Economics & Safety

Understanding the cost of injuries and their prevention

By Melvin L. Myers, Henry P. Cole, Joan Mazur and Steve Isaacs

COST ENGINEERING is part of the education for engineers—and understanding risk is an important part of such a curriculum. However, a critical proviso regarding economics must be made clear at the outset: The first tenet for professional engineers is that they "shall hold paramount the safety, health and welfare of the public" and, furthermore, they "must be dedicated to the protection of the public health, safety and welfare" (NSPE, 2006). Moreover, in the hierarchy of controls, the engineer should first endeavor to eliminate the hazard; second, failing this, guard against the hazard; and third, warn of the hazard (MacCollum, 2006). Another precaution regarding economic analysis is recognizing its limitations as well as its advantages (sidebar, p. 38).

This article reviews a process for changing attitudes—not just for sharing knowledge or comparing alternatives. This work originated in farm safety applications, then expanded to rural safety and moved from high-school education into college-level curricula. The approach can be used in engineering classes to teach both public health awareness and economic principles.

In the farming community, a technique has evolved over the years for understanding the link between the risk of injury and the economic cost of those injuries (Leigh, McCurdy & Schenker, 2001). Economics has a powerful influence on work processes in farming. Changing ingrained attitudes against taking actions to improve safety often requires an incident with severe costs or that causes the death of a family member.

However, these attitudes can also be changed through stories that allow a farmer to model another person's behavior and internalize the stories about others (Cole, 2002). The pairing of a narrative with a farm planning tool has been recognized as a way to bring economics and safety together for more effective change (Scharf, Kidd, Cole, et al., 1998; Isaacs, Cole & Gross, 1997).

Many farmers subjectively believe that severe injuries on the farm are unlikely events. However, when the cost of injuries or fatalities is factored into the logic of injury prevention, protective technologies have been shown to be cost-effective from a social perspective (Myers, Cole & Westneat, 2004, 2005). As shown in Figure 1 (p. 39), economics can demonstrate the significance of catastrophic low-probability injury events through calculations of expected value (which is discussed later).

Research has shown that farmers make benefit/cost analyses subjectively and often do not make decisions based on an accurate accounting of direct and indirect costs (Kidd, Isaacs, Cole, et al., 1998). Direct costs regarding an injury include actual payments for medical care, emergency services, hospital services, drug expenses, rehabilitation services, and medical supplies and equipment expenses. Indirect costs include lost earnings and benefits related to the injury and disruption of work, as well as losses related to home production and the need to restaff or train new staff (Leigh, et al., 2001). A farmer's attitude is an important factor in subjective denial of injury risk, but if the farmer "feels" safer—with, for example, a

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Abstract: *A novel approach to teaching safety involves incorporating safety narratives into economics curricula. Students read and discuss these narratives, then conduct a case analysis to identify an appropriate intervention and a decision analysis that compares the injury outcomes with and without the intervention for a population at risk. Finally, an economic analysis is performed to apply costs to the intervention and the time-value of the cost for injuries averted and associated indirect costs.*

rollover protective structure (ROPS) on a tractor—he is more likely to invest in the protection.

Knowledge is not enough to effect safety behavior. Attitudes must also be changed. To change attitudes, stories have been used effectively to illustrate hazards—and their consequences when an injury occurs—in farming, mining, construction and healthcare. Results from several exercises point to the effectiveness of narratives about people and their predicaments in changing both knowledge and attitudes in making decisions based on human models (Cole, 1997, 2000).

The approach described in this article addresses attitudes and judgment via narratives flowing through to economic analysis. This transition can be described as moving from "pulling at the heart strings" to "pulling at the purse strings." In student learning research, Mazur, Cole, Reed, et al. (2005) observe that instructional effectiveness can be enhanced by engaging students; this can be achieved by personalizing hazard recognition; placing injury reports into an easily understood context; demonstrating the complexities of making safety-related choices; and attending to the consequences of injury incidents.

In 2004, the University of Kentucky launched a study to teach economics to high-school students in rural areas by using narratives that highlighted the cost of injuries and the cost effectiveness of their prevention. The study involved two teachers each from four rural county high schools. After the first year, the instructional materials used in the study were simplified for the target audience (11th-grade students). However, the more-complex version of the exercises was used in high-school accounting classes and in one college-level agricultural management class.

The objectives of the study were to address the following questions through the application of economic concepts:

1) Who in the community is at risk of these types of injuries?

2) What are the costs of these injuries and who bears these costs?

3) In what ways can these injuries be prevented, and why is it cost effective to do so?

Economic concepts were derived from the definition of economics: the study of production, distribution, and consumption of goods and services. Engineers must use economics to communicate with managers, yet they must protect the public from hazards that may be inherent in their designs. Indeed, as part of engineering education, case studies about public health in understanding economics are used to highlight ethical issues that engineers face each day. Riggs (1977) recognized that engineering economics can be understood by examining the different dimensions of cost. The education of engineers can be augmented with the complex version of the injury narratives and the associated economic analysis tools developed in this study. This discussion describes the complex version of the instructional materials.

Method

Four steps were used with these instructional materials. The first step used a paper-and-pencil tabletop narrative exercise. The remaining steps used a combination of written instructions and a computer-based interactive spreadsheet. These latter three steps taught several public health and economic concepts (Table 1, p. 40). The spreadsheet facilitated direct access to the Internet to collect data such as inflation rates and government statistics for injury rates.

The Narratives

The interactive narratives used in the first step were developed in previous studies to change farm workers' safety awareness, attitudes and behavior. The theory and methods of this approach have been referred to as "stories to live by" (Cole, 1997). Participants interact with the story plot and characters, and each other to make decisions at critical points as the story unfolds. Because the stories are based on real cases, they are engaging and memorable. When an audience is reluctant to accept safety messages and information, the narrative approach is more effective than presenting facts and statistics (Morgan, Cole, Struttmann, et al., 2002).

These narratives differ from a typical story in three ways:

1) They span the range of the Haddon (1980) matrix from preevent contributors through the injury event to postevent consequences, which provide the time course for the narrative (Table 2). The narratives also show the interaction between the environment, the technology and the people involved in the incident.

2) As students work through each narrative, they ponder and make decisions as the story unfolds. This differs from passive storytelling in that it

Advantages & Limitations of Economic Analysis

Advantages

•Clarifies choices among alternatives by evaluating consequences systematically and rationally.

•Makes explicit the estimates of costs and benefits, and the assumptions on which they are based.

•Permits the expressions of gains and losses in a common monetary metric.

Limitations

•Uses methods and terminology that are inappropriate or inaccurate for some types of effects.

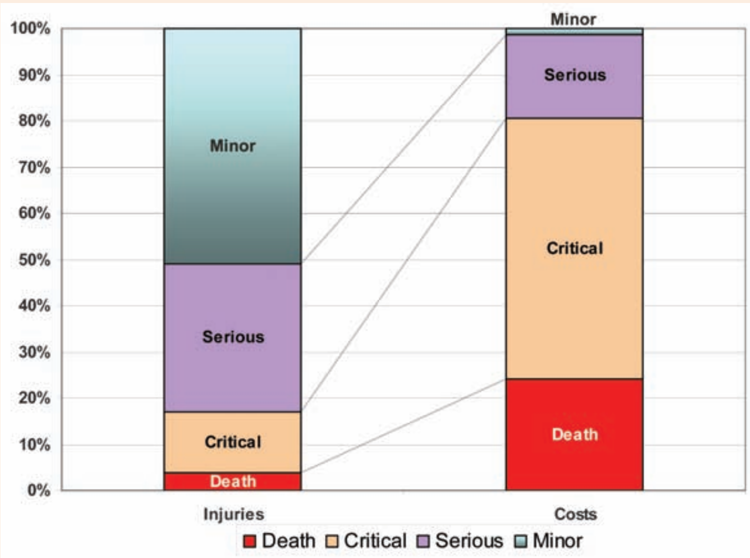
•Contains shortcomings consistent with market imperfections (e.g., imperfect information, externalities, imperfect competition, transmitted injustices or inequities).

•Omits possible uncertainty, such as the fact that the relationship between exposure and disease/injury may be unknown.

Note. *Adapted from* Technology, Law and the Working Environment, *by N.A. Ashford and C.C. Caldart, 1996, Washington, DC: Island Press.*

Figure 1

Injuries Averted Compared to Their Potential Costs



Note. *Based on data from a U.S. Department of Transportation study.*

engages students in actively making decisions that affect the story plot, and injury/noninjury outcomes for the characters.

3) As students consider these critical and potentially life-and-death decisions, they do so within the context of the exercise and the safety of a classroom setting. It is far better to encounter a difficult decision in a classroom exercise than during a real-world event (Cole, 2002).

Case Analysis

The second step is the continuation of the story with an analysis to determine cost factors that relate to the injury incident; identify one or more interventions that would have prevented the injury; and establish the cost of the intervention (Myers & Pana-Cyan, 2000a, b). The effectiveness of the preventive actions is determined as well.

The case analysis also examines the different cost perspectives associated with the injury. Across the different narratives used, these perspectives include that of society (see "social cost" in the glossary below), the farmer, a rural household, the family of a nonfarmer victim, and the employer of a nonfarmer victim. Engineering education curricula can be enhanced with case studies that address public health issues and embody ethics in decision making. Since all engineers are taught economics, incorporating these case studies in the curricula provides an opportunity to learn analytical approaches for considering occupational safety and health issues.

Decision Analysis

The third step is a decision analysis that moves from the case to a population in order to determine the risk of the injury (Myers & Pana-Cyan, 2000a, b; Haddix, Teutsch, Shaffer, et al., 1996). In a decision

Glossary of Economic Terms

Benefit/cost analysis: Weighing the total expected benefits against the total expected costs of one or more actions in order to choose the best or most profitable option.

Breakeven analysis: The point where total benefit received equals the total cost of the intervention.

Cost analysis: The process of estimating the cost of prevention activities.

Cost-effectiveness analysis: An economic analysis in which all costs and benefits (negative costs) are related to a single, common effect. Comparison of alternative interventions (including no intervention) per health outcome achieved and is presented as cost per case (injury) prevented.

Decision analysis: An explicit, quantitative, systematic approach to decision making under conditions of uncertainty.

Direct costs: Costs incurred to secure medical treatment, medications, rehabilitation and long-term care.

Discounting: A calculation that makes current costs and benefits worth more than those occurring in the future because there is an opportunity cost to spending money now and there is a desire to enjoy benefits now rather than in the future.

Expected cost (value): The sum of the probabilities of each possible outcome multiplied by the outcome value.

Indirect costs: Costs such as productivity losses which are not directly associated with prevention and healthcare activities that accrue to individuals, society or employers.

Inflation: A sustained increase in the average price of all goods and services because of an increase in currency.

Opportunity cost: Cost of goods measured in terms of lost opportunity to pursue the best alternative activity with the same time and resources.

Social cost: The total cost to society that includes all costs no matter whom or what incurs the cost.

tree, the risk of the injury with and without the intervention is compared, and the difference provides the increment of protection provided by the intervention. The result of this analysis is the increment of injuries averted as a result of the intervention.

Figure 2 (p. 41) presents an example of a decision tree in which the choice is whether to wear a seatbelt when driving a tractor. For each choice, the probability of a tractor overturn is the same, but the potential for injuries differs.

Thus, as Figure 2 shows, the probability of an injury when wearing a seatbelt ($probability_{injury}$) may be different from when no seatbelt is worn ($^\wedge Probability_{injury}$). The difference in the resulting injury rates based on this decision analysis would provide the increment of injuries averted because of seatbelt use.

Table 1

Concepts Taught with Narrative-Driven Cost Analysis Tool

	NARRATIVE			
Steps after narrative exercise	***Kayles difficult decisions***	***Heather on horseback***	***Sound advice throughout the years***	***No way to meet a neighbor***
Case study	•rollover protective structures •risk •risk factor •benefit •scarcity •economics •microeconomics •macroeconomics •intervention •cost (of inputs) •opportunity cost •explicit costs •implicit costs •direct costs •indirect costs •price •distribution •annual exposure	•annual exposure •benefit •cost (of inputs) •direct costs •discount rate •discounting •distribution •economics •explicit costs •implicit costs •indirect costs •interest •intervention •macroeconomics •microeconomics •opportunity cost •present value •price •scarcity •analytic horizon	•annual exposure •benefit •cost (of inputs) •decibel •direct costs •economics •economies of scale •indirect costs •intervention •noise •opportunity cost •price •scarcity •social cost •supply and demand	•annual exposure •benefit •cost (of inputs) •direct costs •distribution •economics •entrepreneur •indirect costs •insurance •intervention •labor •macroeconomics •microeconomics •opportunity cost •price •productivity •risk •scarcity •social cost •workers' compensation
Decision analysis	•disability •decision analysis •decision tree •sensitivity analysis •loss control •maximum abbreviated injury scale (MAIS) •probability	•disability •decision analysis •decision tree •sensitivity analysis •loss control •MAIS •probability	•disability •decision analysis •loss control •probability	•disability •decision analysis •decision tree •loss control •MAIS •probability
Economic analysis	•discounting •discount rate •expected value •analytic horizon •inflation •productivity •entrepreneur •market •cost analysis •cost-effectiveness analysis •benefit/cost analysis •present value •cash flow	•expected value •productivity •entrepreneur •market •cost analysis •cost-effectiveness analysis •benefit/cost analysis •cash flow	•expected cost •inflation •productivity •entrepreneur •market •cost analysis •cost-effectiveness analysis •time analysis	•analytic horizon •benefit/cost analysis •cost analysis •cost-effectiveness analysis •discounting •discount rate •entrepreneur •expected cost •inflation •market •productivity •present value

Economic Analysis

The economic analysis associates costs with different levels of injury severity and calculates the costs of the injury over a time horizon, such as the potential remaining lifetime of the victims (Pana-Cyan & Myers, 2000; Gold, Siegel, Russell, et al., 1996). These costs include both direct and indirect costs (see glossary, p. 39) and represent the cost of no protection compared with the cost of the protection. The costs are based on estimates of highway-collision-related injuries of varying severity (Blincoe, Seay, Zaloshnja, et al., 2002).

Taking these costs together with the cost of the intervention, several analyses are conducted, including a cost-effectiveness analysis, a benefit/cost analysis, a breakeven analysis (payback period of an investment) and an expected value analysis (that illustrates low-probability/high-cost consequences). In the study, the costs were discounted compounded annually to arrive at a present value based upon a

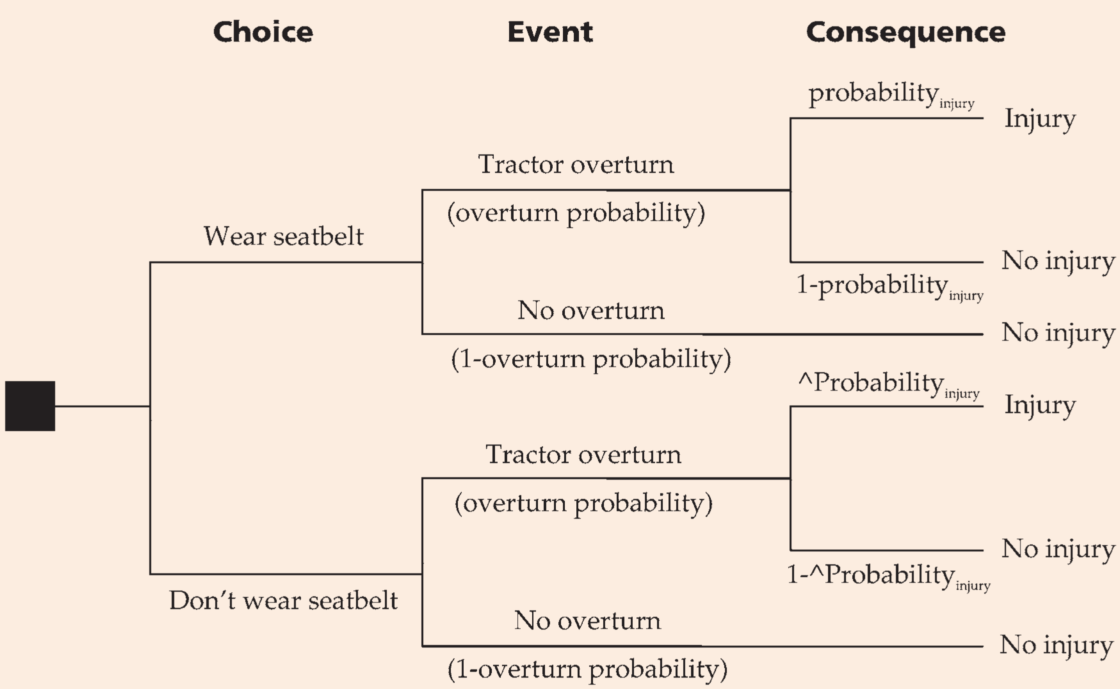
Table 2

Application of Haddon Matrix to Tractor/Auto Collision

	Phase		
Factor	***Preevent***	***Event***	***Postevent***
Environment (hills, roadways, open fields, blind spots)	Hay field across the rural two-lane road from farm yard; left turn on road needed to enter yard driveway.	No passing lane on road.	Roadway strewn with debris. *Intervention:* Move hayfield access across from yard driveway.
Agent (tractor, horse, farm equipment, automobile, noise sources)	Tractor towing baler and wagon load of hay on road; car approaching from rear at high speed.	Tractor in left lane during left turn; car passes in left lane and crashes into tractor.	Car crushed; tractor overturned. *Intervention:* Install signal light on trailer.
Host (tractor driver, horseback rider, automobile driver)	Auto driver passes slow-moving tractor as the tractor driver turns left.	Neither driver has time to react.	Both drivers killed. *Intervention:* Employ a trailing vehicle.

Figure 2

Simple Decision Tree: Seatbelt Use on Tractor with ROPS



3% social discount rate established as a standard for comparison between studies (Biddle, 2004).

The analytic horizon for each exercise was assumed to be the same as the period of time described in each narrative or a reasonable alternative when considering the full population at risk. Nonetheless, a student can select different analytic horizons to observe the sensitivity of the alternatives. Inflation for past cost figures was adjusted using the U.S. Consumer Price Index for the year of the analysis as entered by the student (available as an inflation calculator on the Bureau of Labor Statistics website).

Formulas for calculating the results from the different analyses are shown below:

•Cost effectiveness = (total cost $_{\text{without intervention}}$ – total cost$_{\text{with intervention}}$)/(total injuries$_{\text{without intervention}}$ – total injuries $_{\text{with intervention}}$)

Where total cost = intervention cost – (direct + indirect costs related to the injury)

•Benefit/cost (ratio) = (direct + indirect costs)/ intervention cost

•Breakeven (in years) = intervention cost (initial investment)/(direct + indirect costs) per year

•Expected value = Σ (outcome costs x outcome probabilities) (e.g., outcomes can be different categories of injury severity).

Table 3 provides an example of the calculation of expected cost. It is drawn from the "No Way to Meet a Neighbor" narrative. The cost values are based on data from Blincoe, et al. (2002), and the probabilities relate to the effectiveness of turn signals on equipment towed by farm tractors to prevent injury. These probabilities were derived through the decision analysis.

Results

Four narratives were used in this study: 1) a tractor overturn (Cole, et al., 1997; Kidd, et al., 1998); 2) a fall from a horse (Hammett, 1990; Christey, Nelson, Rivara, et al., 1994; Cooper, McGee & Anderson, 2003; Max, MacKenzie & Rice, 1991); 3) noise-induced hearing loss (Depczynski, Franklin, Challinor, et al., 2005); and 4) a roadway collision between an automobile and a tractor towing farm equipment (Hughes & Rodgman, 2000).

The economic analyses that followed each narrative required students to enter direct and indirect costs into a spreadsheet, which displays interactive graphs that change as the data are entered. Several worksheets were used to roll out the analysis in a cascade fashion with instructions from a companion paper document that starts with the case analysis, moves to the decision analysis and concludes with the results of several economic analyses. The concepts taught through each of the four narratives are outlined in the glossary (p. 39).

Kayles Difficult Decisions

The difficult decisions narrative involves a teenager who was injured when operating a non-ROPS tractor as it overturned (Cole, et al., 1997; Kidd, et al.,

Table 3

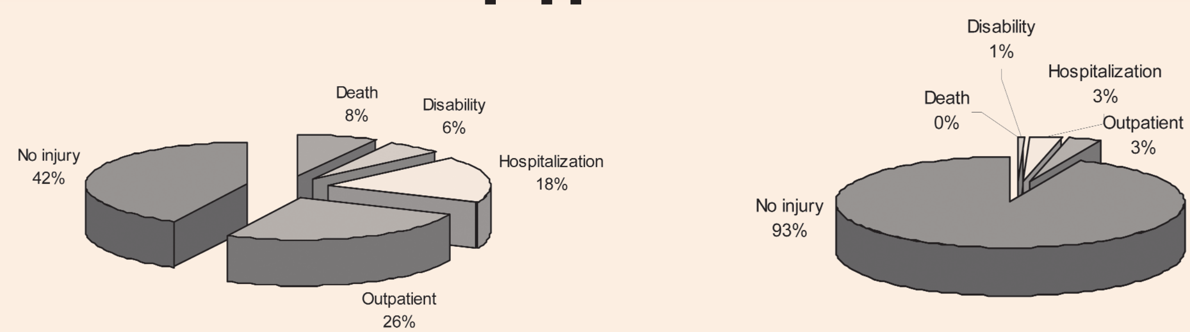
Calculation of Value of Installing Turn Signals on Towed Farm Equipment

Injury	Cost (value)	Probability	Product
Death	$3,957,189	0.01909	$75,527
Disability	$2,824,723	0.06274	$177,228
Hospitalized	$369,347	0.15360	$56,733
Outpatient	$17,652	0.24548	$4,333
No injury	$0	0.51909	$0
Total		**1.00000**	**$313,821**

Note. *Data are from* The Economic Impact of Motor Vehicle Crashes, 2000 (*Report No. DOT HS 809 446), by L. Blincoe, A. Seay, E. Zaloshnja, et al., 2002, Washington, DC: National Highway Traffic Safety Administration, U.S. Department of Transportation.*

Figure 3

Injuries Associated with Tractor Overturns: Non-ROPS vs. ROPS-equipped



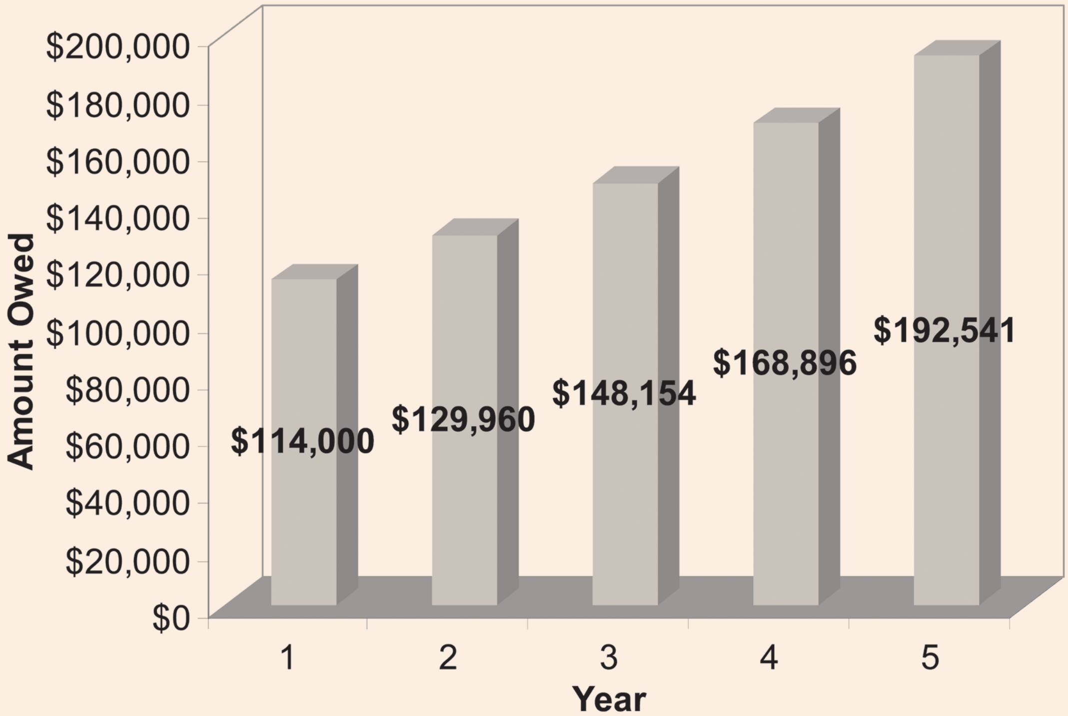
1998). This case identified the preventive intervention as a ROPS and seatbelt at a cost of $795, which was determined based on Internet research. The injury outcome was incapacitation for 6 months.

When this type of incident and intervention were extrapolated to the population at risk, it was determined that $380,000 would be saved for each ROPS retrofitted onto a tractor.

The analytical horizon used in this analysis was 25 years, although the student can vary this value to see its effect on the sensitivity of the results. Figure 3 shows the reduction of deaths and severe injuries associated with installing a ROPS on a tractor. In the exercise, the pie charts shown in the figure changed as the student entered data from the instruction document.

Figure 4

Amount of Money Owed if Borrower Pays Nothing on Credit Card



Heather on Horseback

In this narrative, a 13-year-old girl fell from a horse; she was not wearing a safety helmet and suffered permanent brain damage. The case study identified the intervention as a helmet and adult supervision, with a cost of $3,342 over a 5-year period.

When the intervention costs were extrapolated to the population at risk, it was determined that $411,000 would be saved for each of the interventions in which adult supervision ensured the use of a riding safety helmet by a youth rider over a 5-year period.

The analytic horizon adopted for this analysis was 60 years (the assumed remaining life of the injured girl in the narrative). Figure 4 shows the influence of interest costs from paying nothing on a credit card debt for 5 years as produced by the spreadsheet analysis. In this case, the student entered the interest rate in a spreadsheet to form the bars in this chart.

Sound Advice Throughout the Years

The sound advice narrative follows two people as they progress from teenagers to grandfathers over a period of 39 years (Kidd, et al., 1999). Both were exposed to work-related noise throughout their lifetimes. One wore hearing protection and the other did not. The farmer who failed to use hearing protection suffered serious noise-induced hearing loss. The narrative describes a tragic consequence for this farmer—at age 55, he backed a pickup truck over his

Social Cost Savings for Interventions

Kayles Difficult Decisions
- $380,000 savings per injury averted
- Analytic horizon: 25 years

Heather on Horseback
- $411,000 savings per head injury averted
- Analytic horizon: 60 years

Sound Advice Throughout the Years
- $261,000 savings per person for whom hearing impairment is averted
- Analytic horizon: 39 years

No Way to Meet a Neighbor
- $315,000 savings per injury averted
- Analytic horizon: 30 years

Practical Applications

- Recognize common occupational safety and health problems and their potential consequences.
- Understand the potential catastrophic impact of low probability events.
- Appreciate both the pull at the "heart strings" through the narrative exercise and the pull at the "purse strings" through the economic analysis.
- Understand the social cost of an injury beyond the personal or business cost of an injury.
- Study cases regarding ethical issues related to public health.
- Apply a decision-tree analysis.
- Demonstrate that cost differs depending on whose perspective is used (e.g., the injured person's family vs. society).
- Provide attitude challenges in addition to knowledge transfer.

5-year-old granddaughter because he was unable to hear her screams to stop.

An economic analysis estimates that the 39-year cost of earplugs and/or earmuffs would range from $546 to $1,950. When the costs of noise-induced hearing loss—including hearing-loss-related injuries (Choi, Peek-Asa, Sprince, et al., 2005)—were extrapolated for the population at risk, it was noted that $261,000 would be saved for each case in which hearing was conserved. The analytic horizon assumed for this analysis was 39 years, the same period of noise exposure described in the narrative.

No Way to Meet a Neighbor

The neighbor narrative involves a car passing a tractor towing a hay baler and a fully loaded hay wagon. When the tractor driver turned left into a farm yard, the car driver attempting to pass the slow-moving equipment crashed into the tractor. Both drivers died at the scene.

One risk-reducing intervention in this case was turn signals on the hay wagon, which cost an estimated $200. When extrapolated to the population at risk, the cost savings of preventing the injuries was $315,000. The analytic horizon for this extrapolation was 39 years, the assumed remaining useful life of the two decedents.

Although each narrative-based analysis represents widespread and pernicious hazards, the techniques have limitations when the hazard is of short duration or low consequence, and intervention effectiveness is unknown or costly. Nonetheless, the results of the analyses supplement decision-making information. The cost-effectiveness of each narrative-driven analysis is shown in the "Social Cost Savings" sidebar on p. 43.

Discussion

Students worked in teams of two to four, with each team comprised of high and low achievers, a peer teaching arrangement that worked well. Although many of the students did not live or work on a farm, nearly all drove on narrow rural roads shared with farm equipment. Most knew of tractor-related injury events similar to those described in the narratives.

When the horseback incident exercise was administered, it was noted that far more students ride all-terrain vehicles, motorcycles and bicycles, and engage in sports such as rollerblading and skateboarding. All of these activities pose a high risk for traumatic brain injuries that can be prevented by wearing appropriate head gear. Therefore, narratives and associated cost tools should be developed for these types of activities.

All four narratives and their associated cost tools are relevant for use in engineering classes, especially those that concern safety engineering, product design, professional ethics, and legal and liability issues. As design engineers, students would better understand the ethical and economic importance of designing defects out of products, as well as the implications and costs of failing to do so.

Engineers involved in business operations could bring to bear cost arguments to ensure investment in safer operations and designs, especially where there is a reluctance to invest in safety and the risks of not doing so can be shown in terms of costs. The analysis could be expanded to a profit margin analysis to demonstrate through various scenarios the implications of the additional revenue needed to balance the potential costs involved in injury events (Myers, 2006).

The examples used show cost savings, but include only the action to intervene, not the pro-

University Educator Applications

- Bring ethical decision-making into the classroom through the narratives and case studies.
- Build an appreciation of the narrative technique as a method of instruction that is engaging and memorable.
- Understand the financial dimension of injuries and how injury costs are distributed.
- Use public health problems as a way to teach engineers economic principles (e.g., discounting, economic analysis, payback period).
- Introduce students to interactive applications of spreadsheet programs.
- Appreciate the concept of exposure as an essential factor in calculating injury rates.
- Calculate injury rates and the increment of injuries averted by an intervention.
- Emphasize the need to eliminate hazards or reduce risks at the program/product design stage.

grams that influence the intervention. Some interventions may show costs rather than savings. Previous studies of intervention programs, whether public (Myers, et al., 2004) or private (Myers, et al., 2005), show a net cost rather than a savings for the intervention. Furthermore, low exposure rates or noncatastrophic consequences related to an injury event may not show savings.

Conclusion

An approach that uses safety narratives based on real cases and in which students interact with the story plot and characters can be a useful way to teach the economics of injuries and their prevention. The narratives serve two purposes:

1) The narratives are engaging and memorable, and are an effective way to increase awareness and change attitudes.

2) By pairing the narratives with a spreadsheet that continues the story through an examination of the cost of injuries, the distribution of these costs (who pays them) can be calculated in a concrete, real-world context rather than in an abstract manner. In addition, the cost-effectiveness of preventive actions can be demonstrated in a concrete, easy-to-understand manner.

The combination of real-world narratives and economic analyses provides the potential to teach a large number of economic and safety concepts in a small amount of time. The addition of the revenue side of economics also needs to be explored. Cost can be used to demonstrate the impact on profit through profit-margin analysis and, thus, the revenue needed to replace the cost incurred because of the risk of injuries. ■

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