SUBCOMPACT CAR CRASHWORTHINESS

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Design modifications were made and tested on 1974 Pintos so that the crashworthiness of the subcompact car could be improved. These modifications consisted of replacing the sheet metal with bulk structure, i.e., foam-filled (stabilized) sheet metal, and of altering the passenger compartment configuration. The effective safe barrier equivalent velocity of the modified vehicle in conjunction with an advanced airbag restraint was found to be approximately 50 mph (80 km/h) in head-on and angled-barrier crashes and in two-car angular and offset collisions. The result of this study has been to provisionally establish the prototype feasibility of meeting the proposed 1979 Federal Motor Vehicle Safety Standard 208 amendments requiring 45 to 50-mph (72 to 80-km/h) barrier equivalent velocity frontal crash protection with a subcompact car.

•THE phenomenal growth rate of the subcompact class of automobiles indicates that it will represent as much as 40 percent of the U.S. vehicle population by 1990 (1). This projected increase, along with the actual growth in the number of subcompact cars, has resulted in much attention being focused on the safety problems of this vehicle class. Identifying and correcting some of those problems were the objectives of the Minicar, Inc., contract to the National Highway Traffic Safety Administration (NHTSA) (2). The results of this effort to September 1974, which are described in this paper, may be found in a more detailed form elsewhere (3).

The dramatic increase in the subcompact car population will result in their being more frequently involved in accidents than they are currently. In trying to help mitigate the deaths and injuries that will result from these accidents, decisions must be made on which of the accident modes is most common and costly, and, then, proportionate efforts should be expended for improving the crashworthiness of those modes. As shown in Figure 1, the 1972 societal cost of frontal offset and angular impacts is greater (because they are more frequent and severe) than that of pure frontal impacts and should, therefore, be given priority (4, 5).

A large share of those costs is due to vehicle-to-vehicle accidents that are not closely simulated by the barrier tests often used in validating past structural improvements (6). Unfortunately, Federal Motor Vehicle Safety Standard 208 also focuses attention on barrier crash tests. To ameliorate this problem, we tried to take the two-car real-world accident compatibility problem into consideration in the program to improve subcompact car crashworthiness. In particular, we found that the relationship between frontal structure improvements and consideration for protecting occupants of vehicles struck in the side has not received sufficient attention. Minicars, Inc., studies (7) show that there may be a need to adjust the optimal force-deflection characteristics of the structure for a frontal impact so that its intrusion on the impacted car in front-to-side impacts can be limited.

As a result, a ramped crush characteristic has been derived that is acceptable for all accident modes, although not ideal for any. In 50-mph (80-km/h) frontal barrier impacts, it results in a total crush of about 37 in. (94 cm) with less than 2 in. (5 cm) A post intrusion (to guarantee occupant living space). In angular or offset impacts, because only a portion of the structure is involved, the total crush is about 54 in. (137 cm). These force-deflection characteristics allow the impacting vehicle in a two-car front-to-side impact to take most of the crush and thereby minimize the intrusion in the side-impacted car.

These crush characteristics are not ideal from the restraint point of view either

(8) because they result in less occupant ride down and, therefore, require more occupant interior stroke at a given velocity. In future programs, a further compromise between an optimum restraint pulse and the derived structural characteristics should be effected by trading off interior occupant stroke against frontal crush distance. However, the ideal frontal crush pulse, the available occupant interior stroke, the acceptable intrusion, and so on are all peripheral to the real problem to minimize occupant injuries in all real-world impacts.

In this program, as in the past, the solution to this problem was considered to be separable into structural and restraint approaches. Structural performance was judged on crash deceleration pulse and intrusion; occupant packaging was judged on pulse and resulting dummy injury criteria. Because these criteria could not be adequately related to the injuries in real-world accidents, the structural and restraint areas have not been integrated for high-velocity performance.

There are many schools of thought regarding the relationship between accident injuries and dummy injury measures. Results of tests in which unrestrained cadavers and dummies impact interior vehicle padding and plastic laminate glass, supported by Minicars' computer evaluations, indicate that a relationship exists between the abbreviated injury scale (AIS) and dummy chest severity index (CSI) such as shown in Figure 2 (9). A suggested combination of the head injury criteria (HIC) and CSI injury levels can be based on the findings of Baker, O'Neill, Haddon, and Long (10). On the other hand, in accordance with Tarriere, Fayon, and Walfisch (11) and Warner et al. (12), when the occupant is decelerated at a particular g level, the chest injury level resulting from belts may be more represented by the upper bounds of the curves, and airbag restraints may be closely related to the performance indicated by the lower bounds. Therefore, for a clear understanding of how to solve the real problem, these relationships must be more adequately treated.

Currently lacking this capability, we have used estimates of the societal cost as a function of velocity for various impact modes (Figure 3) to assess the value of a particular structural or restraint system alternative (4). This was done by determining the effective safe velocity performance of the existing structural system with the best available restraint, and, then, by estimating the portion of the societal costs (the benefits) that would be eliminated.

Through a series of baseline car crash tests, the effective safe velocity of the unmodified Pinto was established in various impact directions (assuming an advanced airbag restraint), and the portion of the societal cost eliminated was compared to the societal cost in 1975 from Figure 1, as shown in Figure 4. This indicates that baseline structure with an advanced restraint could only accrue perhaps 30 percent of the societal benefit possible.

For achievement of a greater portion of the societal savings, the effective safe velocity goals for the project became 50 mph (80 km/h) for frontal, 100 mph (161 km/h) for front-to-front, 40 mph (64 km/h) for frontal pole, 40 mph (64 km/h) for side-structure [20-mph (32-km/h) barrier equivalent velocity], 60 mph (97 km/h) for rear [30-mph (48-km/h) barrier equivalent velocity], and 10 mph (16 km/h) for low-speed impacts. The weight, cost, length, and producibility of the vehicle were to be virtually unchanged (i.e., within about 5 percent of baseline). The simultaneous development of a driver passive restraint was undertaken, and these programs were to be combined at some later date; eventually the driver would be protected at the highest velocity with the best benefit-cost ratio possible (8).

The overall force-deflection characteristics of the baseline car and the desirable modifications were determined by use of various computer models and static crush test data for eight elements of the front end such as shown in Figure 5 (13). Various potential energy management techniques were investigated in addition to the originally proposed foam-filled (stabilized) sheet metal approach. Among the alternative concepts were collapsible tube structures. The failure characteristics of the collapsible tube structures proved to be highly susceptible to loading anomalies (resulting in buckling) even in the frontal mode, and their potential for adequately handling the angular impacts was extremely limited. The uniaxial structure was quickly abandoned in favor of the original concept of an omnidirectional, foam-filled bulk structure.

Figure 1. Estimated 1972 societal cost of subcompact car injuries.

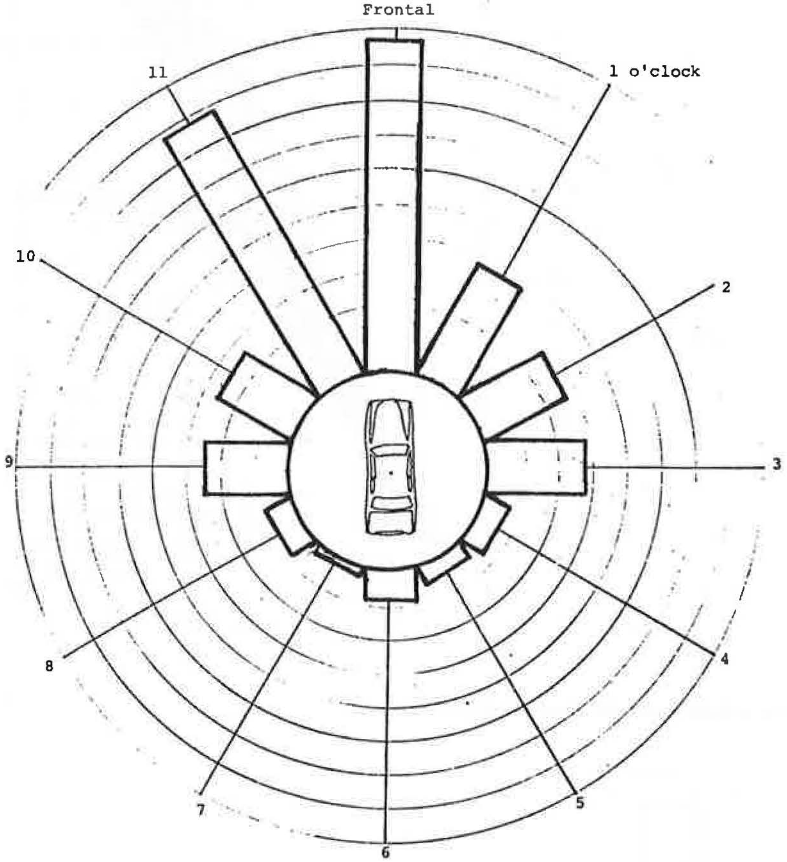


Figure 2. Relationship between chest severity index and abbreviated injury scale level.

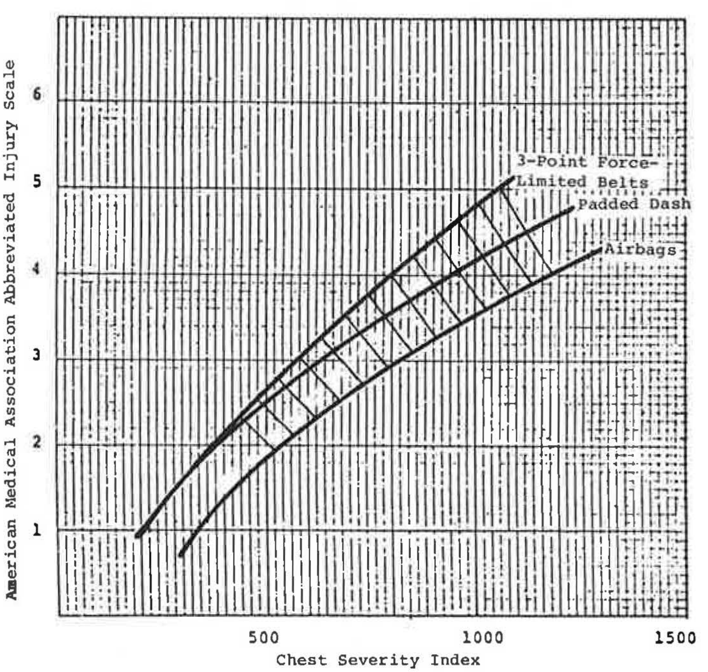


Figure 3. Cumulative 1972 societal costs for various types of vehicle involvement for all vehicles.

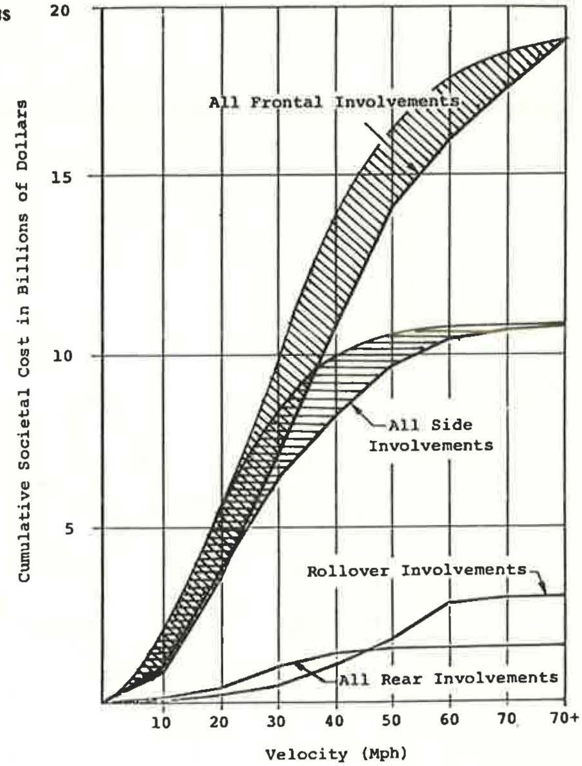
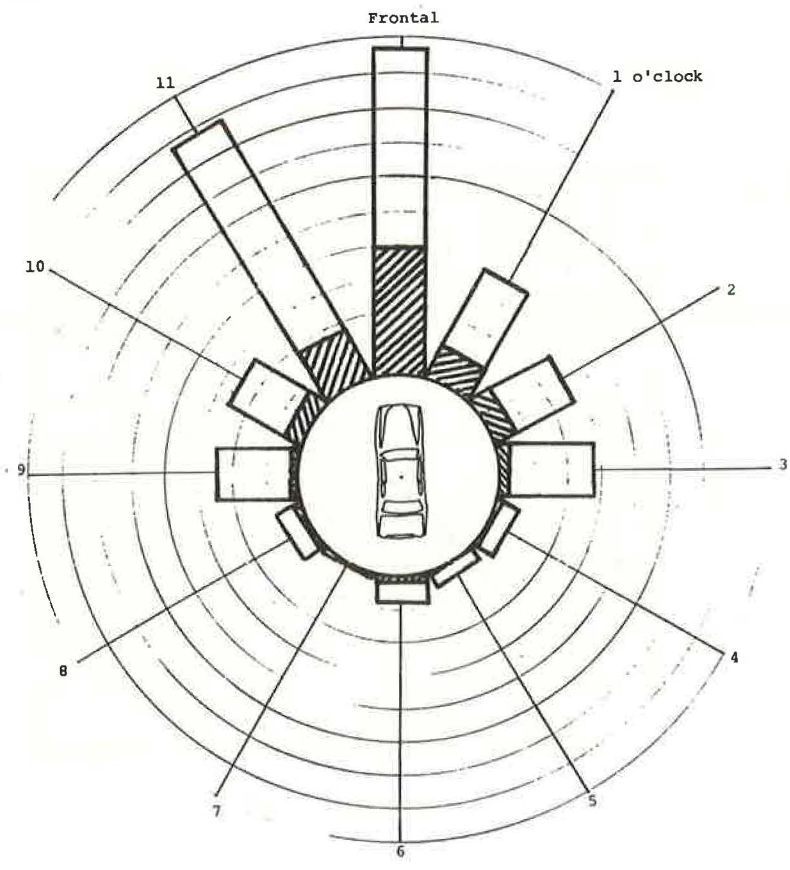


Figure 4. Savings from baseline structure with advanced restraints relative to societal cost.



One possibility for attaining the desired frontal performance was to simply foam fill the fenders and slightly modify the lower frame members and firewall. Three potential problems, however, kept this approach from being used:

1. The baseline vehicle exhibited excessive pitch that was felt to significantly affect the restraint performance during barrier impact ranging from 14 to 34 deg,
2. The side-impact protection required raising and reinforcing the sill structure to limit intrusion, and
3. The baseline structure exhibited substantially poorer performance in the angular mode than could be expected to be corrected by this simple approach.

To reduce the pitch, modifications of the force-deflection characteristics were made so that more energy was absorbed above the center of gravity and less below; in other words, the lower structure was weakened and the upper structure was strengthened. Pulse shaping further required an important reduction in the engine-firewall, force-deflection characteristics.

Improvement of side-impact performance required that the sills be raised for better alignment with impact bumpers. It was also felt that restraint performance could be enhanced by increasing the available interior stroke of the occupant before he or she struck the windshield in the frontal mode. So that both goals could best be accomplished, the body was raised relative to the running gear by 6 in. (15 cm). This was accomplished by removing the vehicle floor and replacing it with a new sheet metal section containing footwells, an enlarged tunnel, and two transverse cross members, one under the seat and one at the B post. The aft portion of the subframe member was reattached to the new floor, which, when combined with larger rear suspension hangers, resulted in raising the body (Figure 6).

The driver seating position in the car is assumed to be fixed with movable controls but is adjustable vertically so that, in conjunction with the sloped hood, forward visibility is improved. Since the running gear and engine of the car are in stock positions, the center of gravity is only raised about 1½ in. (3.8 cm) so that an antisway (roll stabilizer) bar on the rear axle keeps handling virtually unaffected. The raised body created a 6-in.-thick (15-cm) hood section over the engine and left the engine in a position that allows it to translate into the enlarged tunnel during impact. A breakaway (sliding section) drive shaft and breakaway engine cross member assembly made it possible to reduce the lower structure force-displacement level.

An equivalent amount of force was introduced into the upper structure by mounting a 6-in.-thick (15-cm) foam-filled, sheet metal hood. This was designed to cover both the original engine compartment area and the upper fender sections that were now 6 in. (15 cm) thicker than before. The design provides a monolithic section the width of the car with omnidirectional capability to load the firewall, A post, and plenum areas and to complement the lower structure in restricting pitch and resisting intrusion in angular impacts.

For an increase in the force early in the frontal impact and for support of the 10-mph (16-km/h), 6-in. (15-cm) stroke frictional energy-absorbing (E-A) bumper mounts, the original frame forward of the cross member was replaced by 0.083-in. (0.211-cm) notched-steel, 2 by 4-in. (5 by 10-cm) tubing. The fender aprons were replaced by foam-filled sheet metal sections that add support to the frames. The bumper is made of two 3 by 3 by 0.375-in. (7.6 by 7.6 by 0.953-cm) wall-welded and heat-treated aluminum tubes mounted to the E-A units. So that the forces produced during asymmetrical loading (angular and offset collisions) could be increased, the outer fender volume forward of the wheels was also filled with a foamed box.

The doors were modified to include a tubular compression strut from the upper hinge to the latch plate on the B post. This would allow the maximum frontal stroke possible in angular impacts at the target velocity and still provide support to the A post. The foam-filled transverse members and enlarged sill area were augmented by providing a larger section, load-distributing, foam-filled lower door structure for resisting pole impacts.

The rear structure required only the replacement of the lower floor with double-

Figure 5. Force-displacement curves for 1974 Pinto.

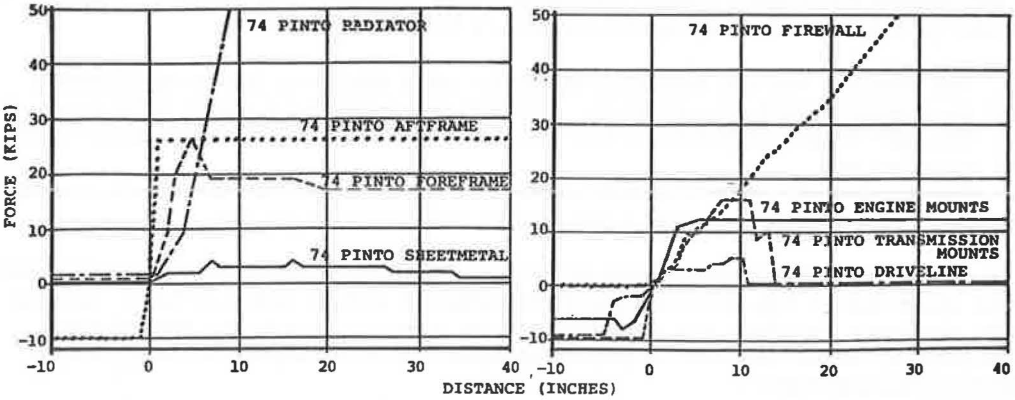


Figure 6. All subcompact car design modifications.

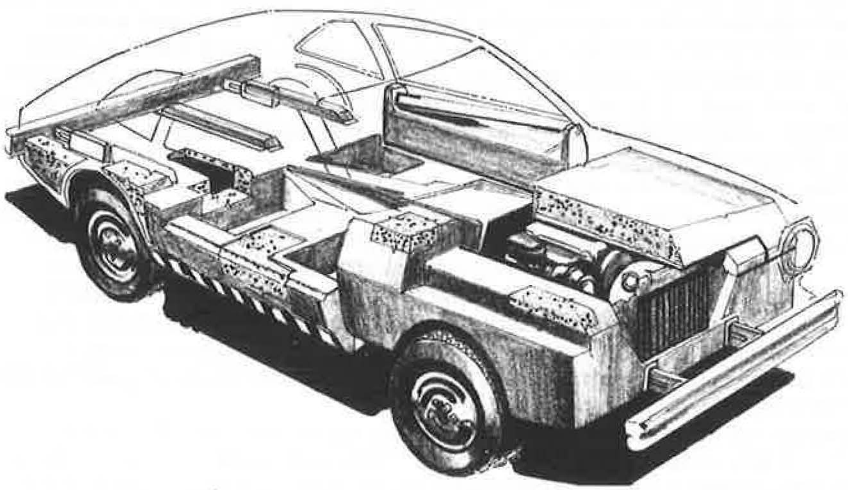
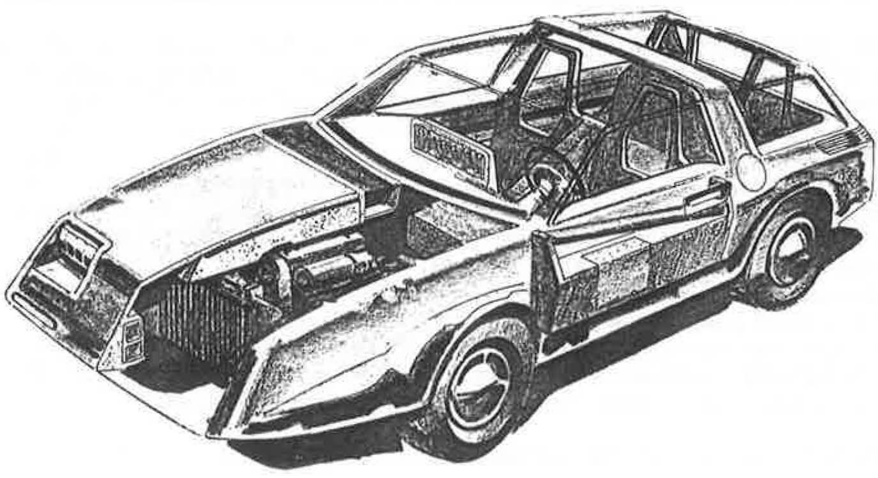


Figure 7. Final styling configuration.



walled, form-filled sheet metal about 3 in. (7.6 cm) thick with three enlarged longitudinal box sections abutting the transverse rear cross member. The rear quarter panels were enclosed and foam filled.

In an effort to mitigate injuries to pedestrians that account for about 10,000 fatalities and 330,000 injuries each year, the vehicle-to-vehicle impact structure was intentionally recessed relative to the exterior surface. This design allows a 2-in.-thick (5-cm) plastic section to provide a resilient surface for pedestrian strikes. The final styling configuration adjusts the front end shape for this purpose but incorporates the same structural modifications as shown in Figure 7.

The front and side modifications resulted in a net increase in weight of 39 lb (18 kg) over the baseline car in the same state of trim. On the other hand, the costs due to the use of 151 lb (69 kg) of aluminum in the bumper and sheet metal sections plus some 67 lb (30 kg) of foam amount to an estimated increased cost of $213.60 to the consumer for a further developed and production-engineered version. Uncertainties in cost estimating suggested a range of cost from $200 to $400.

The results are shown in Figure 8. The additional societal benefits resulting from the revised performance are shown by the striped area and represent the improvement over the baseline vehicle performance shown in Figure 3.

To ascertain the benefit-cost ratio of these modifications, one had to assess the consumer cost of the restraints. The driver airbag restraint was estimated to add 30 lb (14 kg) with a consumer cost of $63.90; however, the front passenger airbag, because of common elements, would add only 23.5 lb (10.7 kg) and would cost the consumer $31.40. Consumer cost, then, is 53.5 lb (24.3 kg) and $79.30, less the existing interlock, inertia reels, and three-point harness weighing 13.6 lb (6.2 kg) and costing $28; therefore, there is a net increase of 39.9 lb (18.1 kg) and $51.30. Because of manufacturing cost uncertainties, we assumed a range of cost from $50 to $200.

The benefit-cost ratio was calculated by dividing the societal benefits by the estimated costs for the restraints in an unmodified structure and in the front- and side-modified structure. Figure 9 shows that benefit-cost ratios of near four are likely, in spite of differences in estimated cost. By using this same procedure, we determined that the rear-end structure modification would not produce a comparable benefit-cost ratio to front and side modifications. The limited rear seat occupancy lowers the societal benefits to be accrued in that mode.

In conclusion, one can say that this structural program and its restraint counterpart have demonstrated, from a preprototype point of view, that, with little sacrifice in cost, weight, or marketable features, the subcompact car can be designed to meet the proposed 1979 modification of Federal Motor Vehicle Safety Standard 208 (14).

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Figure 8. Estimated savings from modified-structural and advanced-restraint performance relative to societal cost.

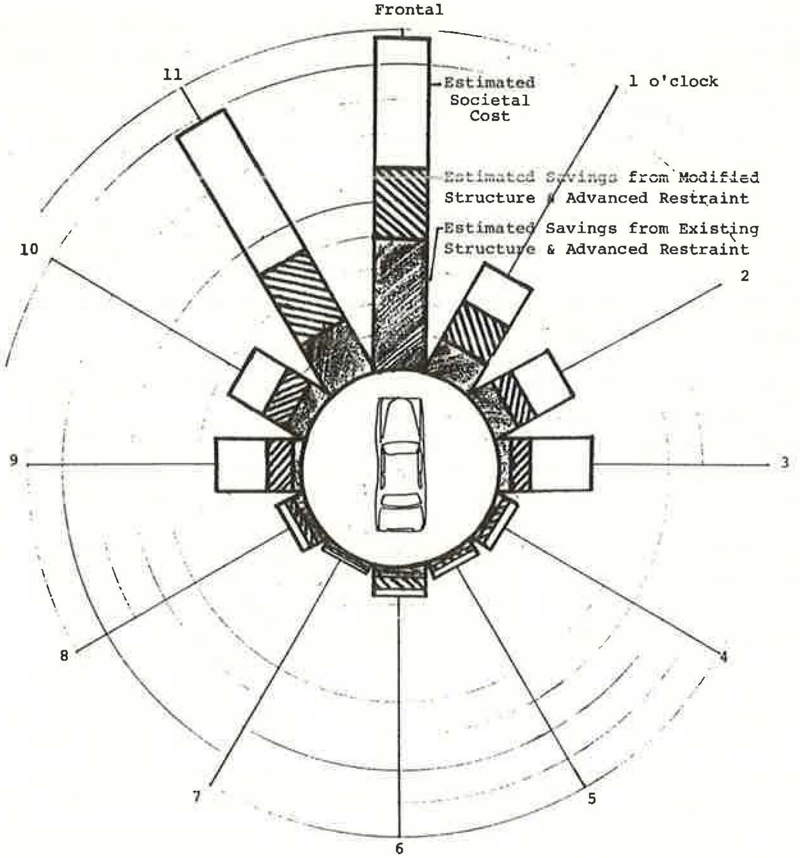
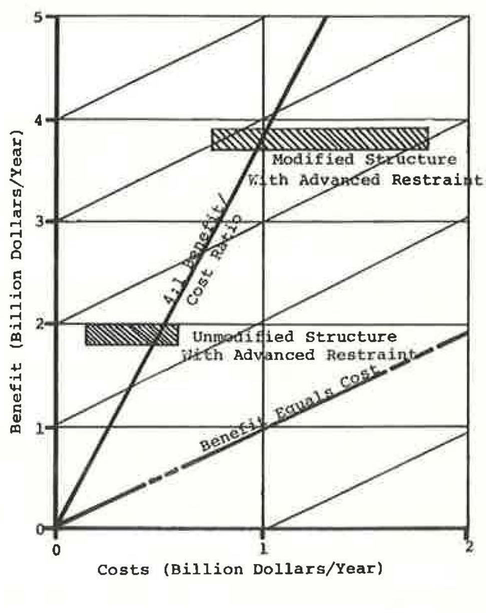


Figure 9. Benefit-cost ratio of subcompact modifications.



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