The model assumes that GM functions as a price leader, and that GM's new car prices will set those of the entire industry. The model is also tractable since it avoids the issue of firm interaction and response in an oligopoly, and relies on available data on GM costs and prices.

Wholesale price for a particular type of vehicle is given as:

$$SP = AVC + AFC + \frac{RK}{Q} \qquad \text{(Eq. 7-2)}$$

where:

WP = wholesale;

AVC = average variable cost;

AFC = average fixed cost;

R = desired return on invested capital (K); and

Q = output quantity.

This can be written as:

$$WP = \left[\frac{AFC + RK/Q}{AVC} + 1\right] AVC$$

$$WP = \left[1 + \frac{TFC + RK}{TVC}\right] AVC$$

where:

TFC = total fixed cost; and

TVC = total variable cost.

Letting $$a_o = \frac{TFC + RK}{TVC}$$

results in

$$WP = (1 + a_o)\ AVC \qquad \text{(Eq. 7-3)}$$

If it is assumed that a_o is the same for all size categories, this equation can be used to represent the cost-price relationship for any class of car, i, as:

$$WP_i = (1 + a_o)\ AVC_i \qquad \text{(Eq. 7-4)}$$

This equation can be further modified to allow for differential markups on various vehicle classes by the addition of a variable m_i as follows:

$$WP_i = (1 + a_o m_i)\ AVC_i \qquad \text{(Eq. 7-5)}$$

Retail price, the "sticker" or manufacturer's suggested price is then expressed as:

$$MSRP_i = d_i \cdot WP_i \qquad \text{(Eq. 7-6)}$$

where d_i accounts for the dealers margin.

This formulation has been modified in one further respect. For the purposes of the Motor Vehicle Goals Study, it was decided that changes in emissions and safety packages and other consumer options would be handled separately from the base vehicles. This was done to avoid the problem of different markups on base car and optional equipment. Two equations are presented,[7-11] the first for the current vehicle and the second for estimating prices of weight-conscious and innovative vehicles.

The first formula gives the manufacturer's suggested retail price for automobiles of current configuration which meet the requirements of Emission Level I and Safety Level I.

$$MSRP_{io} = D_i(1 + a_o m_i)\ AVC_i + E_o + S_o + O_i \qquad \text{(Eq. 7-7)}$$

where:

- $MSRP_{io}$ is the manufacturer's suggested retail price for auto model i in current configuration o;
- D_i is the dealer markup for auto model i;
- a_o is the allocation factor which apportions fixed costs and return on equity to all models;
- m_i is the market adjustment factor for model i to wholesale price;
- AVC_i is the average variable cost for materials and labor for auto model i;
- E_o is the retail price of the current emissions package (Level I);
- S_o is the retail price of the current safety package (Level I); and
- O_i is the retail price of the options package for model i.

This equation assumes the existence of data on prices of vehicles and variable costs which are independent of 1975 emissions, safety, and consumer options such as radios and air conditioners.

The next equation addresses the question of changes in average variable cost, capital requirements, and emissions and safety packages.

$$MARP_{ij} = MSRP_{io} + D_i x \Delta AVC_{ij} + \Delta E_j + \Delta S_j + D_i \text{ x } \Delta K_j \text{ x } AR \qquad \text{(Eq. 7-8)}$$

where:

- $MSRP_{ij}$ is the manufacturer's suggested retail price for auto model i in advanced configuration j;
- ΔAVC_{ij} is the change in average variable cost for auto model i in advanced configuration j;
- ΔE_j is the change in the retail price of the emissions package to meet more stringent emissions requirements;
- ΔS_j is the change in the retail price of the safety package to meet enhanced safety requirements;
- ΔK_j is the average per-car increase in capital investment required to produce the auto design concepts; and
- AR is the desired annual pre-tax return per dollar of investment as defined below.

The changes in average variable cost are estimated by considering changes in direct materials and direct labor costs. The change in direct materials cost is calculated using the change in vehicle weight and the change in average materials cost per pound. It is assumed that the direct labor cost does not change. This assumption is based on two considerations: 1) The industry has strong unions which do not want the labor content of the vehicle to change; and 2) increases in labor content due to increases in complexity occasioned by the implementation of new technology can be offset by decreases in the size of weight of components that have to be handled. It is assumed that changes in variable factory overhead are minimal and can be ignored. Any change in corporate structure is accounted for in the capital term of the equation, so the only markup factor to be applied to the change in variable cost is the dealer markup.

The changes in safety and emissions packages are estimated at the retail price level and, thus, include relevant markups already.

The change in capital is estimated on a per-car basis and is multiplied by an annual return factor for the manufacturer and the markup for the dealer. The additional capital is estimated on the basis of expected economic life, and a corresponding annual return factor is calculated using the following formula:

$$AR = \frac{r}{1 - (1+r)^{-Y}} \qquad \text{(Eq. 7-9)}$$

where:

r is the desired pre-tax rate of return on investment; and

Y is the economic life of incremental investment.

The average per-car increase in capital is multiplied by the desired annual pre-tax return to give the change in wholesale price. This change is marked up to reflect the dealer's markup and is then added to the manufacturer's suggested retail price.

Once certain variables are specified, the formula for the price of the current vehicle can be derived from the above equations, by using data from the 1975 fleet. Table 7-1 gives the values of these variables as a function of car size.

The formula for change in price for new vehicle configurations has been simplified by the assumption that average fixed cost of each model is not affected by the changes. The additional capital required for tooling and equipment is treated as an average for all vehicles as well. Differences in expected economic life of tooling or equipment are included in the calculation of the desired annual return.

These formulas recognize the infeasibility of handling corporate overhead structures on a national fleet basis. The equations focus the question of assessing the cost of change

TABLE 7-1. ASSUMED VALUES OF THE PARAMETERS USED IN THE ESTIMATION OF THE MANUFACTURER'S SUGGESTED RETAIL PRICE

Parameter	Car Size		
	4-pass.	5-pass.	6-pass.
Dealer Markup, D_i	1.19	1.19	1.27
Adjustment Factor, a_o	0.64	0.64	0.64
Allocation Factor, m_i	0.76	0.83	0.86
Economic Life of Incremental Investment, Y	20 Years	20 Years	20 Years
Pre-Tax Return on Investment, r	27%	27%	27%

on changes in direct material capital for tooling and equipment. These two areas lend themselves to more "factual" analysis, because they reflect quantities that are closer to the fundamental resources of materials, labor, and capital.

7.5 PRICE RELATIONSHIP IN SUPPORT OF THE 1981-1984 PASSENGER AUTOMOBILE FUEL ECONOMY STANDARDS

The formulation of cost-price relationships given above has been simplified and changed in one respect for support of the 1981-1984 passenger automobile fuel economy standards.[7-12] The following formulas have been applied to forecast price changes to consumers as a result of product changes:

$$\text{Delta Price} = (1+25\%)(GR \times CI + \text{Delta } VC) \qquad \text{(Eq. 7-10)}$$

$$GR = NR/\ (1 - TR) \qquad \text{(Eq. 7-11)}$$

where:

GR - is the implied gross rate of return on required capital investment;

CI - is the capital investment per produced unit;

VC - is the manufacturers variable cost per produced unit;

NR - is the desired net rate of return on capital investment; and

TR - is the applicable tax rate of the manufacturer.

This formula results from Equation (7-8) when the dealer's markup is assumed a standard 25 percent, when changes in emissions and safety packages are ignored, and AR is replaced by GR. This substitution means that explicit retrieval of additional capital CI is ignored in favor of a manufacturer's average desired rate of return on capital investment. With NR equal to 15 percent and TR equal to 45 percent, the gross rate of return used in Equation (7-10) becomes GR equals 27 percent.

This estimation procedure is intended to be applied to estimate price changes only for fleet averaged and manufacturer aggregated cases. It is not indicative of the pricing strategies of individual manufacturers or individual products of a manufacturer.

7.6 RECOMMENDED APPROACH

The generalized model described in Paragraphs 7.4 and 7.5 stands alone as a candidate methodlogy for use in determining new-car prices as part of the cost/benefit analysis of the Low Speed Automobile Damage Reduction Study. No such models are available for use in estimating aftermarket impacts. Furthermore, little is known about the actual pricing policy that would be followed by the industry for replacement bumpers and other parts associated with damage reduction design changes. Thus, the tasks discussed in paragraphs 7.6.1 to 7.6.3 are recommended for inclusion in the preliminary draft of the statement of work for cost pricing model modifications in the comprehensive study.

7.6.1 Task 1

Modify the cost pricing model discussed in Sections 7.4 and 7.5 for use in the Low Speed Automobile Damage Reduction Study. This task involves gathering published data on retail prices and dealer discounts for each class of automobile to be considered in the study, and recalibrating and testing the model on this new data. The model may have to be modified slightly in order to reflect possible changes in pricing policy due to the nature of the proposed cost changes (i.e., government mandated standards as opposed to style changes). The output of this task is to be a model capable of estimating the change in retail price of a new auto, due to a change in its cost resulting from alternative bumper designs.

7.6.2 Task 2

Develop a model of aftermarket pricing for the components of the automobile damage reduction systems that are to be considered in the comprehensive study. This effort involves a literature review and contacts with appropriate industry and government officials. Assess the feasibility of using a suitably modified version of the new-car, cost-pricing model. If necessary, construct a cost-pricing relationship more reflective of actual market behavior. The primary output of this task is to be a recommended formulation for a cost-price relationship for the aftermarket.

7.6.3 Task 3

Calibrate the model formulation product as an output under the above task for use in the Low Speed Automobile Damage Reduction Study. This task involves gathering data on prices, and dealer markups for replacement parts as well as any other data necessary for the calibration of the model formulation. The data is used to test and exercise the model as well. The output of this task is to be a model capable of predicting price difference of replacement parts for each alternative system to be considered in the comprehensive study, based on differences in cost from the base case system.

7.6.4 Manpower Estimate for Tasks

It is estimated that a nine-month effort will be required to complete these tasks. The breakdown among tasks is as follows:

Task 1 - 3 man-months;

Task 2 - 2-man-months;

Task 3 - 4 man-months.

8. INFORMATION REQUIREMENTS FOR AN IMPROVED BENEFITS ANALYSIS

8.1 GENERAL

In order to remedy the deficiencies in benefit data identified in Section 6, two distinct information requirements appear necessary. First, is the need for one-point-in-time current information on crash frequency and the distribution of crashes by dollar damage, by model year for four car size classes, and for defined impact areas. Second, is the need to track these measures through a period of several years to ascertain the effect of the recently adopted Part 581 regulations.

To expand on the regulations: these require, first, that all cars manufactured after September 1, 1978 sustain no damage to the vehicle, except to the bumper system, in front and rear barrier impacts under 5 mph, and in front and rear corner at 3 mph pendulum impacts. Second, all cars manufactured after September 1, 1979 should manifest only minor dents and displacements on the bumper face under the same test conditions. The effect of these regulations may well become visible before 1978, because auto manufacturers need to gear up for new lines of cars periodically, and it may be cost-effective to build these capabilities into some pre-1979 models.

As shown in Section 6, current data is lacking on the first information requirement due to lack of geographical balance for both repaired and unrepaired damage and lack of make and model balance for repaired damage. A new, nationwide survey of repaired and unrepaired damage, properly designed, will overcome these defects and provide a base of understanding for the entire auto damage problem as it exists today. This base of understanding can be used by both the government and industry as a common reference for discussions about the effectiveness of government regulations on vehicle crash damage.

Insurance industry data, potentially available to the government, can be used to fulfill the second requirement of tracking damage over time. However, it is important that this data be keyed to the reference data obtained from the survey. A way of keying these together is to estimate, from the survey, how much and what kind of repaired damage is wholly or partially reimbursed by insurance.

To summarize: both instruments are needed to provide the required information. Without the survey, there will be no agreed-on absolute measure of vehicle crash damage that can be used for benefit estimation. Although tracking changes in crash damage may be done in many ways, using insurance statistics already generated by the insurance industry is a clear lowest-cost favorite.

The design of the survey is discussed next, followed by a discussion of the design for tracking insurance statistics. Appendix A gives alternative cost estimates for alternative survey sizings, i.e. the number of cars to be included in the sample. Appendix B gives a cost estimate for tracking insurance statistics.

8.2 DESIGN OF THE SURVEY

The purpose of this survey is to obtain national data on crash frequency and the distribution of crashes by dollar damage to the current fleet in today's driving environment. To accomplish this a three-stage sampling procedure shall be followed. First, geographical areas shall be selected that are representative of the nation's registered passenger cars. Then, within each area, body repair shops will be identified. Finally, parked cars in each area and cars awaiting repair in the body shops will be surveyed for unrepaired and to-be-repaired damage.

The philosophy of the survey is as follows (Figure 8-1). The fleet in each geographical area is composed of two parts: mobile cars, and cars that are not mobile and awaiting repair.

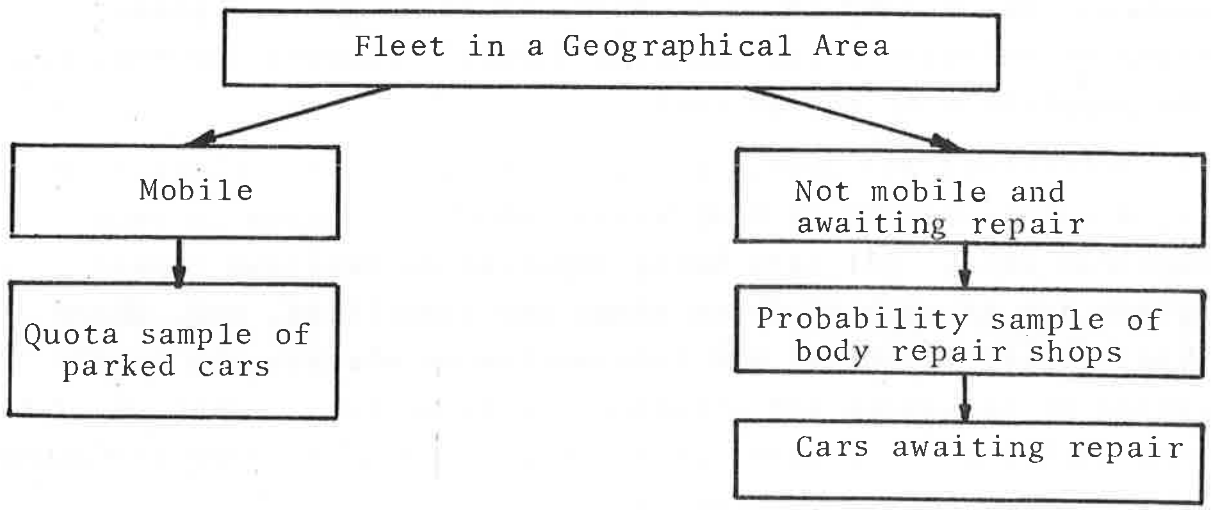


FIGURE 8-1. OVERVIEW OF SURVEY

Mobile cars may be without a scratch, or they may have damage of such a type that the cars can still be driven. This damage may or may not be minor in terms of the cost to repair.

To understand mobile car damage, parked cars to be examined for damage are selected by a quota sampling method from parking lots and city streets. Quota sampling is a non-random method that is more efficient than random sampling in developing adequate statistics on small sub-groups, for example, ten-year old subcompact cars which number about one in 1000. Each selected car is examined for damage, and the examiner makes out a report on type and magnitude of damage (including the fact that a car is not damaged, if such is the case). Windshield mail-back questionnaires are left on cars with damage for the owner to indicate whether he intends to repair the damage and whether insurance will pay for the repairs.

Using estimates of registered passenger cars in the geographical areas surveyed, the samples are expanded and aggregated nationwide. Hence, the results of the sampling process yield estimates of unrepaired and repaired damage frequency and magnitude for the population of mobile cars.

To understand the damage picture for cars that are awaiting repair, a random sample of body repair shops is chosen in each geographical area. All cars being repaired or awaiting repair on a given day in each of these shops are identified, and, where possible, repair estimates and information on whether the repair is covered by insurance are obtained for these cars. Also, by asking when each repair is expected to be complete, the rate or volume of work at each shop becomes evident.

The body shop results are expanded to the nation, using the sampling parameters. For example, if repair data are obtained from one of ten body shops in the selected geographical areas, and these areas include 10% of the nation's registered passenger cars and are representative of the whole, then expansion of the body shop results by a factor of 100 gives a national estimate. This is an estimate of the number of repairs per unit time, and the magnitude of these repairs, among cars that are not mobile but are awaiting repair.

The mobile and non-mobile car results are then combined to provide estimates of the incidence and magnitude of unrepaired damage, and of annual frequency per car and magnitude of repaired damage. The latter is obtained with the assistance of national fleet size estimates. These measures are specific to model year, car size class, and impact area of damage.

The design of the survey instrument and the analysis of its data will, as much as possible, be organized around the data classifications used by the insurance companies, to facilitate comparison between the results from the nationwide survey and insurance company data to be used for tracking changes in vehicle damage.

8.2.1 Preliminary Draft of Survey Statement of Work

A detailed task description of the survey follows. Note that this description is general as would be suitable for a contract statement of work; the contractor will have the responsibility of creating a detailed survey design that will correctly follow standard survey practice and will yield the desired information. Three alternative survey sizes are proposed - small, medium, and large. The task statements of the design are presented next, followed by a detailed explanation of each task.

8.2.1.1 Task 1 - Design a national sample to select approximately X primary sampling units (PSU's), based on the population of registered passenger cars. The selected units shall represent diversity in the U.S. of geography, rural versus urban environment, and size of metropolitan areas.

8.2.1.2 Task 2 - Design a quota sampling technique for selecting parked cars in the PSU's to be examined for damage. Socio-economic criteria should be used to assure that the cars selected will give a representative nationwide sample of cars on the road. The sample should be large enough to give statistical validity nationwide to damage incidents for the selected model years; for four car size classes (subcompact, compact, intermediate and full size) within each model year; and for Y impact areas within each car size class within each model year. The car size classes shall be those commonly used in the domestic automobile industry; imported cars shall be classified by car size in a way that is most consistent with domestic vehicles.

Set parts and labor cost schedules that accurately reflect repair costs on a nationwide average at the time of the survey; these will be used uniformly by the estimators when reporting damage to examined cars.

8.2.1.3 Task 3 - Select by a probability sample a fixed number of body repair shops within each PSU. The sample should be sufficiently large to give statistical validity nationwide to damage incidents for the selected model years, for four car size classes, and the impact areas as described in Task 2.

8.2.1.4 Task 4 - Design all questionnaires, survey forms, and data collection instruments necessary for the performance of all tasks. These include a questionnaaire to be left on the windshield of each car in the parked car survey, described in Task 2, that has identified damage. This questionnaire should very briefly ask, for each separate damage incident, the following:

When did damage occur?

Will damage be repaired and if so when?

Will insurance reimburse part or all of the repair cost?

and an appropriate mail-back technique shall be provided for its return.

Pretest all data collection instruments and survey techniques required for all tasks before proceeding to Tasks 5 and 6.

8.2.1.5 Task 5 - Perform the parked car survey. Each car selected by the quota procedure shall be examined by an experienced appraiser, and damage shall be appraised separately for each incident of damage. The damage record shall consist of an itemized list of parts to be repaired or replaced for each incident, the labor hours required to fix each incident, and a cost estimate based on the standard parts and labor cost schedules developed in Task 2. The appraiser shall also estimate the location of primary impact of each incident by the impact areas as detailed in Task 2.

8.2.1.6 Task 6 - Perform a survey of cars being repaired or awaiting repair in the body shops selected under Task 3. Each repair shop shall be visited on one day, and the shop foreman should be asked the following questions on each car in the shop which is being repaired or awaiting repair:

1) Make, model, year of car.
2) Is the repair covered wholly or partically by insurance?
3) Contract price for repair.
4) Is repair to minimum satisfaction of customer, or to "powder puff" condition?
5) Primary impact area (areas described in Task 2).
6) Estimated impact speed.
7) When will repair be completed?

8.2.1.7 Task 7 - Analyze the results of the parked car and body shop surveys to obtain nationwide estimates of cash frequency and the frequency distribution of cost-to-repair the resulting damage. The parked car appraised cost estimates shall be combined with the stated body shop estimates for a complete picture of vehicle damage. The annual frequency and distribution of damage by dollar amount shall be estimated for each cell of the following four-way classification:

1) Location (impact areas as defined in Task 2)
2) Age (model years are defined in Task 2)
3) Car size (four sizes)
4) Repaired insured, repaired uninsured, or unrepaired

8.2.1.8 Task 8 - Obtain insurance company statistical records of accident claims nationwide. Estimate the same frequency and distribution of damage by dollar amount as in Task 7, but for repaired insured damage only, from these records. Estimate the correction needed for the insurance-derived results to infer the more complete results of Task 7, to be used while tracking insurance statistics over time.

8.2.1.9 Task 9 - Write a final report fully describing the methodology, data and conclusions of the survey.

8.2.2 Additional Comments on Survey Statement of Work

In Task 1, X should be 40, 100, or 200 PSU's for the small, medium, or large survey size respectively.

The rationale for primary sampling units is to save a considerable amount of money by performing the survey only with geographically compact areas. The random selection of PSU's from a large number of defined areas will ensure that bias will not be introduced into the results.

In Task 2, Y is three impact areas (front, sides, rear) for the small size survey, and six areas (square front, front corners, right side, left side, square rear, rear corners) for the medium and large size surveys. The model years to be included in the three size surveys are the following, assuming the current model year is 1976:

SMALL	MEDIUM	LARGE
Last 4 model years individually (1976-1973)	Last 6 model years individually (1976-1971)	Last 14 model years individually (1976-1963
Previous two together (1972 and 1971)	Previous two together (1970 and 1969)	1962 and earlier lumped together
Previous five together (1970, 1969, 1968 1967 and 1966)	Previous three together (1968, 1967 and 1966)	

The quota sampling technique proposed in this task is an efficient way of finding enough cars of each type for adequate statistics on damage. Random sampling would be too expensive due to the scarcity of many of the car types desired. Quota sampling is efficient because parked cars on streets and in parking lots are so abundant; hundreds of cars may be scanned in minutes. The task sets quotas for each desired car type and defines systematic search procedures for finding enough cars to fill these quotas, but also the right cars in the sense that the resulting sample is representative.

For the three size surveys, total sample sizes to provide adequate results are 7000, 30,000, and 40,000 cars respectively. These numbers are discussed more fully in Appendix A.

The model years to be included in the small and medium surveys to be conducted in Task 3 are the same as described in Task 2. The model years for the large survey are the following:

1) Last 9 model years individually (1976-1968);

2) Previous two together (1967-1966);

3) 1965 and earlier lumped together.

The scope of the body repair shop survey is not as detailed as that of the parked car survey by model year in the large size case, because of the need to limit the number of body repair shops visited. Even so, it is estimated that more than 25 percent of body repair shops in the United States must be visited to yield adequate information in the large survey case, assuming, of course, that each shop is visited only once to maximize cooperation. More details are given in Appendix A.

The body shops to be sampled should yield an aggregate of 14,000, 55,000, and 150,000 repaired cars respectively for the three size surveys. These numbers are discussed more fully in Appendix A.

The windshield questionnaire of Task 4 will help determine how many of the damage incidents visible at the time of the survey will be repaired. In addition to the question "will damage be repaired", the questions of when damage occurred and when it will be repaired help decide how valid is the owner's stated intention to repair. The question on insurance is necessary for determining what fraction of repaired cars have insurance claims and are thus part of insurance company records (done in Task 7).

In Task 5, for each PSU, an individual (who is also an experienced appraiser) is expected to both find cars under the quota and assess damage. His use of standard cost schedules will eliminate bias due to differing repair costs from one area of the country to another. Since the survey aggregates all results nationwide, regional differences in repair costs are not of interest.

The survey of Task 6 is designed for the minimum inconvenience and maximum speed of execution in each body shop. A few simple questions are asked concerning only the cars now present in the shop, thus avoiding resource to memory or records of previously repaired cars. Survey personnel do not examine the cars, since this could lead them to get in the way of shop operations and become a nuisance to owners. Note that unlike the parked car survey, no information is obtained concerning the details of the damage and the parts and labor required, but only the overall contract price or estimate, since for the foreman to provide the former would be too time-consuming. In analyzing the results (Task 7), adjustments should be made to account for regional variations in repair costs.

The questions on estimated impact speed should furnish useful information in the statistical analysis. The question on timing of completion will give analysts an estimate of the average rate of business of each shop; without it, only the inventory of cars in the shop would be obtained. The results of field testing these questions may require altering their form or eliminating non-essential points if answers cannot be provided for a significant number of cases.

The results of Task 7 will give the information on crash frequency and dollar distribution that was shown to be needed in Task 5 above. It also divides damage in three ways: unrepaired, and repaired insured and uninsured, since the characteristics of damage are likely to differ among these categories. The information on repaired insured damage will relate to that developed in Task 8.

Task 8 is useful since insurance company records give partial information, that is, on repaired insured damage only. This information can be used to check consistency with the survey. An additional requirement of Task 8 is to relate this partial information to the complete information of Task 7, so that as the insurance statistics are tracked year to year in the future (described below), these results may be used to infer the complete information on damage within some reasonable error.

8.3 DESIGN FOR TRACKING INSURANCE STATISTICS

The purpose of tracking insurance statistics is twofold. First, it permits the study of changes in damageability from one model year to the next. Second, and related, it allows nationwide damage estimates that are obtained in the survey of the accident environment to be updated for future years.

A uniform set of statistics should be obtained from 1971, since model year 1971 is taken as the standard predamage-regulation product, through 1980 at the latest, since 1980 is the last model to be subject to changing regulations now on the books. However, some results can be obtained using a subset of these calendar and model years. For example, calendar years 1974 and 1975 can be combined with calendar years 1976 and thereafter assuming 1976 is the first year of the tracking activity. After each additional year of the tracking, a new comparison of damage history for the entire period can be made.

Since the insurance statistics will be considered as a nationwide aggregate, it is unlikely that there will be any problem of statistical significance, even when classifying damage in a given year by model year, car size class, and primary impact point (twelve clock positions).* At least one insurance company, namely State Farm, has dollar damage distributions classified in this way, so the data is available.

*Except when going back to very old cars, which in the present context become less interesting with age.

Efficiency considerations dictate that insurance statistics tracking should be aligned to the greatest extent feasible with the data organization of the insurance companies themselves. This keeps to a minimum the cost burden of information retrieval on the companies, and the burden of data manipulation on the government. Another general guideline for this task is to maintain compatibility with the survey, so that the tracking process may be regarded as starting from the survey as an initial point, and can be used to update the survey.

8.3.1 Task 1

Survey the major insurance companies, associations, and insurance-related institutes for organization and availability of data of the kind needed. Select specific data sources to be used.

8.3.2 Task 2

Obtain from each source the following statistics for all desired years that are available at the initiation of the work effort (beginning if possible September 1 to correspond to the model year cycle):

1) Number of paid auto damage claims by model year, car size class (subcompact, compact, intermediate, full-size), and impact point (twelve impact points corresponding to standard "clock position".)
2) Distribution in each category by claim cost including deductible.

The car size classes shall be those commonly used in the domestic automobile industry; imported cars shall be classified by car size in a way that is most consistent with domestic vehicles.

8.3.3 Task 3

Combine data from the different sources, eliminating double-counting, and expand to nationwide estimates of the same quantities specified in Task 2.

8.3.4 Task 4

Analyze the results of Task 3 to show trends, if any, in the damageability of successive model years.

8.3.5 Task 5

Write a report describing the methodology, data, and conclusions of the tracking effort.

8.3.6 Task 6

Repeat Tasks 2 through 5 for each new year of data to be included in this work effort, as this becomes available. Report at the end of each year of work the methodology and conclusions based on cumulative data obtained through that year, with particular attention being given to trends in the damageability of new model years entering service.

8.3.7 Task 7

Apply correction factors developed in the previous survey of the accident environment to each new year of data described in Task 6, to obtain estimates of nationwide damage after the year of the survey.

9. PLANNING THE TEST PROGRAM

9.1 OBJECTIVE

The objective of this section is to develop alternative test programs with different levels of confidence and requiring different levels of NHTSA budget expenditures in order to verify the damage protection afforded by prototype low speed damage reduction systems. Additionally, the basic test program is to delineate all test parameters and post-test inspection procedures. The test program will consider various crash modes in addition to barrier and pendulum tests.

For fulfilling the desired objectives of the test program, a number of related options to determine damage cost data are presented. These options consist of: a) analytical modelling techniques (Paragraph 9.2.1); b) barrier and pendulum test procedures for crash damage cost data estimation (Paragraph 9.2.2); c) vehicle-to-vehicle real-world crash tests of front, rear and corner impacts (Paragraph 9.2.3).

The analytical methods would have the lowest cost outlays but would be unreliable in precision of estimating cost for repair of damage. Barrier and pendulum tests are presently being used, but they do not replicate the real-world crash environment.

The method employing vehicle-to-vehicle crash tests to replicate the real-world crash environment would yield the best data, but, in order to cover the necessary variations that are possible, this test program would involve a substantial number of crash cases and millions of dollars in cost. These options are described in the following paragraphs, including discussion of their respective benefits, deficiencies, and costs.

9.2 TEST OPTIONS

9.2.1 Analytical Crashworthiness Methodology

An actual, real-world test program to ascertain damage costs incurred by various car collisions at varying speeds is, by its nature, bound to be expensive. A real-world test program will produce the most accurate estimate of repair costs for a limited set of test cases, but evidence shows that extrapolating repair cost data, from tests alone, for cases and car design parameter variations not tested is not reliable. As a subsidiary aid for extrapolating the results of crash tests, analytical, structural, and dynamic studies could be developed, tested, and checked against the actual physical test results. There are two reasons that reduce the effectiveness of developing, validating and using analytical models alone to determine and define the damage costs associated with a particular bumper design at a specific impact speed. On the analytical side, the large deflections and nonlinearities in complicated metal geometrical structures do not permit the use of simplified linear mathematical models for accurate cost damage predictions. On the physical side, curvature of the colliding structures causes initial or intermediate overriding of structural components during the crash interval and extends a simpler linear crash case into two or three dimensions.

In spite of these difficulties, there are advantages to using analytical tools, and, therefore, work should continue in the development of analytical, structural crash models, and in the checking of analytical solutions against real-world test results. Analytical models which use lumped-parameter-systems encompassing masses, springs, and damping components, have been developed and used but with little success in the lower speed ranges, to date. In this regard, unique features of automobile structural crashworthiness are described in following paragraphs to point out the difficulties with simplified analysis. When the desired end result of an analysis is to be able to differentiate a small increment in the optimum low-speed, no damage case, the difficulties are most evident. Four important unique features of automobile crash damage are identified for analytical consideration:

1) <u>Complexity in Automobile Structural Geometry</u>

The frame portion of an automobile (if any) is inherently three-dimensional, and the metal portion is, generally, shell-type (but usually not a shell of revolution) structure with a large number of cutouts. The only symmetrical property possessed by an automobilestructure is about the longitudinal, vertical center plane.

2) Large (Plastic) Deformations

It is evident that during an automobile collision, the impact forces are sufficiently large to induce large deformations on the automobile structure. Therefore, in the structural analysis of an automobile collision, it is essential that both the geometrical nonlinearity, due to large changes in geometry of the structure, and material nonlinearities, resulting from the plastic strains, be included. For example, when the deformations reach the elastic limit, plastic flows occur, Hook's Law no longer holds, and the stress-strain relations become nonlinear.

3) Short-Time Duration Response and High Material-Straining Rates

The major structural crash response in an automobile collision takes place in an extremely short time interval (about 0.1 seconds). As a result, the rates of material straining become very large, and the effect of material strain rate sensitivity on the dynamic elastoplastic behavior must be included in the analysis. This is especially true for mild structural steel which is commonly used in the production of automobiles.

4) Complexity of the Collision Dynamics

Except for a few special cases, both elastoviscoplastic and rigid body components of motion are present in an automobile collision. The problem is further complicated by the continuous or intermittent changes in the kinematical boundary conditions resulting from partial or full contact of two surfaces; contact of a mass point (such as the engine mass) with other portions of the structure or some other mass point; etc.

Analytical mathematical models developed with lumped parameters are difficult to extend beyond the case of front or rear centered collision with no rotation. Making greater use of digital computers and developed canned computer programs, the finite element techniques of structural analysis are being applied to the complex shapes used in automobile design. The finite element idealization of the vehicle structure has produced considerable success for elastic structures undergoing small deformations. Attempts have been made to extend the finite element approach to large deformation problems that occur in vehicle crashes with resultant large, geometric nonlinearities. Automobile manufacturers are continually expanding their bank of computer programs by using finite element techniques for design analysis of new body shapes. Although results from purely analytical studies cannot, at present, be used as the sole source of establishing an optimum zero damage collision speed for bumpers, it is worthwhile to continue comparing analytical results with actual test data in order to refine the analytical techniques. With this ongoing process, the confidence level in analytical testing will increase, so that several planned tests will be required.

In conclusion, at the present time, a number of structural analysis programs are being developed for automobile strength design data. These programs and models give results for higher speed collisions (e.g., 30, 40 or 50 mph), and, so far, they are not capable of differentiating repair and damage data for a crash speed of only a few miles per hour.

Considerable effort has been expended, under Title II of Public Law 92-513, in modelling vehicle crashes and then comparing these model simulations to actual crash conditions. Prime emphasis in this work has been directed toward the speed range from 15 mph to 35 mph. The results obtained from the comparison indicated that considerable development is still necessary to bring analytic modelling to a useful point for estimating crash damage.

9.2.2 Pendulum and Barrier Testing

This paragraph includes a brief description of the current Federal bumper standards and the pendulum and barrier test procedures as stipulated for vehicle protection in low speed collisons. Both the pendulum and barrier tests are intended to provide consistent data for the number of test trials specified. Previous test programs, involving different types of vehicles, using these standard pendulum and barrier tests have revealed some dispersion in cost of repair data as estimated by independent mechanics for identical tests. However, these tests are simpler than vehicle-to-vehicle combination tests in that less variables are present for final correlation. The following paragraphs are a brief summary of the present barrier and pendulum tests.

9.2.2.1 Synopsis of Standard No. 215; Exterior Protection (Federal Register Title 49, 571, 215)

1) Scope: The Standard establishes requirements for impact resistance, and the configuration of front and rear vehicle surfaces in order to maintain safe vehicle operation in low-speed collisions and to reduce override/underride in higher speed collisions.

2) Test Requirements: The test requirements specify the impact speeds for which no-damage to safety systems must be provided:

a) For vehicles manufactured between September 1, 1972 and August 31, 1973;
   - barrier type impacts (specified below);
   - longitudinal forward speed of 5 mph;
   - longitudinal rearward speed of 2-1/2 mph.

b) For vehicles manufactured after September 1, 1973:
   - pendulum-type impacts (specified below) followed by barrier type impacts;
   - longitudinal forward speed of 5 mph;
   - longitudinal rearward speed of 5 mph.

(Exceptions):
   - no corner impact requirement between September 1, 1973 to September 1, 1975, extended until September 1, 1976 for vehicles with wheel base of 120 inches or longer;
   - no pendulum testing required for convertible type vehicles with 115 wheel base or less between September 1, 1973 and October 31, 1974.

3) Test Conditions: In this section, the Standard specifies the testing conditions for laboratory evaluation of compliance with the requirements. The experimental conditions are:

- unloaded vehicle, front wheels straight;
- tires inflated to manufacturer's recommendations;
- brakes disengaged, transmission in neutral;
- trailer hitches removed.

a) Conditions for Pendulum Tests: Two different, contoured blocks are to be impacted with the vehicle. The physical dimensions (24 inches wide and 36 inches high) are specified in the Standard. Both of the impact devices have a 4.5 inch wide, 24 inch long impact edge of hardened steel, which is used for contacting the vehicle. The impact edge is the most forward surface on one of the test devices; while the other test device, basically identical to the first, is equipped with two forward surfaces, the second one being located 6 inches above the impact edge. The mass of the impact device is equal to the mass of the vehicle.

b) Conditions for Barrier Tests: The test device is a fixed collision barrier that is perpendicular to the line of travel of the vehicle and is impacted with the engine running at idle speed.

4) Test Procedures: This section of the Standard describes how the pendulum test devices are to be impacted to the vehicle:

a) Longitudinal Impact Test Procedures: Two front end impacts and two rear end impacts must be carried out at a minimum of 30 minute intervals. The impact edge is perpendicular to the vehicle longitudinal axis, the edge touches the vehicle before the pendulum action, and the contact points on the vehicle are displaced 2 inches vertically and 12 inches longitudinally. Impacting is carried out with a pendulum action of the test device which has two forward surfaces, at a height of 20 inches, or with the device with one forward surface at a height between 16 and 20 inches. The impact device must be suspended with a radius of 11 feet or more, and must maintain the impact plane vertically. Impact speed is 5 mph.

b) Corner Impact Test Procedure: A total of four impacts are to be carried out; one front and one rear corner impact at a height of 20 inches, using the double-surfaced test device and, similarly, one front and one rear corner impact at a height between 16 and 20 inches using the single-surfaced test device. Impact speed is 3 mph. The pendulum conditions are similar to those in the longitudinal tests. The impact edge forms a 60° angle with the vertical longitudinal plane of the vehicle.

9.2.2.2 Synopsis of "Part 581, Bumper Standard" (Federal Register Vol. 41, No. 44, pp. 9349-50, March 4, 1976)

1) Scope: The Standard establishes requirements for the impact resistance of vehicles in low-speed front and rear end collisions.

2) Effective Date: September 1, 1978 (Actually, the Standard specifies two sets of requirements; one applicable from September 1, 1978 to August 31, 1979; and another one applicable from September 1, 1979 on.)

3) Range of Application: This applies to passenger motor vehicles only.

4) Requirements: The requirements specify the impact speeds for which no-damage vehicle protection must be provided:

a) For vehicles manufactured between September 1, 1978 and August 31, 1979:

- pendulum-type corner impact at a speed of 5 mph;
- pendulum-type front and rear impacts at a speed of 5 mph;
- barrier-type front and rear impacts at a speed of 5 mph.

b) For vehicles manufactured on or after September 1979:

- same impact speeds as in (a) above;
- more restrictive protection criteria than in (a). (See Protection Criteria below.)

5) Protection Criteria: The Standard defines the vehicle systems which must operate as normal after impacts. These systems are:

- lamps (except licence plate lamp);
- hood, trunk, doors;
- fuel, cooling, and exhaust systems;
- propulsion, suspension, steering, braking;
- bumper pressure vessel used to absorb impact energy.

The Standard also defines the extent of damageability which is permitted within the scope of this Standard. This is:

- the face bar can have a 3/4 inch permanent deviation from the original contour relative to the vehicle frame;
- on the bumper surface, a 3/8 inch deep permanent deviation from the original contour is permissible at the point of contact;
- the exterior surfaces, except for the bumper face bar, cannot have separation of surface materials, paints, coatings, etc.; (This criterion is somewhat eased for the period between September 1, 1978 to August 31, 1979. During this time, separation of materials is permitted, not only on the bumper face bar, but also on associated fasteners attaching the face bar to the chassis).
- the contact force between the vehicle parts and the impacting test devices must be less than 2,000 lbs. (This force is not the impacting contact force on the bumper, but other contact forces which might develop when, and if, the protruding surfaces of the test device touch the vehicle fender, hood, etc.).

6) Test Conditions and Test Procedures: The test conditions and test procedures are the same as those of Paragraph 9.2.2.1 3) and 4).

9.2.2.3 Summary - In summary, the barrier and pendulum tests do provide a fairly repeatable task and minimize the number of test variables. It should, however, be noted that neither test is a good representative of the actual real-world crash environment encountered by the bumper system. As examples, the barrier test is a more severe test, as the barrier absorbs virtually no energy from the impact, but it does, however, equally distribute the force of the impact over the entire face bar. The pendulum test is not as severe as the barrier test in that the pendulum does absorb some of the impact energy, but the pendulum impact is transmitted to the bumper system by the more severe line contact of the impact ridge.

9.2.3 Real-World Testing

The success of a particular bumper system design can only be judged by its performance in the real-world environment. This real-world environment represents the diverse impacts to which the vehicle population is subjected. Present bumper system design is not directed toward this environment, but toward the barrier and pendulum tests presently conducted on vehicles. Only after the environment in which the bumper is to operate has been defined, can a designer construct and test a bumper system providing adequate low-speed protection to the vehicle population.

The first step toward preparation of a test plan, for real-world testing of bumper systems, must, then, be that of fully defining the real-world accident environment. Present knowledge, both that of industry and government, is very limited, and is not sufficient from which to construct a test plan with any confidence that it does, in fact, simulate the real-world accident environment.

Both GM and Ford have conducted limited field surveys in an attempt to define the accident environment. There is agreement between the manufacturers that identification of the real-world accident environment can, as proposed by TSC, be obtained only from actual field data whether it be insurance data, tracking of fleets of vehicles, or some other means. Only after this type of accident analysis has been conducted will it be possible to construct a valid and logical test plan to ascertain the adequacy of any bumper systems employed on vehicles. Parameters which should be obtained from the accident analysis should include object impacted; estimated speed of impact (if possible); angle of impact; status of vehicle or vehicles at impact, i.e., brakes, number of occupants etc.; underride or override; pieces repaired or replaced; cost; etc.

Assuming that the accident environment is defined, the next step in constructing the test plan is to select the vehicles and the bumper systems to be tested. The number of possible combinations of bumpers and vehicles is enormous and must be reduced to a reasonable number by some appropriate means while considering the variations in vehicles of the same weight class and their compatability with selected bumper systems. Additionally, the various weight classes of vehicles may be found to have different accident environments, e.g. subcompacts may tend to underride full size vehicles.

A good "first cut" to obtain "real-world" bumper accident and repair data from vehicle collisions has been suggested by Chrysler Corporation. Chrysler suggested that a selected set or sets of a given vehicle type be outfitted with selected bumper designs. Then, as accidents occur and are investigated, the data would be analyzed for these vehicles. This program was envisioned to involve 700,000 vehicles over a two or three year time scale. Although this suggested program could provide considerable accident repair cost damage data, it, of course, would not provide data with much precision on the actual vehicle crash speeds.

Without the results of an accident survey or sufficient data from the Chrysler type program, it is not possible to construct a complete real-world test program to adequately evaluate various bumper system designs. However, the necessary ingredients that must be incorporated in a real-world test program are outlined in following paragraphs.

1) <u>Vehicle Types</u>

In an effort to provide a representative sample of the vehicle population, vehicles from each of the four domestic manufacturers and at least one foreign manufacturer should be tested.

Additional, vehicle sizes (classes) of each manufacturer should be represented. Although only the bumper systems are being tested, the vehicle and bumper backup components will, possibly, limit or extend the damage to a particular vehicle from a specific bumper design. This is primarily attributed to the differences in vehicle design accessory manufacturers.

2) <u>Bumper Types</u>

Once the vehicles which will be tested have been selected, the bumper systems must be designed or, in some instances, modified for installation on the vehicles. Each vehicle will be tested with a series of different bumper designs which will be impacted in several different ways at as many as four speeds. The bumper designs to be tested are shown below and described in Section 2.

a) Current steel bumper system;
b) High-strength low-alloy steel bumper systems;
c) Aluminum bumper systems or hybrid;
d) Soft face bumper system.

3) <u>Impact Speed and Type</u>

The test speeds selected for each bumper system cannot, within reason, be obtained with any degree of accuracy from either the accident survey or a Chrysler-type program. Instead, they must be selected based on the bumper design and type of impact. It will, however, be possible, in some instances, to limit the number of speeds at which a bumper system is tested. This speed limitation would be based on either a preset damage level, as determined by repair costs, or deformation of the basic vehicle.

Type of impact information can only be obtained from an accident survey, and the impact types that are tested can only be postulated. These impacts include:

a) Car to car:

(1) Vehicle to vehicle (front to rear);
- with underride or override (depends on braking);
- with neither.

(2) Vehicle to vehicle (head-on);
- with underride or override;
- without either.

(3) Cover impacts at various angles.

(4) All of the above with various size vehicles, e.g., full-size impacts subcompact.

(5) Vehicle to side target vehicle.

b) Car to object:

(1) Fixed object;
- size and weight;
- shape;
- impact angle;
- impact location;
- moveable objects.

From the above impact types, the most prevalent types and the conditions associated with them must be identified (e.g., braking, accelerating, etc.) prior to construction of a detailed test program.

4) Vehicle Conditions

Additional factors that must be considered when developing the test program are the vehicle weight; number of occupants; brake setting (on or off); front wheel orientation; tire inflation; transmission locked or neutral; etc. Quite possibly, several combinations may be required to reflect the real-world environment.

On the basis of the above comments, a series of test matrices, as shown in the sample of Table 9-1, may be constructed considering all the possible test variations that could result from the combinations of the collision types, test conditions, vehicle sizes, bumper types, and impact speeds. It is readily seen that the total cost of this test program could be enormous. Additional inputs into the test programs, such as accident surveys, should highlight specific problem areas and allow for reducing the number of tests to a minimum. With the present arrangement of 17 vehicles, 4 different bumper designs to be tested at 3 or 4 different speeds with various collision types and test conditions (estimate 6), it is possible that a total of 14,000 tests could be run. Obviously, this approach is not feasible, and the number of tests must be reduced to a manageable level by defining the actual bumper environment.

9.3 ESTIMATED COST OF A BASIC SET OF BUMPER TESTS

This section delineates an attempt to estimate the cost of a very basic set of bumper low speed crash test programs. To accomplish this objective, a set of basic tests are shown in Table 9-2, 9-3 and 9-4. Table 9-2 contains the minimum set of tests required for two vehicle types (subcompact and intermediate) coupled with two bumper types (hard steel and soft face) as these vehicles are impacted front and rear into a barrier. Table 9-3 is similar to Table 9-2, and shows the minimum test set for corner impacts of these same two vehicle types with two representative bumpers, but this time for corner impacts into a barrier. The tests in Table 9-2 and 9-3 should then establish repeatable data for the more simple tests into barriers. Table 9-4 attempts to select a representative minimum required set of tests involving the same vehicles and bumpers used in vehicle-to-vehicle crashes. The data accrued from test set 3 will probably not be as repeatable within identical test parameter conditions, but this data can be compared to the similar test data in test set 1 and 2.

To estimate the cost of performing the nine basic sets shown in Tables 9-2, 9-3, and 9-4, first assume the 5 mph crash tests

TABLE 9-1. SAMPLE TEST MATRIX - COLLISION TYPE BULLET CAR FRONT TO TARGET CAR REAR (SQUARE OFF)

Test Conditions:

A. Brakes

Bullet and Target Car Brakes Applied Just Before Impact

B. Vehicle Weights (Total including occupants)

Bullet Car____________

Target Car____________

VEHICLE TYPE	BUMPER TYPE	BUMPER DESIGN SPEED	IMPACT SPEED
Subcompact A1	Current Steel	(1)	2-1/2, 5, 7-1/2
	HSLA	(1)	2-1/2, 5, 7-1/2, 9
	Aluminum	(1)	2-1/2, 5, 7-1/2,
	Soft Face	(1)	2-1/2, 5, 7-1/2, 9
Subcompact A2			
⋮			
Subcompact A_N			

(1) To be determined by designer

TABLE 9-2. TEST SET #1-CAR FRONT AND REAR INTO BARRIER
(For 5 Mph "No Damage" Bumper Design)

CAR TYPE	BUMPER	IMPACT TYPE	NO. OF TESTS REQUIRED				NOTES
			SPEED IN MPH				
			5	7	9	12	
Subcompact	Hard Steel	Front to barrier Rear to barrier	3	3	3	3	Front and rear collisions into barrier may or may not be possible on same car before repair.
Subcompact	Soft Face	Front to barrier Rear to barrier	3	3	3	3	
Intermediate	Hard Steel	Front to barrier Rear to barrier	3	3	3	3	
Intermediate	Soft Face	Front to barrier Rear to barrier	3	3	3	3	

TABLE 9-3. TEST SET #2-CORNER IMPACT TESTS (For 5mph "No Damage" Bumper Design)

CAR TYPE	BUMPER	IMPACT TYPE	NO. OF TESTS REQUIRED				NOTES
			SPEED IN MPH				
			5	7	9	12	
Subcompact	Hard Steel	Front to barrier Rear corner to barrier	3	3	3	3	
Subcompact	Soft Face	Front to barrier Rear corner to barrier	3	3	3	3	
Intermediate	Hard Steel	Front to barrier Rear corner to barrier	3	3	3	3	
Intermediate	Soft Face	Front to barrier Rear corner to barrier	3	3	3	3	

TABLE 9-4. TEST SET #3 - 2 CAR COLLISION-FRONT TO REAR (5 mph "No Damage" Bumper Design)

#1 CAR TYPE	#2 CAR TYPE	#1 CAR BUMPER	#2 CAR BUMPER	IMPACT TYPE	NO. OF TESTS REQUIRED			
					SPEED IN MPH			
					5	7	9	12
Subcompact	Subcompact	Hard Steel	Hard Steel	Front to rear	3	3	3	3
Subcompact	Subcompact	Soft Face	Soft Face	Front to rear	3	3	3	3
Subcompact	Subcompact	Hard Steel	Soft Face	Front to rear	3	3	3	3
Subcompact	Subcompact	Soft Face	Hard Steel	Front to rear	3	3	3	3

produced no important damage costs. The remaining test speeds used shown as 7,9, and 12 mph, produce a cost for the first 3 sets of tests computed as follows:

Assume a base cost C_B and N tests. Then, the cost of a series of bumper tests follows a simple formula such as:

$$C_{TOTAL} = C_B + C_i \times N + \sum_{S=7,9,12} C_{r,s} \times N_S$$

where:

C_B = base cost of test set-up;

C_i = cost of one collision test;

N = total tests;

S = Speed, 7,9,12 mph;

$C_{r,s}$ = cost of repair at a speed S;

N_S = number of tests at a speed S.

For purposes of this example, for testing two vehicle types and two bumper types as shown in Tables 9-2, 9-3, and 9-4, the following values are selected:

C_B = \$100,000;

C_i = \$2,000;

$N = 3 \times 36 = 108$;

S = 7,9,12;

$C_{r,s}$

$C_{r,7}$ = \$100;

$C_{r,9}$ = \$300;

$C_{r,12}$ = \$500;

$N_S = N_7 = N_9 = N_{12} = 36$.

then:

$$C_{TOTAL} = \$100{,}000 + \$2{,}000 \times 108 + 36\ (\$100 + \$300 + \$500)$$

$$= \$348{,}400$$

If a set of impacts into the side of a car is determined to be of value, then an additional test set is shown as set #4, in Table 9-5. Assuming an increase in side damage costs at collision speeds 5,7,9, and 12 mph to have the following costs, the additional incremental cost of this set #4 will be:

$$C_{\#4} = C_B + C_i \times N + \sum_{S=5,7,9,12} C_{r,s} \times N_S$$

when: $C_B = \$100,000;$

$C_i = \$2,000;$

$N = 72;$

$S = 5,7,9,12;$

$C_{r,s}$

$C_{r,5} = \$100;$

$C_{r,7} = \$200;$

$C_{r,9} = \$400;$

$C_{r,12} = \$600;$

$N_S = 18$

then:

$$C_{\#4} = \$100,000 + \$2,000 \times 72 + 18\ (\$100 + \$200 + \$400 + \$600)$$

$$C_{\#4} = \$267,400$$

For the total of four sets as shown for a 5 mph "no damage" bumper design, the total costs would be $615,800.

It is important to note that these dollar values are only examples of how the cost of testing bumpers may be estimated. Additional costs would be incurred in designing and manufacturing bumper systems for use in testing.

TABLE 9-5. TEST SET #4 - CORNER IMPACT INTO SIDE
(For 5 mph "No Damage" Bumper Design)

CAR #1 TYPE	CAR #2 TYPE	BUMPER #1 CAR	NO. OF TESTS REQUIRED			
			SPEED IN MPH			
			5	7	9	12
Subcompact	Subcompact	Hard Steel	3	3	3	3
Subcompact	Subcompact	Soft Face	3	3	3	3
Subcompact	Intermediate	Hard Steel	3	3	3	3
Subcompact	Intermediate	Soft Face	3	3	3	3
Intermediate	Subcompact	Hard Face	3	3	3	3
Intermediate	Intermediate	Soft Face	3	3	3	3

9.4 GUIDELINES FOR PREPARATION OF REQUEST FOR PROPOSAL (RFP) FOR LOW SPEED DAMAGE REDUCTION BUMPER TEST

9.4.1 RFP Guidelines

An RFP for executing the test program should cover, as a minimum, the following requirements:

1) Test facilities requirements:

   a) test course with safety and remote control capabilities;
   b) on-site car and bumper repair capabilities;
   c) pendulum and barrier equipment, where necessary;
   d) high speed (1,000 frames/second) photographic and video-tape equipment;
   e) instrumentation for recording vehicles deflection and deceleration;
   f) capability for conducting car to car crashes;
   g) impact speed must be maintained with ± 0.5 mph of the target speed; and
   h) suitable means for aborting a test for improper speed or failure of other instrumentation.

2) The contractor should be responsible for all vehicle procurement inspection and repair.

3) NHTSA should have rights of approval on the damage appraisers.

4) Contractor report preparations should include:

   a) plan of work and methodology;
   b) maintenance of vehicle log for each car, (this log shall list all maintenance, repairs and test preparation activities, and photographs should be used to supplement repair descriptions;
   c) weekly and monthly summaries of tests and cumulative costs of programs in progress; and
   d) final report, to contain, as a minimum, the following: (1) pre and post test still photographs; (2) list of

repair parts and labor costs; (3) test weight, (4), impact speed; (5) dynamic and static deflection of vehicle including bumper system; (6) pre and post impact velocity, etc.

9.4.2 Preliminary Draft of Statement of Work for Test Program

9.4.2.1 Background

According to Title 1 of the "Motor Vehicle Information and Cost Savings Act" (PL 92-513), the Secretary of Transportation shall promulgate "bumper" standards that "seek to obtain the maximum feasible reduction of costs to the public and to the consumer." To define such standards, NHTSA plans to conduct a comprehensive study of low speed automobile damage reduction systems. The purpose of this program is to establish estimates of the total consumer benefits, costs, weights, and energy usage for several near - optimum net benefit bumper systems and performance levels fron which performance requirements with feasible manufacturing lead-time may be selected and justified for Title I rulemaking. Lifetime consumer benefit estimates will include an analysis of real-world, low-speed accident statistical data and controlled, low-speed crashes using selected near-optimum bumper systems for which materials and manufacturing technologies are presently available.

9.4.2.2 General Requirements

In response to the background requirements, the NHTSA plans coordinate and, essentially, parallel programs covering (1) an analysis program; and (2) a motor vehicle crash test program.

The contractor must control his own test facility and shall furnish the necessary qualified personnel, equipment, materials, test vehicles, instrumentation, and services to conduct the "Low Speed Automobile Damage Crash Test Program" described herein. Instrumentation shall satisfy SAE Recommended Practice J211a. The contractor is expected to have sufficient resources to allow the parallel preparation and testing necessary for a compressed schedule.

The test contractor's crash facility must be suitable for conducting fixed barrier collision, moving barrier collision, and car-to-car crash tests. The fixed collision barrier shall comply with Part 571 (CFR), and the moving barrier shall conform to SAE Recommended Practice J972. Both barriers shall be instrumented to provide crash impact force measurements. The fixed barrier, the impact site for the moving barrier, and the car-to-car crash site must provide for high speed (1000 frames/second) moving picture cameras fixed to obtain side, overhead, and bottom, views of the test vehicles. High speed crash test filming is to be at 1000 fps in color and of a quality suitable for analysis. Impact speed must be maintained within ± 0.5 mph of the target impact speed, and the facility must have suitable means for aborting a test for improper speed or failure of critical instruments or cameras (recognizing there is a practical limit to using any abort system). The contractor shall provide inforamtion on the capability of his abort system.

Data collected under this contract may not be released to any persons not directly associated with the contract without the express written permission of the Contract Technical Monitor (CTM).

1) <u>Task 1 Plan of Work and Methodology</u>

The contractor shall prepare a Plan of Work and Methodology for a program designed to develop test data for the Low Speed Automobile Damage Reduction System Study.

The contractor shall include, as a part of the Plan of Work and Methodology, a milestone chart and a financial chart to show actual versus planned expenditure curves.

The Plan of Work and Methodology shall be submitted to the Contracting Officer for approval with four (4) copies to the CTM within four (4) weeks after the effective date of the contract. Approval by the Contracting Officer, with the recommendations of the CTM, will be given two (2) weeks after receipt or two (2) weeks after resubmittal in the event that the initial submission is unacceptable.

Until approval of the Plan of Work and Methodology is received from the Contracting Officer, no significant costs shall be incurred. Only those costs necessary for planning purposes will be allowable for reimbursement.

2) Task 2 Vehicle Procurement and Inspection

The contractor will procure and inspect appropriate vehicles and modify the vehicles, as necessary, for the contractor to install the bumper types as directed by the CTM.

Prior to any testing, the contractor will inspect the vehicles and ascertain that they are properly assembled and free of defects such as loose structural or suspension components. A vehicle log will be prepared for each car listing all maintenance, repair, and test preparation activities. Black and white photographs will be used to supplement repair descriptions. The vehicle log book format will be submitted to the CMT for approval. As testing is completed on each individual vehicle and bumper system, the log book will be delivered to the CTM.

3) Task 3 Vehicle Refurbishment

Upon completion of a test, the contractor is to refurbish these cars to the extent necessary to conduct a meaningful test. Cars previously damaged to now be used as "bullet" cars in car-to-car tests will have the front end structure restored to a suitable level for use with the designated bumper system. However, any parts which represent on energy management element must be refurbished so as to allow adequate crash damage analysis. "Bullet" cars must also be restored such that they can be safely towed at the required speeds and will track properly. Static target cars for rear end crashes are to be restored such that the undamaged test portion sits at the proper attitude and the vehicle rolls freely upon its own wheels.

4) Task 4 Test Plan and Procedures

The contractor is to prepare a test plan covering the test series and also is to prepare detailed test procedures for each type of test. The plan and the detailed procedures will be submitted to the CTM for approval.

The test procedures will prescribe preparation for testing, the conduct of the test, and the facilities to be used; and will describe forms, and equipment for recording test results, instrumentation lists with respective accuracies, calibration requirements, data acquisition methodology, and data reduction methodology. Test activity will not start until the last plan is approved, and no vehicle will be prepared for a specific test until the specific test procedure is approved.

Except as modified in this statement of work, or later in test plans or procedures approved by the CTM, the vehicle test conditions will conform to FMVSS No. 215.

5) Task 5

The CTM will define a series of tests involving front and rear vehicle crashes and corner impact crashes in accordance with the findings and analysis of the real-world crash environment.

6) Task 6 Test Data

After the completion of each crash test, the contractor will reduce and analyze the test data and damage appraisals. Final test reports are to be furnished to the CTM within two weeks.

With respect to the vehicles, the contractor is to provide: (1) pre- and post-test still photographs; (2) test weight (total and at each wheel); (3) impact velocity; (4) pre and post-impact velocities versus time as appropriate; (5) acceleration versus time, when applicable, (6) dynamic crush versus time for key structurer, e.g. bumper and frame; and (7) static crush. Data on maximum dynamic crush should be obtained from at least two sources, and comparisons made, e.g. high speed motion pictures, scratch tubes, or double integration of acceleration data. In addition, the contractor is to have a minimum of two insurance adjustors independently and separately appraise the damage to each vehicle after each crash. The adjustors are to complete damage assessment sheets giving labor hours and dollars as well as materials and parts costs with the objective of restoring the car in a manner suitable for satisfying a consumer. The contractor is to describe his method for keeping the appraisals independent and separate.

9.4.2.3 <u>Reports, Briefings and Films</u>

The contractor shall furnish a monthly letter-type progress report in ten (10) copies to the Contract Technical Monitor (CTM) and one (1) copy to the Contracting Officer no later than the tenth of the month following the month being reported. The report shall include but not be limited to the following:

1) accomplishments made during the reporting period;
2) funds committed during the reporting period;
3) what is planned for accomplishment during the next reporting period;
4) preliminary or interim results, conclusions, trends or other items of information that the contractor believes to be of timely interest to NHTSA;
5) problems or delays that the contractor has experienced in the conduct of his services;
6) specific action that the contractor would like NHTSA to undertake to alleviate a problem; and
7) updated milestone and financial status charts.

9.4.2.4 <u>List of Deliverable Items</u>

1) PLAN OF WORK AND METHODOLOGY;
2) TEST PROCEDURES;
3) MONTHLY REPORTS;
4) MONTHLY/INTERIM/FINAL BRIEFING MATERIAL;
5) BUMPER TEST MOVING PICTURES AND SLIDES;
6) IMPACT TEST DATA INCLUDING APPRAISAL, ESTIMATES, SPEED, ETC.;
7) TEST REPORTS ON EACH IMPACT;
8) VEHICLE LOGS; and
9) FINAL REPORT.

APPENDIX A

ALTERNATIVE COST ESTIMATES FOR THE SURVEY

Task 1. Design of the national sample.
Cost: $25,000.

Task 2. Design of the parked car survey.
Cost: Small survey, $20,000; medium, $25,000; large, $30,000.

Task 3. Selection of body shops.
Cost per PSU: $200.

In the small survey, the plan is to use 40 PSU's; in the medium, 100 PSU's; and in the large, 200 PSU's. Hence, total cost is $10,000 for the small survey; $20,000 for the medium; and $40,000 for the large.

Task 4. Design and pretest all data collection instruments, etc., and all survey procedures.
Cost: $15,000.

Task 5. Performance of the parked car survey.

As an example, assume that the surveys were performed in late 1976, but prior to the introduction of any significant number of 1977 model year vehicles. Then, the model years making up the survey are 1976 and prior years. An estimate, based on R.L. Polk fleet data and an assumption of 1976 model year car sales at 9.9 million, of the age distribution of the fleet at the time of the survey is shown in Table A-1.

TABLE A-1. AGE DISTRIBUTION OF FLEET AT TIME OF SURVEY (LATE 1976)

Model Year	% of Fleet
1976	10.4
1975	9.1
1974	9.3
1973	11.9
1972	10.8
1971	9.8
1970	7.8
1968	6.7
1967	4.7
1966	3.8
1965	2.8
1964	1.7
1963	1.1
1962 & earlier	2.2

According to the Ford Motor Company surveys of parking lot damage[A-1], 1974 vehicles had .253 average incidents of damage in their first year of service. The surveys defined a "normal" curve of damage accumulation by age for vehicles of 1971 vintage and earlier. Assuming that as 1972, 1973 and 1974 cars age they retain the same relationship to this "normal" curve as when the Ford survey was made, and that model years 1975 and 1976 have identical damage propensity to 1974 (all these had the 5 mph requirement front and rear), Table A-2 gives the average damage incidence which would be expected at the time of the survey.

TABLE A-2. AVERAGE DAMAGE INCIDENCE OF FLEET AT TIME OF SURVEY (LATE 1976)

Model Year	Average Damage Incidents/Car
1976	.253
1975	.52
1974	.68
1973	1.01
1972	1.60
1971	1.47
1970	1.55
1969	1.63

TABLE A-2. AVERAGE DAMAGE INCIDENCE OF FLEET AT TIME OF SURVEY (LATE 1976) CONTINUED

Model Year	Average Damage Incidents/Car
1968	1.69
1967	1.75
1966	1.80
1965	1.85
1964	1.89
1963	1.92
1962 & earlier	1.95+

In addition the Ford survey showed (see Table A-3) the distribution of damage by impact area (1974 model year vehicles).

TABLE A-3. DISTRIBUTION OF DAMAGE BY IMPACT AREA (1974 MY VEHICLES)

Impact Area	% of Damage Incidents
Square Front	12.7
Front Corners	24.3
Sides	35.5
Square Rear	7.4
Rear Corners	20.1

Assume the side incidents are fairly evenly divided between right and left sides. Then, square rear is the smallest category of damage incidents among the six impact areas of interest. Thus, if X cars of any size category in model year 1976 are scanned for damage, the smallest number of damage incidents found in any one impact area is:

$$S(.253)\ (.074) = .018722X \qquad \text{(Eq. A-1)}$$

so, if X = 2670 cars, the formula indicates 50 incidents of this type nationwide, enough for a cost-to-repair distribution.

This analysis holds for the large and medium-sized surveys. For the small survey, only three impact area classifications apply. In this case, the smallest category by impact area is rear, at 27.5%. Hence, for 1976 cars, the smallest number of damage incidents in one impact area is:

$$X\ (.253)\ (.275) = .069575X \qquad \text{(Eq. A-2)}$$

so, if X= 720 cars, the formula indicates 50 incidents of this type, enough for a cost-to-repair distribution.

Using this methodology, and summing over all model years of interest in the three cases, results in the following sample sizes:

Small survey: 7000 cars, or 175 in each of 40 PSU's;
Medium: 30,000 cars, or 300 in each of 100 PSU's;
Large: 40,000 cars, or 400 in each of 100 PSU's;

To keep the number this small, minimum quotas must be established for each model year and car class; the quota size will vary by model year. Quota sizes may have to be adjusted as the survey proceeds to compensate for errors in the data on which the above calculations depend.

Cost breakdown in each PSU:

a) An appraiser can choose and assess 50 cars/day. Assume also, 2 days' training and $80/day. Small survey: 5-1/2 days, $440; medium: 8 days, $640; large: 10 days, $800.

b) Two days of work by field supervisor including travel: $200.

Cost per PSU: Small survey, $640; medium, $840; large, $1000.

Total cost: Small, $25,000; medium, $85,000; large $100,000.

Task 6. Performance of the body repair shop survey.

Assume the same fleet distribution as discussed in Task 5. According to the Ford surveys of repaired damage[A-1], approximately .25 incidents of repaired damage occur per vehicle-year. The same source gives the distribution of repaired incidents by impact area as shown in Table A-4.

TABLE A-4. DISTRIBUTION OF REPAIRED INCIDENTS BY IMPACT AREA

Impact Area	% of Damage Incidents
Square Front	15.9
Front Corners	21.1
Sides	43.8
Square Rear	7.1
Rear Corners	12.1

Take the small size survey. Using R. L. Polk data on auto registrations, the smallest combination of fleet size in a given year and car size class in the model years of interest is 1974 compacts; 1974 cars are 9.3% of the fleet, and compacts form 20% of this group. The smallest impact area among the three considered is rear, with 19.2% of damage incidents. Hence, out of a 95.2 million-car fleet, the smallest set of repaired damage incidents for a given model year, car size, and impact area is:

$$(95.2 \text{ million})\ (.093)\ (.2)\ (.192)\ (.25)$$
$$= 84,955 \text{ cars/year}$$

Projections from the U.S. Census of Business show that there were about 40,000 top and body repair shops in 1976. Assuming that damaged cars awaiting repair in a shop remain there for about one week, 2% of the annual repairs of a shop will be there on a given day. Hence, in order to have a minimum of 50 repaired cars of each type in a nationwide random sample of body shops, X body shops must be sampled, where

$$X = 50(40,000)/84995(.02) = 1177$$

This is about 30 shops per each of 40 PSU's.

Similar analyses yield about 4700 shops for the mid-size survey or 47 per each of 100 PSU's, and 12,800 shops for the large survey or 64 per each of 200 PSU's.

Carrying this reasoning backwards gives an estimate of the number of cars surveyed in the body shops. For example, in the small survey 1177/40000 fraction of body shops are visited, with 2% of their annual repairs being in the shop at the time of visit. Hence, (95,200,000) (.25) (1177/40000) (.02) = 14,000 repaired cars are surveyed. Similarly, the medium survey has 55,000 cars and the large one has 152,000 cars.

Cost breakdown in each PSU:

a) Surveyor consumes 2 hours' working time per shop when respondent, 1 hour when not. Assume 75% of shops visited are respondent, $4.50/hour pay for surveyor.

Small survey: 30 shops respondent, 10 not, 70 hours @ $4.50/hr = $315.

Medium: 47 respondent, 16 not. 110 hours @ $4.50/hr = $495.

Large: 64 respondent, 21 not. 149 hours @ $4.50/hr = $671.

b) Training and supervision: $150.

Cost per PSU: small survey, $465; medium, $645; large $821.

Total cost: small, $20,000; medium, $65,000; large, $165,000.

Task 7. Analysis of the results.

a) Coding and punching data. Assume 30 complete records can be done per hour, and pay is $4/hour. Small Survey: 7000 parked cars. Of these, 70% had damage and were issued windshield questionnaires. Assume only half the questionnaires were returned. Hence, 2450 questionnaires must be coded along with the appraisers' records on the cars.

Also, 14,000 cars from body shops survey, for a total of 23,450 records. Cost: $3100.

Medium Survey:	30,000	parked cars
	10,500	questionnaires
	55,000	body shop repairs
	95,500	records

Cost: $12,700

Large Survey:	40,000	parked cars
	14,000	questionnaires
	152,000	body shop repairs
	206,000	records

Cost: $27,500

b) Analysis and computer time

Small survey:	$12,000
Medium:	$18,000
Large:	$25,000

Total Cost: small, $15,000; medium, $30,000; large $50,000.

Task 8. Obtain and use insurance company statistical records.

a) Cost of Obtaining Data:

Based on past experience, insurance companies will supply data free, if it is in a format that they have used for their own purposes. Insurance companies must, under the Motor Vehicle Information and Cost Savings Act, supply information desired by the Government, but the Secretary of Transportation must, in determining what shall be requested, "consider the cost of preparing and furnishing such reports and information". This may imply an obligation to pay for costly information. This potential cost cannot be estimated at the present time.

b) Cost of analysis: $10,000

Task 9. Final report.

Small survey, $5,000; medium, $10,000; large, $15,000.

The task-by-task cost estimates are summarized in Table A-5 along with total costs for the three size surveys.

TABLE A-5. TASK COST ESTIMATE SUMMARY

Task	Small	Medium	Large
1	$25,000	$25,000	$ 25,000
2	20,000	25,000	30,000
3	10,000	20,000	40,000
4	15,000	15,000	15,000
5	25,000	85,000	100,000
6	20,000	65,000	165,000
7	15,000	30,000	50,000
8	10,000	10,000	10,000
9	5,000	10,000	15,000
Total	$145,000	$285,000	$450,000

APPENDIX B

A COST ESTIMATE FOR TRACKING INSURANCE STATISTICS

Task 1. Survey and select data sources.
Cost: $5,000.

Task 2. Data acquisition and processing. Insurance companies are required to furnish data needed by the Government, under the Motor Vehicle Cost Savings and Information Act, but may need to be reimbursed for the cost of providing it.
Cost: $10,000.

Task 3 and 4. Combine data to give nationwide estimates of insurance claims, and show trends in damageability.
Cost: $15,000.

Task 5. Report.
Cost: $10,000.
Subtotal for initial effort; Tasks 1 through 5: $40,000.

Task 6. Repeat Tasks 2 through 5 for each new year of data. Requires manipulation of only one year's data for each repetition and avoids start-up costs, hence, cost is less than the initial cost of Tasks 2 through 5.
Cost: $20,000 per iteration.

Task 7. Apply correction factors to Task 6 data for updated estimates of nationwide total damage.
Cost: $5,000 per iteration.
Total costs: Assume the initial effort is done in 1977 using 1976 and earlier data. Additional iterations are done for 1977, 1978, 1979 and 1980. Total is $40,000 + $25,000 x 4 = $140,000 spread over five years.

APPENDIX C

BUMPER SYSTEMS FRONT AND REAR

A cost comparison study of front end bumper systems has been conducted. Included in the study is an "All Soft" system patterned after the "New York Taxicab" system. This system covers the entire front fascia of the car (Figure C-1). As a consequence, all of the systems studied include similar fascia components, such as grille, headlamp housing, stone shield, etc., so that they can be compared with the "All Soft" system.

Figures C-1, C-2, and C-3 present, of the three basic concepts that were evaluated, the "All Soft" (System 3), the "All Hard" and the "Hybrid". As can be seen, the "Hybrid" (System 4) combines the soft fascia with a steel bumper plate and hydraulic energy absorbers.

Four variations of the "All Hard" system were studied. They included:

1. A current production system with a plated steel bumper, a backup bar assembly, hydraulic energy absorbers, and a die cast grille and headlamp housing assembly (System 1).
2. The same system as above except with an ABS (acrylonitrite-butadiene-styrene) material being substituted for the die cast grille and headlamp housing (System 2).
3. The same system as No. 2 except with a high strength low alloy steel (60K psi - yield) bumper face plate substituted for the current production bumper face plate and backup bar assembly (System 5).
4. The same system as No. 2 except with a high strength aluminum alloy (7046) substituted for the current production bumper assembly.

A summary of comparative costs and weights of these six systems is presented in Table C-1. A detailed summary of each systems cost and weight is presented in Tables C-2 through C-7.

Table C-8 presents a comparison die cast zinc and ABS material as applied to a grille and headlamp housing. Table C-9 presents a comparison of bumper materials.

Detailed studies were not made on the rear bumper system. Cost and weight differentials for these components, however, would be similar to those on the front bumper systems for comparable parts.

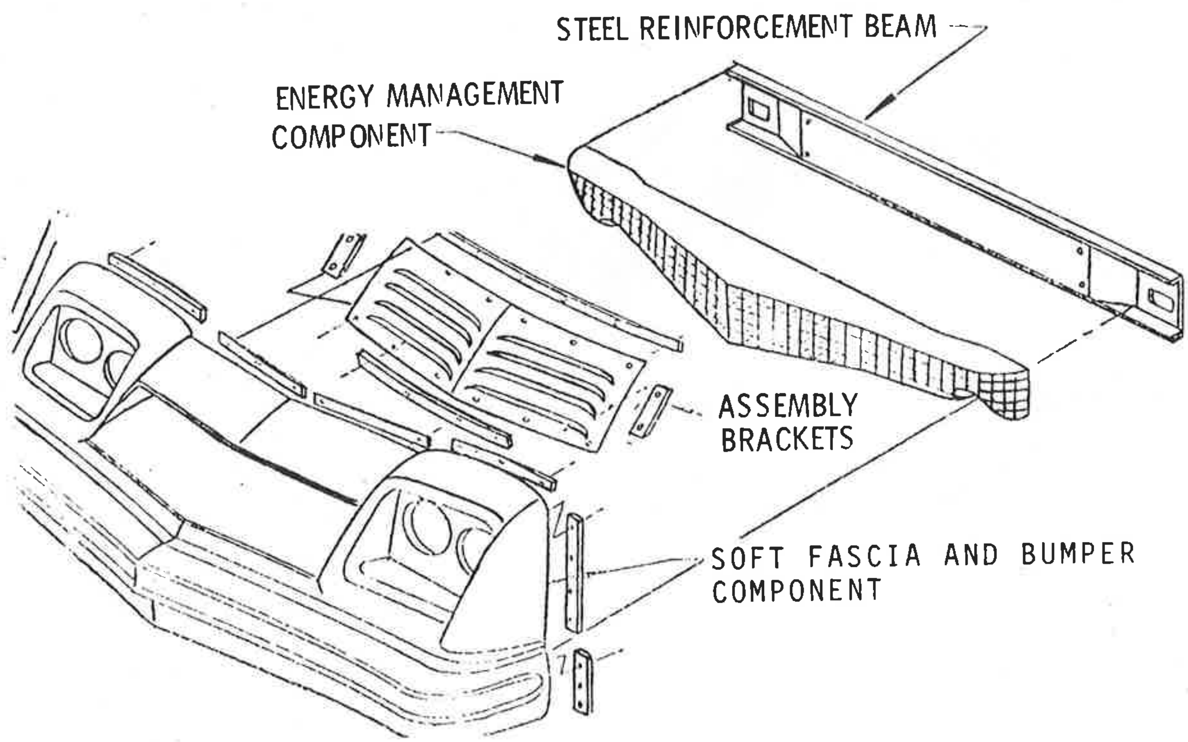


FIGURE C-1 SOFT FRONT END AND BUMPER COMPONENTS
REACTION INJECTION MOLDING

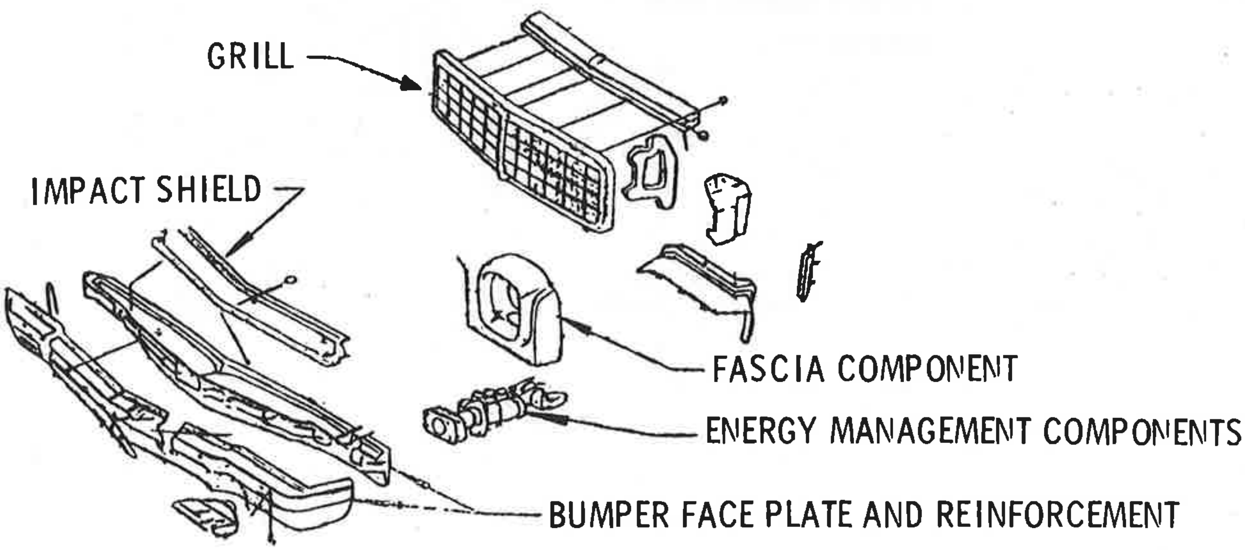


FIGURE C-2 TYPICAL "ALL HARD" SYSTEM EXPLODED VIEW

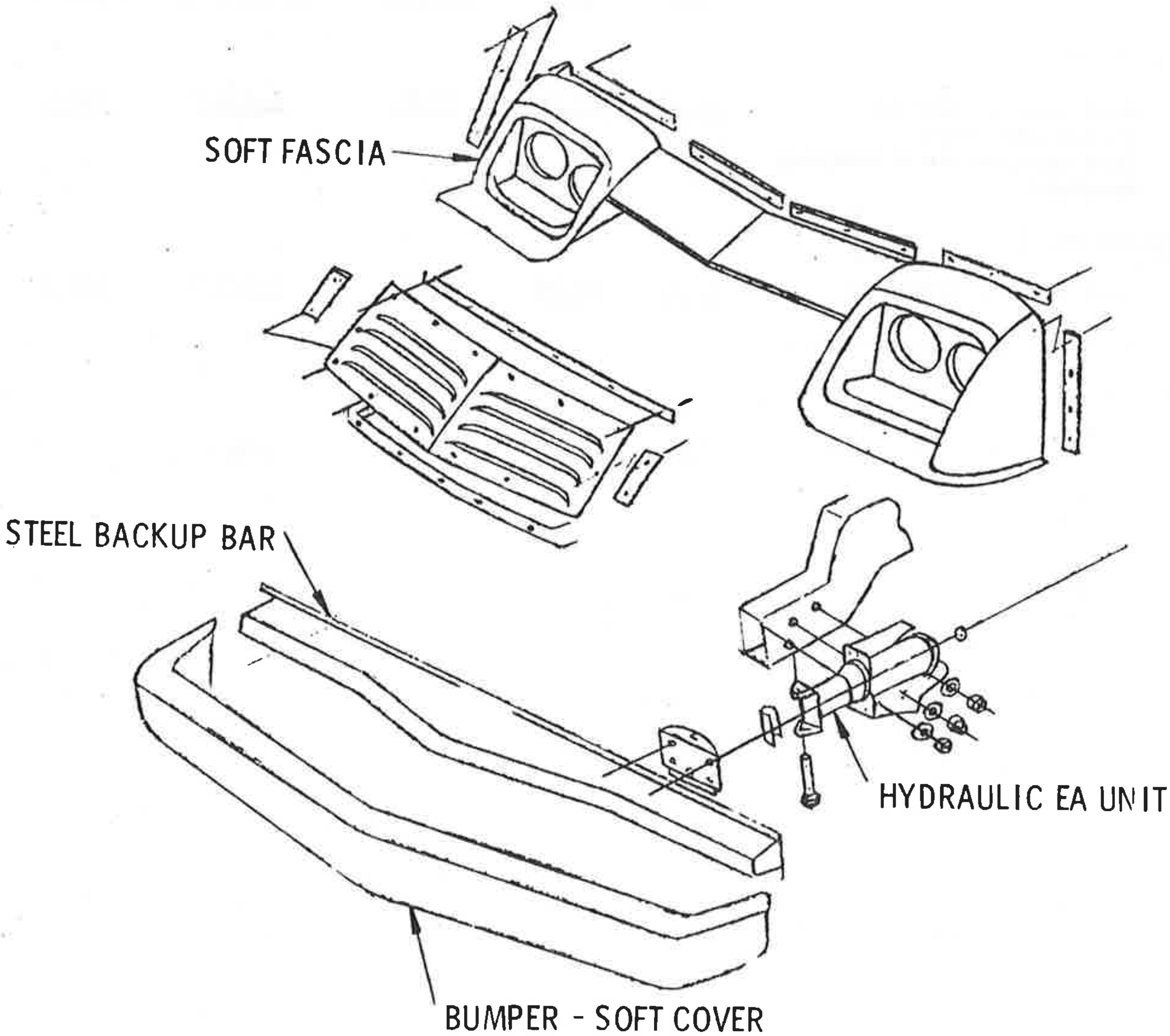


FIGURE C-3 HYBRID SYSTEM

TABLE C-1. PRODUCTION COST ESTIMATES SUMMARY* SOFT VS. HARD, 5 MPH BUMPER SYSTEMS

	Matl. ($)	Labor & Burden ($)	Total Part Cost ($)	Die Model & Tooling Cost ($000)	Weight (Lbs.)
System No. 1					
Hard Fascia, Hydraulic Energy Absorbers (Die Cast Grille & Headlamp Housing)	41.12	19.72	60.84	2,252.7	148.4
System No. 2					
Hard Fascia, Hydraulic Energy Absorbers (ABS Grille & Headlamp Hsg.)	32.47	14.58	47.05	2,273.5	129.9
System No. 3					
Soft Fascia, Soft Energy Absorber	31.73	10.90	42.63	2,061.2	92.0
System No. 4					
Hybrid Soft Face Soft Fascia, Hydraulic Energy Absorbers	49.79	16.18	65.97	4,204.5	145.5
System No. 5					
Same as System No. 2 Using a HSLA Steel Bumper Face Plate	21.59	13.24	34.83	2,035.0	75.9
System No. 6					
Same as System No. 2 Using an Aluminum - 7046 Face Plate	23.00	13.51	36.51	2,195.0	54.6

*Intermediate size automobile - 4,000 lbs.

TABLE C-2. PRODUCTION COST ESTIMATES HARD FASCIA, HYDRAULIC ENERGY ABSORBERS DIE CAST GRILLE & HEADLAMP HOUSING - CURRENT PRODUCTION*

Part Name	Matl. ($)	Labor & Burden ($)	Total Part Cost ($)	Die Model & Tooling Cost ($000)	Weight (Lbs.)
Steel					
Radiator Grille Header Panel Assembly	0.61	0.50	1.11	136.0	3.5
Radiator Grille to Header Panel Bracket	0.28	0.20	0.48	28.0	0.9
Radiator Grille Bracket - R & LH	0.53	0.37	0.90	44.0	2.3
Frt. Fender Retainer R & LH	0.10	0.40	0.50	26.0	0.8
Face Bar Assembly	11.35	3.02	14.37	312.5	36.5
Frt. Bumper Filler Panel	0.39	0.10	0.49	56.0	2.8
Front Bumper Reinforcement Assembly	9.56	1.42	10.98	247.9	50.5
License Plate Mounting Bracket	0.46	0.06	0.52	28.0	2.8
Stud Plate Assembly	0.57	0.15	0.72	26.2	1.6
TOTAL STEEL	23.85 (1)	6.22	30.07	904.6	101.7
Zinc Die Casting					
Radiator Grille	5.70	6.77	12.47	289.0	12.0
Headlamp Housing R & LH	6.78	2.54	9.32	232.2	16.0
TOTAL ZINC DIE CASTING	12.48 (2)	9.31	21.79	521.2	28.0
Other					
Frt. Fender Filler R & LH	0.86	1.46	2.32	55.5	1.7
Frt. Bumper Shock Absorber Unit (2 required)	3.93	2.73	6.66	771.4	17.0
TOTAL OTHER	4.79	4.19	8.98	826.9	18.7
GRAND TOTAL	41.12	19.72	60.84	2,252.7	148.4

(1) Average cost per pound of $0.235 includes all scrap, offall, finishes, etc.

(2) Average cost per pound of $0.446 includes all scrap, sprues, finishes, etc.

*Intermediate size automobile - 4,000 lbs.

TABLE C-3. PRODUCTION COST ESTIMATES HARD FASCIA, HYDRAULIC ENERGY ABSORBERS ABS GRILLE & HEADLAMP HOUSING - MODIFIED CURRENT PRODUCTION*

Part Name	Matl. ($)	Labor & Burden ($)	Total Part Cost ($)	Die Model & Tooling Cost ($000)	Weight (Lbs.)
Steel					
Radiator Grille Header Panel Assembly	0.61	0.50	1.11	136.0	3.5
Radiator Grille to Header Panel Bracket	0.28	0.20	0.48	28.0	0.9
Radiator Grille Bracket R & LH	0.53	0.37	0.90	44.0	2.3
Frt. Fender Retainer R & LH	0.10	0.40	0.50	26.0	0.8
Face Bar Assembly	11.35	3.02	14.37	312.5	36.5
Frt. Bumper Filler Panel	0.39	0.10	0.49	56.0	2.8
Front Bumper Reinforcement Assembly	9.56	1.42	10.98	247.9	50.5
License Plate Mounting Brkt.	0.46	0.06	0.52	28.0	2.8
Stud Plate Assembly	0.57	0.15	0.72	26.2	1.6
TOTAL STEEL	23.85 (1)	6.22	30.07	904.6	101.7
ABS Casting					
Radiator Grille	2.78	1.42	4.20	279.0	5.5
Headlamp Housing R & LH	1.05	2.75	3.80	263.0	4.0
TOTAL ABS	3.83	4.17	8.00	542.0	9.5
Other					
Frt. Fender Filler R & LH	0.86	1.46	2.32	55.5	1.7
Frt. Bumper Shock Absorber Unit (2 required)	3.93	2.73	6.66	771.4	17.0
TOTAL OTHER	4.79	4.19	8.98	826.9	18.7
GRAND TOTAL	32.47	14.58	47.05	2,273.5	129.9

(1) Average cost per pound of $0.235 includes all scrap, offall, finishes, etc.

*Intermediate size automobile - 4,000 lbs.

TABLE C-4. PRODUCTION COST ESTIMATES SOFT FRONT END SOFT FASCIA, SOFT ENERGY ABSORBERS*

Part Name	Matl. ($)	Labor & Burden ($)	Other Matl. ($)	Total Part Cost ($)	Die Model & Tooling Cost ($000)	Weight (Lbs.)
Plastic Parts						
Fascia & Headlamp Support Panel	0.75	0.30	NA	1.05	127.0	3.0
Fascia Less Grille (RIM)	7.86	3.45	0.62	11.93	700.0	13.0
Grille (IM)	2.99	1.81	0.66	5.46	484.5	5.4
EA (IM)	8.86	1.84	NA	10.70	475.5	16.0
TOTAL	20.46	7.40	1.28	29.14	1,787.0	37.4
Steel Parts						
Fascia to Front Fender Retainer	0.50	0.36		0.86	62.0	1.3
Upper Fascia to Radiator Support Retainer	0.44	0.24		0.68	22.0	1.1
Grille to Fascia Retainer Assembly	0.20	0.53		0.73	20.0	0.6
Energy Absorbing Mgmt. Reinforcement Assembly	8.28	2.22		10.50	144.0	50.0
Stud Plate Assembly	0.57	0.15	—	0.72	26.2	1.6
TOTAL	9.99	3.50		13.49	274.2	54.6
GRAND TOTAL	30.45	10.90	1.28	42.63	2,061.2	92.0

*Intermediate size automobile - 4,000 lbs.

TABLE C-5. PRODUCTION COST ESTIMATES HYBRID SOFT FACE SOFT FASCIA, HYDRAULIC ENERGY ABSORBERS****

Part Name	Matl. ($)	Labor & Burden ($)	Total Part Cost ($)	Die Model & Tooling Cost ($000)	Weight (Lbs.)
* Bumper Bar **	25.61	5.19	30.80	1,743.5	52.0
Front Bumper Reinforcement Assembly	9.56	1.42	10.98	247.9	50.5
Stud Plate Assembly	0.57	0.15	0.72	26.2	1.6
Front Bumper Shock Absorber Unit	3.93	2.72	6.66	771.4	17.0
Fascia to Front Fender Retainer	0.50	0.36	0.86	62.0	1.3
Upper Fascia to Radiator Support Retainer	0.44	0.24	0.68	22.0	1.1
Grille to Fascia Retainer	0.20	0.53	0.73	20.0	0.6
Fascia Less Grille	4.58	3.45	8.03 ***	700.0	13.0
Radiator Grille	3.65	1.81	5.46 ***	484.5	5.4
Fascia and Headlamp Support Panel	0.75	0.30	1.05	127.0	3.0
GRAND TOTAL	49.79	16.18	65.97	4,204.5	145.5

* Includes Reference System face plate with soft covering instead of nickel chrome plate.
NOTE: Bumper bar material equals $15.84-urethane, $7.70-steel and $2.07 for plated molding; labor equals $3.67-urethane, $1.09-steel and $0.43 for plated molding. If plated molding is not desired, subtract its cost from values shown.

** A substitution of the HSLA bumper face plate would change the costs as follows: 68.56 4,214.4 140.25

*** Includes cost for paint, plating and/or other materials.

****Intermediate size automobile - 4,000 lbs.

TABLE C-6. PRODUCTION COST ESTIMATES HARD FASCIA, HYDRAULIC ENERGY ABSORBERS ABS GRILLE & HEADLAMP HOUSING - HIGH STRENGTH STEEL BUMPER**

Part Name	Matl. ($)	Labor & Burden ($)	Total Part Cost ($)	Die Model & Tooling Cost ($000)	Weight (Lbs.)
Steel					
Radiator Grille Header Panel Assembly	0.61	0.50	1.11	136.0	3.5
Radiator Grille to Header Panel Bracket	0.28	0.20	0.48	28.0	0.9
Radiator Grille Bracket R & LH	0.53	0.37	0.90	44.0	2.3
Frt. Fender Retainer R & LH	0.10	0.40	0.50	26.0	0.8
Face Bar Assembly	10.03	3.10	13.13	321.9	33.0
* Frt. Bumper Filler Panel	0.39	0.10	0.49	56.0	2.8
License Plate Mtg. Bracket	0.46	0.06	0.52	28.0	2.8
Stud Plate Assy. (2 pcs.)	0.57	0.15	0.72	26.2	1.6
TOTAL STEEL	12.97	4.88	17.85	666.1	47.7
ABS Casting					
Radiator Grille	2.78	1.42	4.20	279.0	5.5
Headlamp Hsg. R & LH	1.05	2.75	3.80	263.0	4.0
TOTAL ABS	3.83	4.17	8.00	542.0	9.5
Other					
* Frt. Fender Filler R & LH	0.86	1.46	2.32	55.5	1.7
Frt. Bumper Shock Absorber Unit (2 required)	3.93	2.73	6.66	771.4	17.0
TOTAL OTHER	4.79	4.19	8.98	826.9	18.7
GRAND TOTAL	21.59	13.24	34.83	2,035.0	75.9

* Eliminate these costs for a free standing bumper system

**Intermediate size automobile - 4,000 lbs.

TABLE C-7. PRODUCTION COST ESTIMATES HARD FASCIA, HYDRAULIC ENERGY ABSORBERS ABS GRILLE & HEADLAMP HOUSING - ALUMINUM BUMPER**

Part Name	Matl. ($)	Labor & Burden ($)	Total Part Cost ($)	Die Model & Tooling Cost ($000)	Weight (Lbs.)
Steel & Aluminum					
Radiator Grille Header Panel Assembly	0.61	0.50	1.11	136.0	3.5
Radiator Grille to Header Panel Bracket	0.28	0.20	0.48	28.0	0.9
Radiator Grille Bracket R & LH	0.53	0.37	0.90	44.0	2.3
Frt. Fender Retainer R & LH	0.10	0.40	0.50	26.0	0.8
Face Bar Assy.-Alum.-7046	11.44	3.37	14.81	481.9	11.7
* Frt. Bumper Filler Panel	0.39	0.10	0.49	56.0	2.8
License Plate Mtg. Bracket	0.46	0.06	0.52	28.0	2.8
Stud Plate Assy. (2 pcs.)	0.57	0.15	0.72	26.2	1.6
TOTAL STEEL & ALUMINUM	14.38	5.15	19.53	826.1	26.4
ABS Casting					
Radiator Grille	2.78	1.42	4.20	279.0	5.5
Headlamp Hsg. R & LH	1.05	2.75	3.80	263.0	4.0
TOTAL ABS	3.83	4.17	8.00	542.0	9.5
Other					
* Frt. Fender Filler R & LH	0.86	1.46	2.32	55.5	1.7
Frt. Bumper Shock Absorber Unit (2 required)	3.93	2.73	6.66	771.4	17.0
TOTAL OTHER	4.79	4.19	8.98	826.9	18.7
GRAND TOTAL	23.00	13.51	36.51	2,195.0	54.6

*Eliminate these costs for a free standing bumper system.

**Intermediate size automobile - 4,000 lbs.

TABLE C-8. PRODUCTION COST ESTIMATES BUMPER ASSEMBLY*

Part Name		Matl. ($)	Burden ($)	Total Part Cost ($)	Die Model & Tooling Cost ($000)	Weight (Lbs.)
(1) Current Production - Face Bar Assembly		11.35	3.02	14.37	312.5	36.5
Front Bumper Reinforcement Assembly		9.56	1.42	10.98	247.9	50.5
	TOTAL	20.91	4.44	25.35	560.4	87.0
(2) High Strength Low Alloy (HSLA) Steel (60,000 PSI Yield) Face Bar Assembly		10.03	3.10	13.13	321.9	33.0
(3) High Strength Aluminum - 7046 (60,000 PSI Yield) Face Bar Assembly Aluminum - 7046		11.44	3.37	14.81	481.9	11.7
Comparison -						
Item (1) less Item (2)		+10.88	+1.34	+12.22	+238.5	+54.0
Item (1) less Item (3)		+ 9.41	+1.07	+10.54	+ 78.5	+75.3
Item (2) less Item (3)		- 1.41	-0.27	- 1.68	-160.0	+21.3

*Intermediate size car - 4,000 lbs.

Does not include energy absorber.

TABLE C-9. GRILLE AND HEADLAMP HOUSING COMPARISON

Zinc Die Casting					
Radiator Grille	5.70	6.77	12.47	289.0	12.0
Headlamp Housing R & LH	6.78	2.54	9.32	232.2	16.0
TOTAL ZINC DIE CASTING	12.48[1]	9.31	21.79	521.2	28.0
ABS[2] Casting					
Radiator Grille	2.78	1.42	4.20	279.0	5.5
Headlamp Housing R & LH	1.05	2.75	3.80	263.0	4.0
TOTAL ABS	3.83	4.17	8.00	542.0	9.5
Comparison - Zinc Die Casting Less ABS Casting	+8.65	+5.14	+13.79	-20.8	+18.5

(1) Average cost per pound of $0.446 includes all scrap, sprues, finishes, etc.

(2) ABS = Acrylonitrite - Butadiene - Styrene

APPENDIX D

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