

Design Tradeoffs: The Social Costs of Vehicle Fire Protection

Robert R. Scheibe
GT Engineering

Tyler Scott
University of Washington

Leland E. Shields
Leland E. Shields, Inc

Richard O. Zerbe
University of Washington

ABSTRACT

Rational design for fire safety necessarily includes consideration of risk tradeoffs that tend to reduce one risk but may increase another. Traditional engineering design criteria can be supplemented with important factors that rely on expertise from other disciplines. Engineering analysis may be able to address reduction in fire risk due to the introduction of new technology, but may not address the social costs associated with this new technology. For example, the resultant increase in vehicle cost may prevent some people from purchasing a vehicle (impacting individuals' lives), may reduce the number of vehicles sold (impacting manufacturers), and may reduce taxes collected (impacting the government). This must be weighed against decreased risk of property damage, injury, and fatality due to fire. In this paper, the methods of benefit-cost analysis from economics were applied to make this evaluation. Benefit-cost analysis facilitates the decision-making process by providing measures in monetary terms of the important costs (including social costs) and benefits as a common metric for comparing the options. Its use here is intended to demonstrate a means of encompassing all factors of importance to the design process. Because the use of monetary terms is rejected by some when associated with issues of vehicle safety, the appropriateness of the application of benefit-cost analysis is discussed along with methods of presenting results to address these concerns.

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INTRODUCTION

Though national estimates of fire-caused fatalities and injuries from vehicle collisions are relatively small compared to trauma-caused fatalities and injuries [1], considerable industry and governmental attention has been focused on the issue. Perhaps because injuries from fire are particularly alarming, the toll of their effects has focused automotive designers on finding reasonable solutions to reducing the propensity for fire and limiting its effects.

The challenge with any design decision is to satisfy a goal or produce a "benefit" while keeping the "cost" of that solution within the realm of acceptance. Many of these benefits and costs are difficult to measure and evaluate. Traditional studies have considered benefits that may include

a reduction in injuries, fatalities, or property damage. Costs may include the direct financial burden of design implementation or the cost of possible reduction in product utility or adverse consequences from the design change.

Techniques to evaluate the trade-offs in automotive fire safety design improvements have been the subject of previous studies. NHTSA has used techniques for evaluating cost effectiveness of fire countermeasures for possible rulemaking decisions [2]. For non-crash, injury related cases, the cost of a design change was compared with the benefit of estimated injury reduction, where injury reduction was assigned a monetary value. Additionally, for crash cases involving injury, the FMVSS 301 Upgrade [3] was evaluated by estimating the number of lives likely to be saved compared with the manufacturing cost to implement the design

modification. As an example, the “cost effectiveness” analysis projected costs between 1.96 and 5.13 million dollars per life saved by the upgrade to fuel tank integrity for rear impact performance, which was compared with a value of 3.7 million dollars per statistical life (for 2004 economics).

In Shields et al. [4], trade-offs between the benefits of passenger compartment fire retardant and the health risk from its use were examined. A method was presented for comparing the risk of fire injury or fatality (and the related benefit from reducing that risk) with the possible adverse toxicological consequences of a particular fire retardant. The study demonstrated that there are real, adverse health effects from the use of fire retardant, so the assessment of benefit must be considered in a comprehensive manner that considers both the cost and benefit. But the study highlighted the difficulty in quantitatively comparing cost and benefit terms from disparate points of view - those of toxicology and fire safety.

In this paper, an alternative means is presented for evaluating fire safety design decisions through an economic benefit-cost analysis. Such a technique has two advantages: it monetizes the quantification of benefits and costs, thus allowing direct comparisons, and it allows for all benefits and costs to be more broadly considered. Here, we present a framework for analyzing the benefits and costs associated with vehicle fire safety, with the intent of demonstrating how such a policy analysis might proceed. While the scope and goals of this paper preclude a highly detailed analysis, the methods presented herein serve as a theoretical basis for more complex analyses. Given sufficient data (or adequate resources for data collection), the policy analyst could readily expand this basic framework to include more subtle societal impacts such as the effect of fire reduction cost on the affordability of vehicles and the consequential effect it may have on jobs, access to employment, tax revenue, and a host of other factors.

FIRE SAFETY DESIGNS

Design changes to achieve fire safety benefits have frequently been presented in technical literature and some are already in use in certain applications. Though actual devices and designs are not the focus of this paper, they include three broad categories of designs: those which a) prevent or inhibit the initiation of fire, b) extinguish or suppress fire, or c) prevent or inhibit propagation of fire to the passenger compartment. They include such concepts as automatic electrical shutoffs to disconnect power from the battery in the event of collision, devices to interrupt fuel flow (either through electrical or mechanical means) in the event of collision or rollover, fuel tank filler neck designs that are less prone to fuel spillage in collisions, fuel tank placement and protection mechanisms that improve crashworthiness, active fire suppression devices to extinguish fires, and fire-suppressant materials under the hood [5].

Pre-engineered fire protection systems are commonly utilized in applications such as transit vehicles and armored

vehicles in combat environments. Hodges, in a 2006 paper [6], made the point that these systems are designed for specific and well-understood fire risks, that these risks have not been as well defined for passenger vehicles, and that no standardized threat scenarios and associated tests have been developed to evaluate interventions in passenger vehicles. The author [6] concluded that use of a fire protection system designed for one application may not be appropriate for another seemingly similar application. Of relevance to the current paper, it is necessary to consider trade-offs associated with the application of even existing technology to a new or extended usage.

SOCIETAL CONSEQUENCES

Some of the fundamental benefits of fire safety design improvements are obvious: a reduction in fatalities, injuries, and property damage. But the societal consequences - which could be benefits or costs - may be more subtle and abstract. Benefits of opting for safer designs may include a certain peace of mind - a willingness to pay for improvements that prevent a form of injury that is particularly disturbing. Fewer automotive fires may produce other consequential benefits including a reduction in medical costs and greater productivity.

Societal costs may include cascading effects from the higher financial cost of the improved design. Higher cost vehicles may reduce access to transportation for part of the population because purchasing a vehicle may become more difficult or impossible. Reduced access to vehicles may influence where people choose to live, what jobs they take, and what income they earn. The reduction in vehicle sales may have additional economic impact on national GDP and corporate profits that may affect the availability of jobs and the collection of government tax revenues.

SOCIAL BENEFIT-COST ANALYSIS

Because the study presented herein is intended only to explore and demonstrate a methodology to evaluate the benefits and costs of fire safety design improvements, the scope was reduced to simplify the analysis. This benefit-cost analysis will only consider benefit to the reduction in fire-caused fatalities. Non-fatal injuries and property damage from fire will not be directly addressed, though some of the design improvements may reduce the likelihood and/or severity of these consequences.

From a study of the National Fire Incident Reporting System (NFIRS) and the National Fire Protection Association (NFPA) conducted from 2003-2006, there were an estimated 240 deaths due to collision fires and 163 deaths due to non-collision unintentional fires annually during that period [4]. These statistics were used as the basis for the analysis.

Benefit-cost analysis (BCA) or the equivalent term cost-benefit analysis (CBA) is used by economists and engineers to determine the value of investments, most typically social investments. The basis benefit-cost formula [7] is:

$$\Delta W = \Delta CS + \Delta PS + \Delta GR + \Delta EX$$

(Equation 1)

where W = social welfare, CS = consumer surplus, PS = producer surplus, GR = government revenue, and EX = external effects. Consumer surplus is the difference between the maximum price a consumer is willing to pay for a good or service and the actual price paid (reflecting that the benefit derived from the good or service outweighs the cost paid by the consumer). Similarly, producer surplus is the difference between the minimum price a producer would be able to sell a good or service for (i.e., the production cost) and the actual price attained. Since a social BCA is concerned with a project's overall effect on societal welfare, the equation also includes changes in government revenue and external effects. External effects, commonly called externalities, refer to benefits or costs accrued to individuals who are not involved in the transaction; in the absence of market intervention, external effects then are not conveyed by prices. The basic rule for BCA is that the production of the good should be continued as long as the marginal (incremental) social benefits exceed the marginal social costs, as shown above in Equation 1 (i.e., ΔW is positive). While the exact categories into which various benefits and costs fall will depend greatly upon the scope and intent of the analysis, Equation 1 demonstrates that in order for a project to be chosen, total net benefits should be positive.

Figure 1 graphically represents the concepts of a BCA and Equation 1 adding a hypothetical flat-rate tax on production of a good. In this figure, the pre-tax market equilibrium was at production level q^* and price p^* . The imposition of a tax of t on each unit sold raises the effective price to be p^*+t ; at this increased price, the consumer quantity demanded is reduced to q^t . The consumer surplus before the tax is ZEB and after the tax is ZCA; therefore the reduction in CS (ΔCS) is represented by ACEB. Similarly, when producers sell q^t units at price p^*+t , the government receives t for each unit sold, thus government revenue equals $t \times q^t$ (as GR had previously equaled zero for this market, $\Delta GR = ACFG$). Lastly, since the producer now receives p^t for each unit sold, producer surplus is reduced such that $\Delta PS = BEFG$. Since this hypothetical example assumes no external effects (either positive or negative), $\Delta EX = 0$. Thus, the project in this example would not actually pass a benefit-cost test, as one can clearly see that the increase in government revenue ($\Delta GR = ACFG$) is smaller than the combined loss in consumer and producer surplus ($\Delta PS = BEFG + \Delta CS = ACEB$) by an amount equal to the area of triangle CEF. This area, known as deadweight loss, represents a loss of economic efficiency, in this case because some individuals for whom the marginal benefit of the good or service outweighs the marginal cost do not purchase the good or service (since their marginal benefit exceeds marginal cost by an amount less than t). If we did not assume the absence of any externalities, however, the project might pass the benefit-cost test, for instance if the tax was

intended to correct for a negative externality associated with the good or service such that q^t was the socially efficient production level (i.e., marginal social cost does not equal marginal private cost).

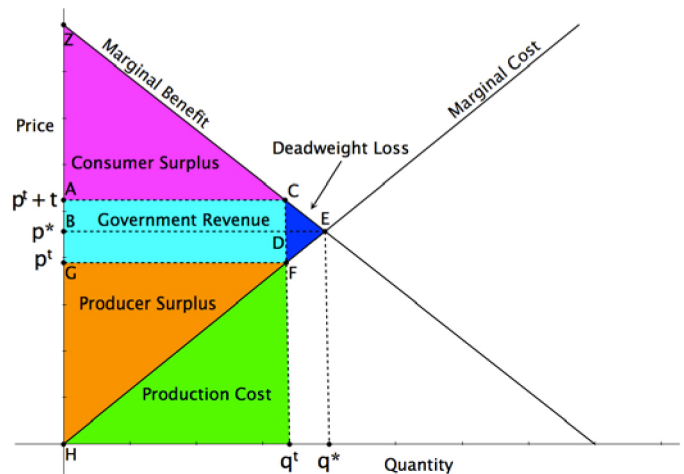


Figure 1. Benefit-cost equation

APPLICATION OF SOCIAL BENEFIT-COST ANALYSIS

Decision making regarding the treatment of risk, particularly that pertaining to human health and livelihood, is a highly difficult and often controversial endeavor. At the outset, it is important to recognize that in every application, the level of risk can never be zero. Though this might seem unsettling, especially in cases of catastrophic failure (e.g., a nuclear power plant) or particularly dreadful occurrences (such as death by motor vehicle fire), this truth must form the basis for all risk-related policy.

Through this lens, the fundamental question regarding any risk is then "What is the optimal acceptable level of risk given the tradeoffs necessary to reach a particular level of safety?" or more simply, "How safe is safe enough?" For specific consideration of vehicle fires, this has been addressed previously [2,4]. For social risks the economic decision rule is that spending on risk reduction should proceed as long as the additional spending is less than the additional social savings from risk reduction. Thus, the optimal level of risk reduction will be the equilibrium point where the marginal benefit of an incremental reduction in risk equals the marginal cost of achieving the incremental reduction.

The product manufacturer will normally weigh the relative merits of implementing various design features and modifications against their inherent tradeoffs. The optimal business decision for the company may not be the same as the socially optimal decision because the company will weigh its private cost of achieving increased safety against its private benefits in the form of increased demand for the safer product and decreased costs for potential legal defense due to product

failure. Since the company's private benefits and costs represent a portion of the total social benefits and costs, safety will be under-produced from a social perspective to the degree that the marginal social benefit exceeds the marginal private benefit. The implication of this is that the equilibrium "safety point" reached by a private company may be different from the socially efficient safety point. The differences can and are moderated through regulation and litigation, though optimization through these methods has inherent inefficiencies and can be debated and analyzed [8].

Because a complete, efficient market for safety does not exist, companies facing product safety issues encounter a dilemma: There is no recognized guideline for the socially efficient level of safety. After complying with regulations, a standard approach as described above might be for a company to consider its likely legal costs including legal damages in case of product failure and weigh this against the cost of added safety. However, even conducting such a study might not be looked upon favorably by a jury in a products liability case [9]. Similarly, a company might attempt to estimate customers' willingness-to-pay (WTP) for an increase in safety, weighing this increased benefit against the increased cost of providing a safer product.

Economists recommend another approach that allows a company or regulatory body to compare the social costs of product failure (i.e., negative social benefits) to the social costs of increased safety. That is, they could perform a social benefit-cost analysis. This would have the advantage of furnishing a well-recognized rationale for determining an appropriate level of risk. Moreover, this approach would be consistent with governments' own attempts to analyze regulations, including those involving safety [2, 10]. In crafting regulation (e.g., a law requiring that all vehicles be fitted with a certain fire-resistant device or setting a minimum standard for material strength used in fuel tanks), a government agency attempts to set requirements at a socially efficient level.

Often, a regulatory body (or private firm) pre-specifies an outcome, in this case a desired risk level, that is not based upon a full benefit-cost analysis, and then the private firm attempts to identify the least-cost means by which to achieve this goal. This more limited form of financial analysis is known as a cost-effectiveness analysis. (As an example, pre-specified risk levels are found in FMVSS 301, for issues such as allowable fuel leakage after a crash test.) When the specified risk level is in fact the socially efficient level, the cost-effectiveness approach will yield the same outcome as the benefit-cost model. However, without estimating the marginal costs and benefits of decreased risk (i.e., conducting a full benefit-cost analysis) there is no guarantee that the level of risk attained is efficient (optimally balances all costs and benefits).

A social benefit-cost analysis in this context is now considered. Products may fail because they do not work correctly in the context of normal activity or because an accident may cause them to fail. In both cases damages may

occur. The social damages (i.e., costs) will consist not only of property damages but also may include injury or death. To perform such an analysis one needs to be able to estimate: (1) the expected frequency of vehicle fire due to both non-collision and collision causes; (2) the type and cost of harms caused by vehicle fire, including property damages and health and livelihood costs; (3) the marginal cost of fire protection, including not only private costs experienced by the company in terms of increased production cost, resultant price increase, and demand shift, but indirect social costs such as the effect on tax revenue, loss of utility experienced by those who are now unable to purchase a car, or change in other (e.g., toxicological) health risks; and (4) the discount rate that should be applied to harms occurring in the future. (The discount rate reflects the opportunity cost of funds and the time value of money. That is, any investment comes at the expense of making an alternative investment, and a dollar today is worth more to an individual than a dollar a year from now; for simplicity, one might think of the discount rate as being an inverse application of an interest rate. The relevant decision rule would then be that the level of safety should be increased as long as the social value of additional safety is greater than the social costs of providing it.)

THE APPROPRIATENESS OF UTILIZING A BENEFIT-COST FRAMEWORK FOR EVALUATING SAFETY RISK

Any incremental risk reduction represents a tradeoff, as the consumer must forgo the purchase of another good or service according to his or her budget constraint. For this reason, Cameron [11] describes the monetary value assigned to a reduction in risk as representing the consumer's willingness to swap money for safety. While assigning monetary figures to life and health impacts might initially appear distasteful, it is important to note that the values are not intended to posit the intrinsic worth of a human life. Six-figure dollar amounts often encountered in popular media and unfortunately described as the "value of a statistical life" actually represent a ratio of the marginal value of a small reduction in mortality risk (generally the risk of sudden death in the current time period) over the marginal utility of a small change in income [12]. That is to say, such values reflect the rate at which an individual is willing to swap his own money for a small reduction in mortality risk. Note that economists use the ratio of these marginal values because one would expect this tradeoff rate to change depending upon the individual's initial position in terms of both income and safety, as willingness to swap income for safety is dependent upon both how much income one has and one's comfort with the current level of risk (i.e., one who has lots of money would likely be more willing to trade some for additional safety; and one who is uncomfortable with the level of risk may be willing to pay more to reduce it).