Interventions to Reduce Risks Associated With Vehicle Incompatibility

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Accepted for publication July 18, 2011.

Occupants of smaller, lighter passenger cars are more likely to be killed or injured in collisions with larger, heavier sport utility vehicles and light trucks than in collisions with other cars. Interventions are needed to reduce this vehicle “incompatibility” and its consequences. The authors conducted a systematic literature review to identify evaluations of interventions to reduce incompatibility. They reviewed engineering, biomedical, and other technical literature. To be included, a study must have 1) evaluated an intervention to reduce vehicle incompatibility, or its consequences, in a crash; 2) reported new research; and 3) been published in English from 1990 to 2010. Seventeen studies met the inclusion criteria. Interventions were designed to reduce the aggressivity of larger vehicles or improve the crashworthiness of smaller vehicles. Effective interventions included 1) modified bumper heights, 2) improved side strength of smaller vehicles, 3) side-impact air bags, 4) changes to vehicle stiffness, and 5) modifications of other front-end structures. Some of the interventions shown to be effective are now in wide use. However, others have yet to be required by regulators or voluntarily agreed to by manufacturers. If larger, heavier vehicles remain on the nation’s roads, countermeasures will be needed to reduce risks for occupants of other vehicles.

accidents, traffic; evaluation studies as topic; motor vehicles; wounds and injuries

Abbreviations: FMVSS, Federal Motor Vehicle Safety Standard; IIHS, Insurance Institute for Highway Safety; LTV, light truck vehicle; NHTSA, National Highway Traffic Safety Administration; SUV, sport utility vehicle.

INTRODUCTION

There were 33,808 motor vehicle crash deaths and more than 2.2 million injuries in the United States in 2009. Of the fatalities, approximately 13,000 were occupants of passenger cars and another 10,000 were occupants of light truck vehicles (LTVs), including pickup trucks, vans, and sport utility vehicles (SUVs) (1). Of 11,458 occupants killed in 2-vehicle crashes in 2009, 1,675 persons were killed in crashes between cars and other cars; 3,717 persons were killed in crashes involving cars and LTVs, and 2,929 of them were occupants of the car (1). Collisions with large trucks (e.g., large commercial vehicles) are even more risky for occupants of passenger cars. Of 1,040 occupant death cases in crashes between large trucks and passenger cars, 1,022 involved occupants of the car (1).

Crash incompatibility can be defined as “design differences between vehicle types which result in disproportionate damage patterns to the vehicles involved in a collision” (2, p. 761). Over the past 30 years, the crash incompatibility of vehicles has represented an increasing threat to the public’s health. Since the 1970s, the number of LTVs in the United States has risen dramatically. This increase means that, in any given crash, the possibility that vehicles of different sizes and shapes will be involved is greater than ever. This increase in LTVs has largely been driven by the growth in popularity of SUVs. SUVs represented just 1% of new vehicle sales in 1970, but this figure had grown to 31.5% by 2010 (3, 4).

These changes in the US vehicle fleet are of particular public health concern because of the “aggressivity”—or risk that a vehicle poses to occupants of other vehicles in a collision—of LTVs relative to that of other vehicles. For example, in an analysis of collisions involving fatalities in 2002, the National Highway Traffic Safety Administration (NHTSA) found that, in head-to-head collisions between cars and light trucks, the occupants of the car were 3.3 times more likely to die than the occupants of the LTV (5). When an LTV struck the side of the car, its occupants were 20.8 times more likely to die than the LTV occupants (5).
Many design factors can contribute to crash incompatibility. Vehicle mass, geometry (especially the height of the vehicle’s bumper and frame), and stiffness appear to have particularly important effects on crash incompatibility (2, 6). Initially, incompatibility research primarily focused on the effect of vehicle mass on injury risk (3). As early as the late 1960s, crash testing performed by the National Highway Safety Bureau (now NHTSA) identified disproportionate safety risks to occupants of very light passenger cars in collisions with heavier cars (7). Likewise, early epidemiologic analyses suggested a higher fatality risk for occupants of smaller, lighter cars (8, 9).

Although mass continues to be recognized as an important factor in vehicle compatibility, much of the more recent incompatibility research has focused on vehicle geometry. When the energy-absorbing structures (such as the bumpers) of colliding vehicles match up, the occupants are more protected than if these structures are overridden or underridden (3). For example, a 2003 analysis of crash fatality data conducted by NHTSA found that the driver of a passenger car struck by a tall SUV on the driver's-side door was 2.4 times more likely to die than if struck by a car that was the same weight as the SUV (6).

Vehicle stiffness also contributes to crash incompatibility. Theoretically, vehicles are less aggressive if they have less total front-end rigidity, making them more likely to safely absorb some of the energy of the impact and less likely to intrude into the occupant compartment of the struck vehicle (10). Vehicle stiffness relates to the injury potential of collisions differently depending on the size of the vehicle. Increasing the stiffness of larger cars, such as LTVs, may increase the aggressivity of those vehicles, whereas increasing the stiffness of smaller cars may improve their crashworthiness in collisions with larger vehicles (11, 12).

To identify research evaluating interventions for incompatibility, we conducted a systematic literature review. We were particularly interested in 1) the range and effectiveness of interventions available to motor vehicle makers to address crash incompatibility; 2) methods and disciplines represented in the interventions available to motor vehicle makers to address crash incompatibility; 3) aspects of the feasibility of the interventions, including cost and consumer acceptance; and 4) whether the interventions were (or were not) already required for most vehicles (and when).

METHODS

Search strategy

We used 2 primary methods to identify potentially relevant research: 1) searches of electronic databases and 2) examination of the references in identified articles. Databases we searched were PubMed, Society of Automotive Engineers technical papers, Transportation Research Information Service (now combined into the TRID database of the Transportation Research Board), National Technical Information Service, and Google Scholar. These databases were chosen to reflect the biomedical, engineering, and epidemiologic literature. Search terms, in various combinations, included the following: accident, car, SUV, truck, LTV, motor vehicle, crash, collision, (in)compatibility, aggressivity, mismatch, mass, rigidity, stiffness, and geometry. Abstracts of all articles were examined, and full texts of potentially relevant articles were then reviewed. Searches were conducted in 2009 and 2010 and cover articles published in English through December 2010. Peer-reviewed journal articles, government reports, and privately published research were all eligible for inclusion.

Inclusion criteria

To be included in the primary portion of our review, articles had to report new research or reanalyze existing data. Review articles, opinion pieces, or purely policy analyses were excluded. In addition, articles must have evaluated the effects of some intervention to reduce incompatibility, not simply address risk factors for injury risk or examine interventions not specifically associated with reducing incompatibility. For example, seat belts and frontal air bags are already well known to reduce death rates in crashes. We did not, however, limit the nature of the outcome measure studied. For example, crash forces, compartment intrusion, or death rates were all acceptable outcomes.

We also determined that included studies must have focused on interventions intended to reduce risk of injury given that a crash has occurred, not those solely intended to prevent crashes from occurring (i.e., electronic stability control systems or antilock brakes). However, we excluded evaluations of interventions primarily intended to reduce injuries in single-vehicle collisions, such as strengthening vehicle roofs to prevent injury in rollover crashes.

We also excluded articles that solely examined the effects of vehicle mass—a well-known contributor to crash risk—preferring to focus on potentially modifiable aspects of vehicle geometry and stiffness. This focus reflects our belief that, at least for the foreseeable future, heavier vehicles are likely to remain on the nation’s roads together with lighter ones.

We focused our search on articles published from 1990 to 2010. Articles published in the last 20 years, compared with older articles, are more likely to represent issues and interventions relevant to the mix of vehicles in today’s fleet. Information in pre-1990 articles was incorporated into background and discussion sections as appropriate.

Analysis

Each article that potentially met our inclusion criteria was reviewed by at least 2 authors. Disagreements regarding inclusion or exclusion of specific articles were resolved by discussion and consensus.

To address our questions of interest, information in articles was abstracted to identify 1) the nature and effectiveness of the intervention(s) studied, 2) methods used, 3) outcome measures examined, 4) considerations of intervention feasibility, and 5) a summary of findings. Given the wide variation in methods and outcomes, no meta-analysis was possible or appropriate.

We also reviewed the history of regulatory and formal, voluntary manufacturer agreements to reduce incompatibility to determine which of the interventions were likely to be in wide use on most vehicles. Information in this review was...
abstracted from a variety of sources including federal regulations, automotive safety group materials, and government documents.

RESULTS

Included articles

Among hundreds of articles initially uncovered in our database and reference search, 17 met all of our inclusion criteria (Table 1) (10–26). The articles appeared in the engineering, biomedical, and government technical literature. We characterized the primary methods used as epidemiologic analyses of real-world crashes (2 studies), crash testing/computer modeling of crashes (14 studies), or both (1 study). Twelve other studies examined issues of risks associated with vehicle incompatibility and recommended certain interventions, but they did not directly evaluate those interventions (2, 6, 27–36).

Interventions

We first divided the interventions addressed in the 17 articles into 2 primary categories: 1) those intended to reduce the aggressivity of the larger vehicle and 2) those intended to improve the crashworthiness of the smaller vehicle. Ten articles fit the first category, 5 articles addressed the second category, and 2 articles included interventions in both groups.

The interventions included improving the side strength of the smaller vehicle (2 studies); reducing the stiffness of the larger vehicle or increasing the stiffness of the smaller vehicle (7 studies); 3) improving the compatibility of bumper heights in crashes, generally by lowering the bumper of the larger vehicle (3 studies); modifying other front-end structures to improve compatibility (10 studies); and including side-impact air bags to improve the crashworthiness of smaller vehicles (1 study). Several articles included more than one evaluated intervention.

Effectiveness of interventions

The included studies identify many different effective interventions to reduce crash incompatibility (Table 1). On the basis of the articles’ publication dates, manufacturers knew about many of the interventions well before some were implemented on motor vehicles either through NHTSA regulation or via voluntary agreements by car makers (refer to the next section of this review), although manufacturers may need time to adapt technologies to their own vehicles.

Modifying bumper heights of LTVs to improve compatibility was associated with reductions in cabin intrusion (17, 23) and forces measured on test dummies (24, 25). These changes were also associated with reductions in fatality risk in real-world crashes (13).

Various strategies to redesign the front-end structure of larger vehicles were also associated with improved compatibility, including reductions in crash forces (14, 16), compartment intrusion (10, 19), and test dummy injury measures (11, 24, 25). For example, designing front-end structures to better absorb crash forces, increasing bumper bending strength, or adding subframe components to improve structural interaction were all found to improve compatibility (10, 14, 19, 24). Modifying the front end of smaller vehicles to better withstand crash forces is also possible (10, 21).

Modifying the stiffness of the (larger) striking vehicle can reduce risks to occupants of the struck vehicle (25). In an analysis of computer crash simulation data, Kuchar (22) concluded that a 15% reduction in the stiffness of LTVs reduced deceleration forces in the struck car and would reduce injury rates. Improving the side strength and/or stiffness of smaller vehicles reduced test dummy forces (11, 20) and deformation patterns (12, 26) in the struck vehicle.

Side-impact air bags with head protection reduced the risk of death for the occupants of a passenger car in a collision with an LTV by 46%; torso-only side air bags also reduce risk (25%) (15). Other research has also demonstrated the life-saving potential of side air bags (37).

Major regulatory activity by NHTSA or voluntary agreements by manufacturers

Although articles that present only policy discussions were not included in the primary portion of this review, it is important to note that the evaluated interventions exist within a regulatory context that includes both government and industry policies aimed at reducing incompatibility or its consequences. These policies may affect the feasibility of implementing these interventions on a broad scale.

NHTSA regulation regarding incompatibility is addressed primarily through efforts to improve side-impact protection and consider issues regarding bumper height. Of course, other standards that address crashworthiness generally, such as those mandating head restraints or fire-resistant fuel systems, would also help to ameliorate the consequences of incompatibility.

Figure 1 provides a timeline of major regulatory standards and voluntary agreements to reduce risks associated with vehicle incompatibility through improvements in side-impact protection and bumper height. Federal Motor Vehicle Safety Standard (FMVSS) 214, first implemented in 1973, initially required a static side-impact test. In 1990, FMVSS 214 was amended to require a test with a movable, deformable barrier. Compliance with the new standard was phased in from 1994 to 1997, but neither version of the standard was specifically intended to address compatibility issues.

In 2003, the Insurance Institute for Highway Safety (IIHS) and major motor vehicle manufacturers formed a voluntary working group to address compatibility issues, including side-impact protection (38, 39). That same year, IIHS introduced a new side-impact crashworthiness evaluation program that included a crash test intended to simulate a collision with an SUV or light truck (40). The program yielded a voluntary industry agreement that, by 2008, at least half of new passenger vehicles would meet the standards associated with either a new IIHS side-impact test (to reduce head injury) or NHTSA’s updated 2007 side-impact collision standard (39). NHTSA’s changes to FMVSS 214 now require a test meant to simulate a collision with a pole (41). This performance standard measures forces exerted, in part, on the heads of instrumented dummies. Manufacturers have met this...
performance standard, phased in from 2009 to 2012, by providing side-impact air bags.

NHTSA’s bumper height standard, initially designated as FMVSS 215, was first implemented in 1972 and was intended primarily to protect passenger vehicles (rather than their passengers) from damage (42). In 1982, the standard (today designated as Part 581) was amended to include a testing regime that had the effect of requiring bumper heights for passenger cars to range from 16 to 20 inches (40.6–50.8 cm) (43). Despite research indicating that bumper mismatch between passenger vehicles and LTVs remains a problem, NHTSA has declined to adopt a bumper standard applicable to LTVs (42). Most recently petitioned by IIHS in 2008, NHTSA has received comments on a bumper proposal (42). Nevertheless, as part of a voluntary agreement, major motor vehicle manufacturers agreed that, by 2010, the bumpers of all LTVs would have at least 50% overlap with passenger cars, or, if not feasible, secondary energy absorbing structures would be installed on the LTV to interact with the cars’ bumpers in a crash (39). Neither NHTSA regulations nor voluntary

Table 1. Summary of 17 Studies Meeting Inclusion Criteria, United States, 1990–2010

<table>
<thead>
<tr>
<th>First Author, Year (Reference No.)</th>
<th>Intervention Applies to</th>
<th>Method*</th>
<th>Brief Summary of Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baker, 2008 (13)</td>
<td>Bumper/front-end height</td>
<td>X</td>
<td>Estimated a 19% fatality risk reduction for drivers of cars struck by SUVs or pickup trucks with lower front-end structures (meeting voluntary standards) compared with higher front-end structures.</td>
</tr>
<tr>
<td>Hasegawa, 2007 (14)</td>
<td>Other front-end structures</td>
<td>X</td>
<td>Compatibility between SUVs and passenger cars in offset front-end crashes can be improved by increasing the bumper bending strength of vehicles. In crash tests, doing so increased structural interaction of vehicle front ends and decreased front-end bypass from 60% to 30%.</td>
</tr>
<tr>
<td>McCartt, 2007 (15)</td>
<td>Side air bags</td>
<td>X</td>
<td>Side air bags with head protection and without head protection in cars reduced the risk of death by 46% and 25%, respectively, in side-impact crashes where the striking vehicle was an SUV or pickup truck.</td>
</tr>
<tr>
<td>Ostrowski, 2007 (16)</td>
<td>Other front-end structures, stiffness</td>
<td>X</td>
<td>Examined an “adaptive crashworthiness system” to adjust the front-end stiffness of a striking vehicle depending on crash circumstances. Deceleration graphs suggest that adaptive systems decrease aggressivity of striking vehicles without compromising self-protection.</td>
</tr>
<tr>
<td>Warner, 2007 (17)</td>
<td>Bumper/front-end height</td>
<td>X</td>
<td>In front-corner to side crash tests when the striking vehicle was an SUV and the struck vehicle was a passenger car, cabin intrusion was reduced when the SUV had an additional bumper below the original one.</td>
</tr>
<tr>
<td>Fujii, 2004 (19)</td>
<td>Other front-end structures</td>
<td>X</td>
<td>Crash simulations showed that modifying the front ends of larger vehicles can reduce aggressivity by increasing energy absorption in the engine compartment of smaller vehicles by as much as 30%.</td>
</tr>
<tr>
<td>Fujii, 2003 (18)</td>
<td>Other front-end structures</td>
<td>X</td>
<td>Extended subframe structures in larger cars reduced toe board and A-pillar intrusions into smaller vehicles in simulated crashes.</td>
</tr>
<tr>
<td>Hirayama, 2003 (10)</td>
<td>Other front-end structures</td>
<td>X</td>
<td>In crash tests between heavy and light cars, firewall intrusion was lower for those cars with a homogeneous front structure that was able to absorb impact from a variety of crash configurations.</td>
</tr>
<tr>
<td>Lemmen, 2003 (20)</td>
<td>Stiffness, side strength</td>
<td>X</td>
<td>Analyzed the performance of 4 vehicle models in simulated offset frontal collisions. Injury Severity Scores calculated from forces on test dummies in these collisions can be reduced by optimizing vehicle stiffness.</td>
</tr>
<tr>
<td>Salt, 2003 (21)</td>
<td>Other front-end structures</td>
<td>X</td>
<td>Evaluated a new front-end frame structure for small cars using frontal crash testing between small and large vehicles. Energy absorption in the passenger compartment was reduced by 30% in the small car with the new front-end structure; front pillar and dash panel deformation was also reduced by 85% and 40%, respectively.</td>
</tr>
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</table>

Table continues
agreements directly address other aspects of compatibility we address, including vehicle stiffness or front-end design.

**Feasibility of interventions**

Intervention feasibility is an important factor that influences the potential for an intervention to actually be implemented on motor vehicles and thus reduce incompatibility in the real world. However, the included studies provide little discussion of the barriers to implementation of interventions, including cost, consumer acceptance, or recognition of possible unintended consequences. Consumers demand a mix of different vehicles of varying sizes to meet different requirements. Changes to vehicles that dramatically reduce their utility may not be acceptable. For example, some have suggested that lowering the bumper height of LTVs might compromise off-road performance. However, many LTVs are never used off-road (or even have serious off-road capability) (44).

Unintended consequences of interventions to reduce aggressivity of LTVs might reduce the protection such vehicles provide to their own occupants. For example, reducing the stiffness of front-end structures of LTVs—unless the front

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**Table 1. Continued**

<table>
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<tr>
<th>First Author, Year (Reference No.)</th>
<th>Intervention Applies to</th>
<th>Method*</th>
<th>Brief Summary of Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kuchar, 2001 (22)</td>
<td>Stiffness</td>
<td>X</td>
<td>Computer modeling of frontal collisions of passenger cars and light trucks was validated against injury field data. Reduction of LTV stiffness by 15% through structural modifications, material selection, and geometry reduced peak deceleration forces in the stuck car from 41 G to 35 G and would reduce total injuries in these types of crashes.</td>
</tr>
<tr>
<td>Meyerson, 2001 (23)</td>
<td>Bumper/front-end height</td>
<td>X</td>
<td>In frontal offset crash tests with a Ford Taurus as the struck vehicle, intrusion was compared for a normal vs. a raised Isuzu Rodeo (low and stiff) and a normal vs. a lowered Mercedes ML320 (high and less stiff). Steering column rearward movement for the Taurus was 3–4 cm less in collisions with the lower SUV.</td>
</tr>
<tr>
<td>Nolan, 1999 (24)</td>
<td>Bumper/front-end height, other front-end structures</td>
<td>X</td>
<td>In side-impact tests with a range of striking vehicles, analyses of deformation patterns, test dummy injury measures, and other factors indicated that lowering the hood height of trucks increased compatibility.</td>
</tr>
<tr>
<td>Mizuno, 1998 (11)</td>
<td>Other front-end structures</td>
<td>Stiffness</td>
<td>Aggressivity of vehicles in Japan was calculated by using data from fatal collisions. In both frontal and side-impact crashes, SUVs and minicars were the most incompatible classes of vehicle. Simulations showed that either stiffening the minicar or adding additional crush space to the larger vehicle could reduce injuries, as measured by Head Injury Criteria; chest acceleration; chest deflection; and femur force to the driver dummy of the minicar.</td>
</tr>
<tr>
<td>Wykes, 1998 (25)</td>
<td>Other front-end structures, stiffness, bumper/front-end height</td>
<td>X</td>
<td>Examined the effect of vehicle geometry, mass, and stiffness, with modeling and crash testing data. Geometry outweighed the effects of mass and stiffness in frontal and side-impact collisions. Better structural interaction through factors such as ride height and uniform frontal stiffness can decrease injury potential as measured by chest injury criteria and peak chest compression on test dummies.</td>
</tr>
<tr>
<td>Niederer, 1995 (26)</td>
<td>Stiffness</td>
<td>X</td>
<td>Crash tests evaluated the safety and compatibility of ultrastiff, low-mass vehicles. Car vs. crash barrier deformation tests indicated that these vehicles can improve occupant protection and do not create excessive aggressivity when striking other vehicles.</td>
</tr>
<tr>
<td>Kaeser, 1994 (12)</td>
<td>Stiffness, side strength</td>
<td>X</td>
<td>Three frontal and one side barrier crash test were performed (commercial light car, reinforced version of the same car, and light car with “hard-shell” or fiberglass reinforcement of the car body). The “hard-shell” car body had less deformation and more energy absorption than the other designs, indicating improved safety in collisions with heavier cars.</td>
</tr>
</tbody>
</table>

Abbreviations: LTV, light truck vehicle; SUV, sport utility vehicle.

* An X indicates that the method was used in the study.
end is lengthened—might increase the risk of occupant-compartment intrusion in the LTV.

**DISCUSSION**

Our review indicates that numerous interventions are potentially available to manufacturers to reduce risks associated with vehicle incompatibility. Many of these interventions have been known for many years. We were not, however, able to directly assess the many factors related to the feasibility of these interventions.

The majority of the included studies involved crash testing of vehicles or computer simulations of crashes. It is easier to control some of the many variables involved in motor vehicle crashes using these methods. However, interventions deemed effective in these settings do not always translate to real-world crashes. Future research should focus greater attention on epidemiologic analyses of real-world crashes to validate results found by using other methods. Such research often has the additional advantage of quantifying results in terms of lives saved or injuries averted rather than reductions in crash forces or centimeters of deformation. Health-related outcomes may be more compelling to policy makers and the public, who may need to advocate for widespread adoption of interventions. The quality of the existing epidemiologic studies was high, with appropriate study designs and analytic techniques. Studies utilizing computer simulation and crash test techniques varied greatly in their methods, making it difficult to assess overall study quality.

Most of the included studies focused on interventions applicable to the larger vehicle. Additional research intended to make smaller vehicles safer is also needed. Interestingly, some evidence suggests that risks associated with LTVs, particularly SUVs, in any given crash declined somewhat from 1990–1991 to 2000–2001. An IIHS analysis indicates that, after controlling for vehicle mass, the number of deaths to occupants of passenger cars struck by SUVs was higher in 1990–1991 than in 2000–2001 (38).

Nevertheless, the number of aggressive vehicles on US roads continues to pose a significant threat to the public’s health. However, only a few policy interventions aimed at reducing vehicle incompatibility have been implemented to date, most in the past few years (Figure 1). As of 2012, both LTVs and passenger cars must meet an improved side-impact strength standard. The practical effect of this performance standard is to place side-impact air bags on all new vehicles by model year 2012. In fact, prior to this date, motor vehicle manufacturers have already provided side-impact air bags on most vehicles. The current voluntary industry agreement may help to increase bumper height compatibility. Unlike NHTSA regulations, however, voluntary agreements can be abrogated by industry at any time.

Importantly, these new policies are largely designed to improve the safety of the struck vehicle rather than to reduce the aggressivity of the striking vehicle. Both approaches are necessary. One regulatory option that has been discussed, but not yet implemented, would involve limiting the minimum and maximum force a vehicle imparts in a crash test with a rigid wall. This option would force cars to become somewhat more rigid and LTVs to become less stiff.

In addition to regulation and voluntary agreements, litigation against motor vehicle manufacturers could be one
additional way to speed implementation of interventions to reduce incompatibility. Litigation can provide manufacturers with an economic incentive to make their products safer, especially when regulation is absent or inadequate (45). The US Supreme Court recently affirmed that simply meeting an existing federal safety standard will not insulate a motor vehicle manufacturer from liability for failure to exceed that standard, where doing so might be a reasonable way to enhance safety (46). The hallmarks of such product liability include the foreseeability of harm and the availability of alternative designs, a topic addressed by our review. To date, however, few such lawsuits have been brought against makers of LTVs (47).

Conducting studies and publicizing the results of analyses of the safety of vehicles and the availability of safety devices can also enable consumers to make more informed choices. Some manufacturers may respond to consumer demand by providing safety technology (e.g., side-impact air bags) before they are mandated to do so.

Other trends in the motor vehicle industry suggest that the issue of vehicle incompatibility is likely to remain an important safety concern. As fuel prices rise, pressure to make some vehicles smaller to improve fuel economy may grow. In fact, a number of so-called microcars have recently been introduced in both the United States and abroad. The crashworthiness of these vehicles has been questioned, especially in collisions with larger vehicles (48). As pressure to reduce carbon emissions associated with climate change increases, the proportion of these smaller vehicles on the road may increase. Efforts to increase the corporate average fuel economy standards for the nation’s vehicle fleets may also alter the mix of cars on the road. Although we did not consider weight reduction of vehicles in this review, using lighter-weight materials while maintaining vehicle size may reduce both aggressivity and fuel consumption.

If manufacturers continue to place both very large and much smaller vehicles on the nation’s roadways, crashes involving these vehicles—and resulting deaths and injuries—are inevitable (at least for now). Car makers, which profit from providing consumers with a mix of available vehicles, therefore have an obligation to implement feasible interventions to minimize risks associated with incompatibility. In addition, where voluntary action may not be adequate, regulators also have an obligation to protect the nation’s motor vehicle users.

ACKNOWLEDGMENTS

Author affiliations: Johns Hopkins Center for Injury Research and Policy, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland (Jon S. Vernick); Department of Health Policy and Management, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland (Gregory Tung); and Unit of Social, Statistical, and Environmental Sciences, RTI International, Washington, DC (Jonathan N. Kromm).

This review was supported by grant 5R49CE001507 from the Centers for Disease Control and Prevention. Its contents are solely the responsibility of the authors and do not necessarily reflect the official views of the Centers for Disease Control and Prevention.

Conflict of interest: none declared.

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