CHAPTER 14

TRANSPORTATION

14-1 TRANSPORTATION ACCIDENTS

The Problem

Each year in the United States, there are nearly 45,000 motor vehicle-related deaths and more than 2 million disabling injuries, many of which result in some degree of permanent impairment. Motor vehicles accidents are the leading cause of death between ages 1 and 44 years, and motor vehicle deaths account for more than half of all accidental deaths each year. The cost of motor vehicle accidents now exceeds $250 billion per year. The death rate from motor vehicle accidents is approximately 16 per 100,000 persons.

In addition, studies have revealed a number of other facts about motor vehicle accidents, injuries, and deaths. The data may change over time. Motor vehicle accidents are the leading cause of occupational injuries (35%) and work-related deaths (approximately 40%). For example, in many police departments, more police die as a result of squad car accidents than of gun shots.

Thirty-seven percent of motor vehicle deaths occur between 10:00 P.M. and 4:00 A.M. The death rate per crash generally increases with age. However, it is highest for people between ages 17 and 30 years, and it also increases dramatically with age for people older than 65 years. The death rate is lower for high-income individuals and is higher for males than for females, even after there are adjustments for the greater travel of males.

Approximately 50% of accidents involve frontal crashes; approximately 2% are rear-end collisions. Of the 50,000 motor vehicle accidents each year, roughly 8,000 involved rollover of the vehicle, and more than 5,000 involved impact with trees and utility poles.

Estimates suggest that 50% of drivers involved in fatal crashes have a blood alcohol content (BAC) of 0.10 or more. Some studies suggest that this percentage is significantly higher. Impairment of driver skills begins at a BAC of 0.05 or less, and all states now set driving-under-the-influence (DUI) or driving while intoxicated (DWI) limits at 0.08 percent.

There are many factors that contribute to vehicle accidents and statistics, such as gender and age. Women have a lower accident rate than men do, and the female death rate from motor vehicle accidents is nearly three times less than that for males. The accident rate is by far the highest for people in their late teenage years and early twenties.

Driving for long periods of time leads to higher frequency of crashes. Truck drivers who drive for 10 hr have nearly twice the risk of being in a crash compared with drivers on the road for less than 2 hr.

Passenger restraints contribute to lowering injury and death rates in vehicles accidents. The National Highway Traffic Safety Administration (NHTSA) estimates that more than 8,000 lives were saved between 1983 and 1987 by the use of seat belts. The addition

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of airbags also has helped to reduce injury and death rates at the same time that the number of vehicles and total miles driven continues to increase.

Vehicle size is an important factor in vehicle injuries and deaths. The frequency of injuries among drivers of small cars involved in crashes is more than twice that for large cars. There is also a tendency for small cars to be involved more frequently than large cars in crashes resulting in damage claims.

Event Sequence

The dynamics of vehicle crashes are quite complicated. There are many factors that contribute to the actual crash sequence, depending on vehicle speed, design, and motion. However, a simplified discussion explains some of the basic phenomena of vehicle crashes and impacts.

Frontal Impact When a vehicle runs into a fixed object or another vehicle in a frontal collision, there is a sequence of events that takes place within a fraction of a second. At very low speeds, the bumper and its mounting will absorb the energy of impact. The NHTSA Bumper Standard establishes that a passenger vehicle bumper should absorb the energy from a 2.5 mi/hr impact of the vehicle. For a time, the standard was a 5 mi/hr impact, which some manufacturers still meet. At higher speeds, the structure of the vehicle will absorb the energy of impact by crushing. Today's vehicles are designed to absorb a great deal of energy; older vehicles were not. Because of the absorption of energy by the structure, the rate of deceleration falls quickly with distance from the point of impact. Figure 14-1 illustrates this concept by plotting G load (the ratio of impact deceleration to the pull of gravity). At some distance from the point of impact, there is little deformation of the vehicle structure, and from that point on, the deceleration rate is fairly constant over the rest of the vehicle length.

When a vehicle strikes another object or barrier, it stops quickly. Objects within or occupants continue to move at the original vehicle speed until they impact on something to slow them down. If passengers are restrained to the vehicle structure or its components, they will stop with the vehicle.

Rear-End Collision In a rear-end collision, one vehicle strikes another vehicle in front of it. The front vehicle is usually at rest or may be moving at some speed less than the

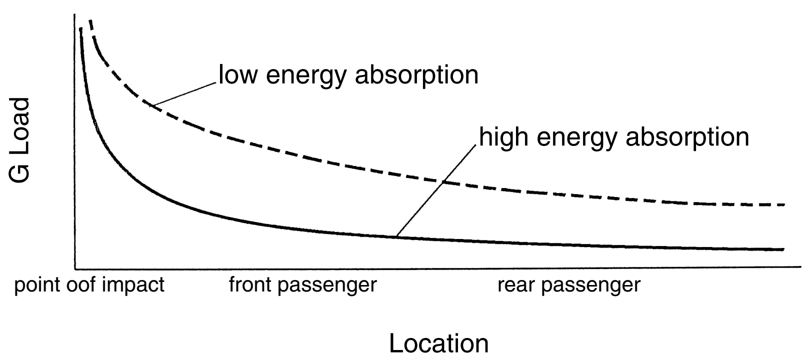

Figure 14-1. Approximate G loads from frontal impact as a function of distance from the point of impact.

striking vehicle. At slow speeds, the bumpers will absorb some energy. At higher speeds the structure of the two vehicles will crush and absorb much of the energy. The front vehicle will accelerate forward unless restrained in some way.

Within a few hundredths of a second after impact, the vehicle occupants in the forward vehicle will press into the seat backs. The seat cushioning and structure will absorb much of the energy related to the acceleration of the occupants. Consider a person sitting in the front seat during a rear-end collision. Unless the head is well restrained by the headrest, it will move rearward over the top of the seat in a phenomenon called whiplash. There are two components to the head movement: translation away from the body trunk and rotation about the neck. If the seat back remains rigid and quite vertical, the rotational component will likely be much greater than if the seat back structure yields. If the seat back yields, it absorbs some of the energy and reduces the rotational component. The resultant force on the head from the two components can be quite sizeable even at fairly low-impact speeds. Depending on the speed at impact, the body may slide backward up the slope of the seat and impact on the rear structure of the passenger compartment.

Rollover If there is enough lateral impact and movement, a vehicle may roll over. The tires may slide or contact another object. If sliding friction or restraining forces are large enough compared with the forces of lateral motion, the vehicle will roll over. The chance of rollover increases for vehicles with high centers of gravity. The vehicle structure may crush during the rollover, causing reduction of the occupant space. Because occupants may be thrown around, use of restraints will lessen the chance for injury. Some vehicles incorporate side impact structural elements to minimize reduction of occupant space. An increasing number of models include side impact air bags to cushion impacts on occupants.

The Second Crash

When a vehicle crashes, the occupants continue in motion until they impact on the interior of the passenger compartment. The term *second crash* refers to this crash of occupants against the interior surfaces of the vehicle after vehicle impact. Very often, the second crash is the primary source of passenger injuries, not the vehicle crash itself.

Vehicles designed to absorb energy and to reduce the transfer of forces to the occupants will reduce the second crash. Passenger restraints and air bags reduce the likelihood of the second impact occurring. Well-anchored seats help minimize the second crash. A seat that lets loose can add mass behind the passenger in a frontal crash. Interiors have many design features to reduce the sources of injury. Padded dashboards that distribute forces, laminated windshields that prevent glass from being imbedded in tissue, and elimination of protruding knobs and controls all reduce the probability of injuries. Energy-absorbing, collapsible steering columns significantly reduced the rate of injury to drivers during the second crash.

Crashworthiness

Crashworthiness refers to the ability of a vehicle to withstand an accident without intrusion of or reduction in the integrity of the passenger compartment. When a crash occurs, not only is it important to minimize the second crash, it is also important to ensure that the passenger compartment stays closed and retains it shape. The idea is to keep occupants inside a protected zone during a crash. Passengers thrown from a vehicle face a much greater risk of injury and death than those who stay inside.

It is important that door latches and locks perform during crashes. Doors must meet structural standards that are intended to provide compartment integrity in side impacts. The energy-absorbing steering column also reduces the injury caused by the steering column being driven into the driver's chest in a frontal crash. Compartment integrity also involves adequate structural strength to prevent collapse during rollover. The main energy absorption components of the vehicle are placed in elements outside the passenger compartment. Passenger restraints not only reduce the second crash, but keep people inside the protected zone. It is also important that fuel systems retain their integrity. If a fuel tank ruptures, spills fuel in the passenger compartment, and ignites, the opportunities for escape and rescue often are lost.

Crashworthiness and integrity of a passenger compartment permit race car drivers to survive crashes at very high speeds. Crashworthiness has improved in most cars over the years. Improved design features have contributed to the reduction in crash injuries and occupant deaths.

14-2 CONTROLLING TRANSPORTATION HAZARDS

There are many factors that can and do contribute to the reduction of motor vehicle accidents and the resulting injuries and losses. In discussing controls, one can apply the models discussed in Chapters 3 and 9. For example, in discussing motor vehicles, the four Ms representing man, machine, media, and management can refer to drivers, vehicles, roadways, weather conditions, regulations, enforcement, and cost.

Vehicles

There are many safety features built into motor vehicles today. The NHTSA has safety standards for motor vehicles: the Federal Motor Vehicle Safety Standards (FMVSS). Table 14-1 lists their titles and identifying numbers. The Society of Automotive Engineers (SAE) also publishes numerous standards for vehicles, including many safety standards. Other Department of Transportation (DOT) agencies also establish vehicle safety standards. The Urban Mass Transportation Administration has safety standards for buses and rail vehicles, and the Federal Highway Administration has safety standards for trucks.

An important design feature for trucks and cars is antilock brakes. For years, large aircraft had antilock brakes. Later, this technology moved to trucks and automobiles. The idea is to sense the moment wheels lock up as static friction between the tires and roadway changes to sliding friction. Because the coefficient of sliding friction is generally less than that for static friction, the sensors interrupt braking for a fraction of a second, allowing a return to static friction, and then braking continues. This sequence repeats frequently until the vehicle stops.

As for back as 1908, air bags were proposed for automobiles. Today, passenger cars have driver side and passenger side air bags as standard equipment. After the introduction of air bags in certain models, it took more than 20 years to make them standard equipment. Some adjustments in inflation rates were made after performance data suggested that some adults were seriously injured during inflation. There also has been controversy about the use of infant and child seats in front seats of passenger cars, because some air bags have caused some deaths. More recently, air bags have appeared in doors of some automobile models to help minimize injury during side impacts.

Some states require annual vehicle inspections to help ensure that vehicles and safety devices are in proper working order. The assumption is that vehicles with working head-

TABLE 14-1 Federal Motor Vehicle Safety Standards (FMVSS, from 49 CFR 571)

Number	Topic	Car[a]	Truck	Bus[b]	Multipurpose Passenger Vehicle[c]	Equipment[d]
100 Series: Accident prevention						
101	Controls and displays	•	•	•	•	
102	Transmission shift lever sequence starter interlock and transmission braking effect	•	•	•	•	
103	Windshield defrosting and defogging systems	•	•	•	•	
104	Windshield wiping and washing systems	•	•	•	•	
105	Hydraulic and electric brake systems	•	•	•		
106	Brake hoses	•	•	•	•	•
108	Lamps, reflective devices, and associated equipment	•	•	•	•	•
109	New pneumatic bias ply and certain specialty tires	•				•
110	Tire selection and rims for motor vehicles	•				•
111	Rearview mirrors	•	•	•	•	
113	Hood latch system	•	•	•		
114	Theft protection	•	•		•	
116	Motor vehicle brake fluids	•	•	•	•	•
117	Retreaded pneumatic tires	•				•
118	Power-operated window, partition, and roof panel systems	•	•		•	•
119	New pneumatic tires for vehicles other than passenger cars					•
120	Tire selection and rims for motor vehicles other than passenger cars		•	•	•	•
121	Air brake systems		•	•		
122	Motorcycle brake systems					
123	Motorcycle controls and displays					
124	Accelerator control systems	•	•	•	•	
125	Warning devices					•
129	New nonpneumatic tires for passenger cars: new temporary spare nonpneumatic tires for use on passenger cars	•				•
131	School bus pedestrian safety devices					•
135	Light vehicle brake systems					
138	Tire pressure monitoring systems	•	•	•	•	
139	New pneumatic radial tires for light vehicles	•	•	•	•	
200 Series: Injury protection						
201	Occupant protection in interior impact	•	•	•	•	
202	Head restraints	•	•	•	•	
203	Impact protection for driver from the steering control system	•	•	•	•	
204	Steering control rearward displacement	•	•	•	•	
205	Glazing materials	•	•	•	•	•
206	Door locks and door retention components	•	•		•	
207	Seating systems	•	•	•	•	
208	Occupant crash protection	•	•	•	•	
209	Seat belt assemblies	•	•	•	•	
210	Seat belt assembly anchorages	•	•	•	•	

(continued)

TABLE 14-1 continued

Number	Topic	Car[a]	Truck	Bus[b]	Multipurpose Passenger Vehicle[c]	Equipment[d]
212	Windshield mounting	•	•	•	•	
213	Child restraint systems	•	•	•	•	
214	Side impact protection	•	•	•	•	
216	Roof crush resistance	•	•	•	•	
217	Bus emergency exits and window retention and release			•		
218	Motorcycle helmets					•
219	Windshield zone intrusion	•	•	•	•	
220	School bus rollover protection			•		
221	School bus body joint strength			•		
222	School bus passenger seating and crash protection					
223	Rear impact guards					•
224	Rear impact protection			•		
225	Child restraint anchorage systems	•	•	•	•	
300 Series: Postaccident protection						
301	Fuel system integrity	•	•	•	•	
302	Flammability of interior materials	•	•	•	•	•
303	Fuel system integrity of compressed natural gas vehicles	•	•	•	•	
304	Compressed natural gas fuel container integrity					•
305	Electric-powered vehicles: electrolyte spillage and electric shock protection	•	•	•	•	
400/500 Series: Other						
401	Interior trunk release	•			•	
403	Platform lift systems for motor vehicles					•
404	Platform lift installations in motor vehicles	•	•	•	•	
500	Low speed vehicles					

[a] Passenger cars.
[b] Busses other than school busses.
[c] Multipurpose passenger vehicles.
[d] Item of motor vehicle equipment.

lights, brakes, and other features will improve highway safety. One study found no detectable impact on accident rates between states that required periodic vehicle inspections and those that did not. The main problem is that equipment failures may occur at anytime, whereas inspection occurs only once each year. Random inspections are reported to be as effective as periodic inspections.

Operators

There are many characteristics of drivers that affect the likelihood of an accident. Drivers must be licensed to operate a motor vehicle, and they must pass written and road tests to receive a license.

The Federal Highway Administration (FHWA) sets minimum qualifications for drivers of motor carriers (commercial motor vehicles). Some of the qualifications include being 21 years old, meeting physical qualifications, having knowledge of safe methods for securing cargo, passing road and written tests, and not being disqualified for certain criminal or driving offenses (including driving under the influence of alcohol or drugs). The FHWA tightened driver qualification standards in response to the Commercial Motor Vehicle Safety Act of 1986.

It is assumed that well-trained drivers drive more safely than those with little or no training. Many states require high school students to take a driver education course before a license is issued. The value of high school driver education is somewhat controversial. For example, one state dropped mandatory driver training in high schools and found that the death rate among teenage drivers dropped. Much of the decline was the result of a delay in the onset of driving. Instead of all students receiving a license at the earliest possible date, many did not begin to drive until after high school.

Another study compared three driver programs for 16,000 participants. The three programs included a control group (no training), a normal training course, and a 70-hr intensive course. Subsequent driving records were monitored for accidents and violations. There were no significant differences in the overall mean rate of accident or overall violation rates.

Recently, drunken driving has received more attention than ever before. Public groups across the nation have formed to get tough on drunk driving. Mothers Against Drunk Driving (MADD) and Students Against Driving Drunk (SADD) are two with national prominence. An accident in Kentucky in May, 1988, stirred national attention and illustrates the public pressure. A busload of school children returning home from an outing was struck by a pickup truck. As a result, two gasoline tanks on the bus ruptured and the spilled fuel burst into flames. Twenty-seven children died from the ensuing fire and many others were severely burned. The driver of the pickup truck reportedly had a BAC two and one-half times more than the legal limit. Some people believe that the driver should have been prosecuted as a murderer rather than a violator of motor vehicle laws. Some believe that design standards for school buses should be improved.

There has been a national effort to change many laws governing alcohol and driving. Many states have raised their legal drinking age to 21 years. In 1987, the Supreme Court upheld the federal law that restricted federal funds to states that did not comply with a set legal age for purchase of alcoholic beverages. Where states have raised the drinking age to 21 years, one study found a reduction of 13% in nighttime motor vehicle deaths. Many employers are becoming stricter with truck drivers who drink. One study showed that in the early 1980s, 15% to 16% of fatally injured tractor trailer drivers tested had BACs of 0.10 or more. By 1986, only 3% had BACs that high. All states have lowered BACs to 0.08 for DUI and DWI cases.

Facilities

The FHWA specifies highway design standards and traffic control devices. The *Manual on Uniform Traffic Control Devices*[1] (MUTCD) provides details on signage, traffic lights, lane markings, traffic and separation devices, and other items. The FHWA approves many standards as acceptable for design of highways and roads; 23 CFR 625 contains these standards. Most are standards of the American Association of State Highway and Transportation Officials (AASHTO).[2]

A few examples of design features that have improved the safety of highways include break-away light poles, break-away signs, energy absorbing guardrail ends, divider barriers, and protected bridge supports.

In the early days of interstate highway design, the bases for light poles were heavy concrete structures that simply stopped a vehicle on impact. Today, they are much smaller and are anchored to small bases by bolts that will shear and separate the pole from the base when struck by a vehicle (see Figure 14-2). Similar break-away technology also has been applied to highway signs (see Figure 14-3).

Guardrails have become a common design feature for major highways, replacing wooden poles with steel wire rope strung between them. Initially, guardrails had an end at the same height as the rest of the guardrail. When a vehicle struck the end of the guardrail just right, the guardrail entered the windshield and pierced through the passenger compartment. Today, the ends of some guardrails extend below ground level. In some locations where the end cannot be buried, a telescoping, energy-absorbing segment is used to terminate the guardrail. Figure 14-4 illustrates some guardrail features.

Early interstate highway designs had a variety of protective barriers for bridges and other locations. Subsequent experience and research led to better barrier designs that prevent vehicles of various sizes from overriding them. Today, there is a standard barrier with a unique cross-sectional shape (see Figure 14-5). These barriers are used in perma-

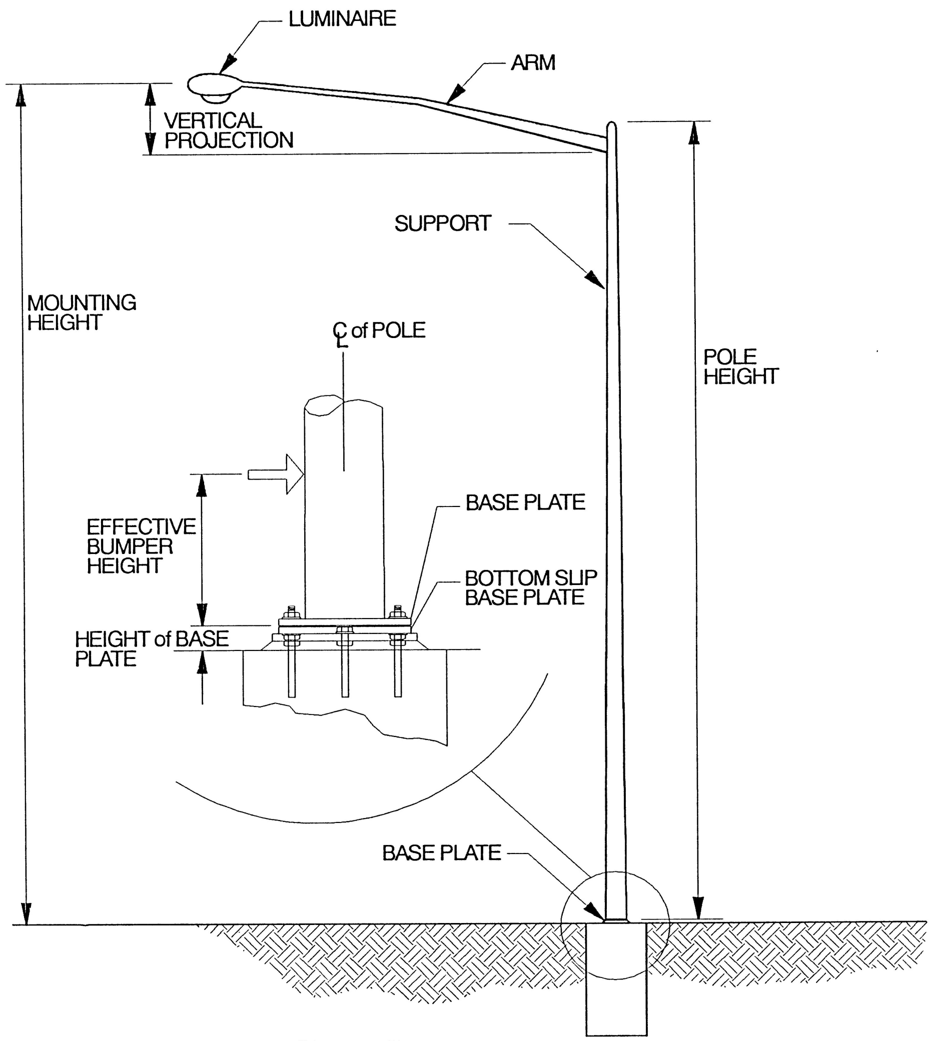

Figure 14-2. Design for break-away light poles.

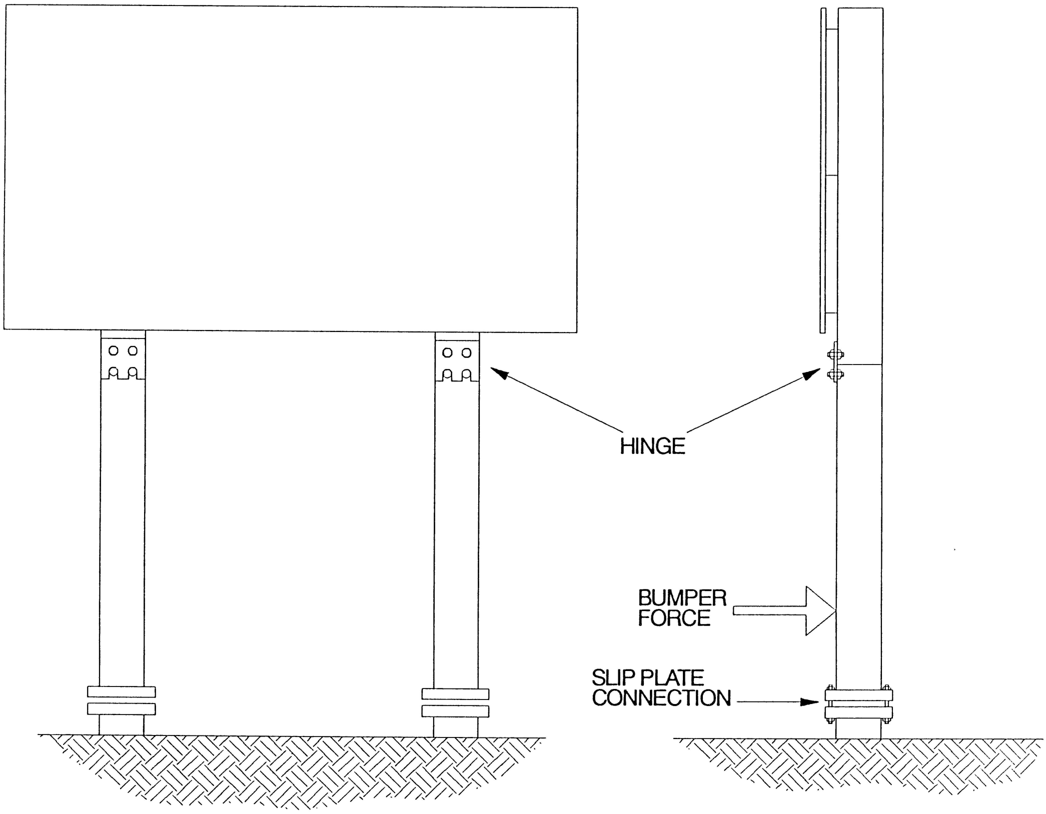

Figure 14-3. Design for break-away highway signs.

nent bridge construction and for temporary and permanent lane separation when there is not enough distance between opposing lanes.

Early interstate highway designs left unprotected those bridge supports and columns located at some distance from the pavement. The columns were immoveable when struck. Occasionally, people used them to commit suicide by driving into them at high speeds. Today, energy-absorbing barriers containing sand or water protect some of them; guardrails and the standard concrete barriers protect others. Figure 14-6 illustrates protection of bridge piers.

Environments

Traffic safety environments are comprised of such factors as time of day, weather conditions, pavement conditions, and other factors.

Accidents occur more frequently at night. Not only is visibility a problem, but the proportion of drivers who have been drinking is higher at night.

Other factors contribute to the increase in nighttime accidents. Lighting of highways and intersections in particular reduce accident frequency. Light from headlights diminishes with the square of the distance from the vehicle. Although objects are visible at some distance, the driver has a limited amount of time to react and stop the vehicle. The distance required for perception, reaction, and stopping must be less than the effective

Figure 14-4. Example of an energy-absorbing guardrail (the QuadGuard system). Telescoping sections collapse when impacted and crushable, foam-filled cartridges absorb energy. (Photo provided by Quixote Corporation, Chicago, IL.)

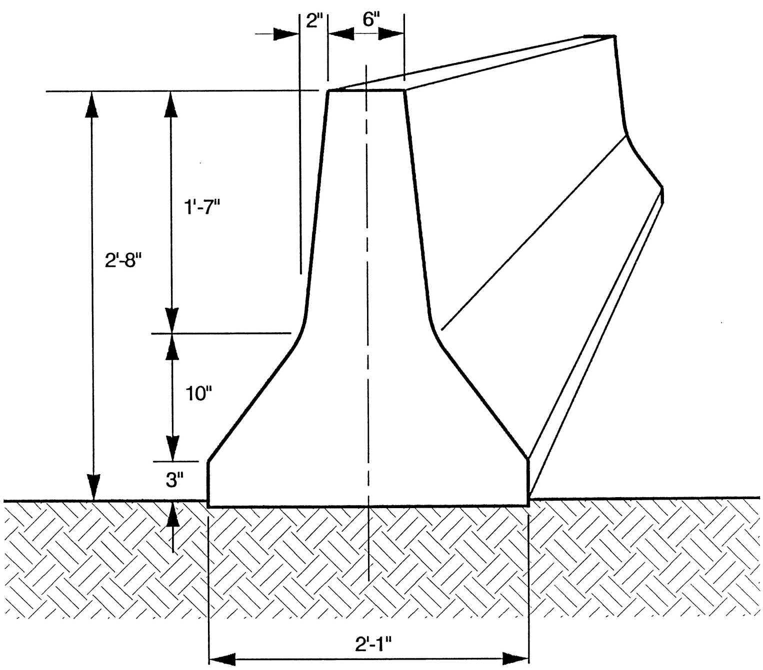

Figure 14-5. Concrete barriers provide protection for highway workers in construction zones, separate opposing traffic lanes and form bridge guardrails.

Figure 14-6. Example of sand-filled plastic barrels (the Energite III inertial barrier system) that protect vehicles from impacting bridge columns and other objects near highways. (Photo provided by Quixote Corporation, Chicago, IL.)

distance for headlights. Wearing sunglasses, having tinted windows, or having certain vision impairments will reduce the effective distance.

Falling rain and snow can hinder visibility, and wet roads and roads covered by ice and snow reduce friction between the tires and the pavement. Consequently, cars cannot stop as quickly nor maneuver as well. Grooves ground into the pavement will improve traction on wet roads.

Pavements normally have some amount of crown to allow water to drain so that pools do not form. If water does accumulate on pavement, hydroplaning can occur. In hydroplaning, a film of water separates the tires from the pavement, reducing friction even further. To enhance traction on wet pavement, tires have grooves in the tread pattern and sipes (cuts or narrow slots in the tread design that allow the tire to flex in small elements). Both tire grooves and sipes allow water to move on the tire surface and help keep tires in contact with the pavement.

Governments in northern climates spend large amounts of money to keep highways clear in winter weather. Snow fences keep drifting snow from accumulating on highways, and roads are plowed and salted. The salt lowers the melting point of snow and ice, allowing them to be removed or to evaporate. Special tread designs on tires can increase traction, particularly for snow conditions, but have a limited effect on ice. Studded tires can improve traction, but they damage pavements, which resulted in their being banned not long after they were introduced. In severe snow and ice conditions, chains provide good traction, but destroy vehicle ride, create vibration and noise, and damage pavements. Some mountan roads require chains at certain times.

Other highway conditions might be affected by shoulder width. Where there is little room between the pavement and a ditch, there is little room to maneuver away from a dangerous situation. Traffic density, merging traffic, and visual distractions are factors of the environment that are related to vehicle accidents. Trees, bushes, and buildings that obscure intersections and people or vehicles emerging from driveways and yards are envi-

TABLE 14-2 Results of One Study of 4,800 Drivers and Driving Distractions

Distraction	Percent
Rubbernecking (viewing a crash, vehicle, roadside incident, or traffic)	16
Driver fatigue	12
Looking at scenery or landmarks	10
Passenger or child distraction	9
Adjusting radio or changing CD or tape	7
Cell phone	5
Eyes not on road	4.5
Not paying attention or daydreaming	4
Eating or drinking	4
Adjusting vehicle controls	4
Weather conditions	2
Unknown	2
Insect, animal, or object entering or striking vehicle	2
Document, book, map, directions, or newspaper	2
Medical or emotional impairment	2

ronmental conditions, too. Community zoning ordinances often control setback of buildings, vegetation, fencing, and other obstruction from roadways.

Recently, distractions of various kinds received increasing attention. Cell phones, global positioning displays, video and DVD players, and other built-in or driver-carried equipment may contribute to visual, auditory, or operational distractions. Table 14-2 presents the results of one study of 4,800 drivers and driving distractions.

Additional study may help understand the effects of a growing number of in-vehicle equipment items. Eating, drinking, smoking, reading, putting on make-up, and similar activities while driving also impact driver attention, control, errors, reaction times, and stopping times. Some government entities have banned cell phone use and other distracting activities in cars. Although the exact relationships between use of various equipment and driver performance is not clear, it is clear that distractions of all kinds can affect driver error rates and performance.

Social, Political, and Managerial Context

In the social, political, and managerial context there are many laws and regulations governing drivers, pedestrians, driving employees, and others. Social pressures to drink or take drugs and drive are part of the context. Traffic problems increase in rapidly growing communities with insufficient funding to develop roadways to meet traffic loads. Lack of funds to maintain roadways and lack of standard laws, signage, and traffic procedures can contribute to accidents.

14-3 ACCIDENT RECONSTRUCTION

Accident reconstruction is the process of collecting evidence from a vehicle accident to determine what happened and what may have caused the accident. Over the years, engineers have developed a number of analytical techniques. Today, computer programs are used to store, compile, and analyze data about particular accidents.

In accident reconstruction, one first collects data at the accident scene. One records the type and model of vehicle, takes photos and records other data about the damage to the vehicle, and records or plots skid marks, impact points, locations of vehicles and vehicle components, and type of pavements or surfaces on a drawing of the scene. Because length of skid marks is critical, police often record this data as part of their on-scene reports.

From the compiled data, equations applying conservation of energy and conservation of momentum allow one to estimate the speed of vehicles before the crash, what vehicle was in what position at the point of impact, and other information. Vehicle damage and examination of remaining components also suggest whether equipment, such as lights and brakes, operated properly. Other observations may suggest defects in the vehicle.

There is a growing number and level of sophistication of software programs for modeling potential crashes or reconstructing crashes for accident site data. Enhancements include data files of vehicle mass and damage data by vehicle make and model. Some programs prepare graphic plots of the vehicle positions before, during, and after a crash overlaid on skid and other site data. Enhancements in analysis software include aerodynamic drag and disturbances, engine drag, tire rolling drag and lateral force, steering maneuvers, braking effects, impact models, and interrelationships among some of these. Computer modeling of crashes is reasonably accurate for certain scenarios. By validating the models against staged accidents, researchers have achieved accuracies within 5% to 10% of real effects.

Some simple examples of accident reconstruction analysis illustrate the approach. One can compute stopping distance, *s*, in feet, for full, four-wheel braking of an automobile, from

$$s = \frac{V^2}{30\mu}, \tag{14-1}$$

where

V is the initial velocity (miles per hour) and

μ is the coefficient of friction for the tires on the pavement.

Using Equation 14-1, one can estimate the initial speed of a vehicle from skid marks, where the vehicle skidded to a full stop.

If only two or three wheels are skidding, an additional factor, *n*, is introduced into Equation 14-1:

$$s = \frac{V^2}{30\mu n}, \tag{14-2}$$

where

n is 0.75 for three wheels braking and

n is 0.50 for two wheels braking.

The total stopping distance is

$$S_p = \text{prebraking distance} + \text{stopping distance}. \tag{14-3}$$

The prebraking distance is composed of perception time plus reaction time. Perception time is the time for recognizing that one should start braking. Reaction time is the time necessary to move the foot onto the brake pedal and begin braking.

In front and rear collisions, one can estimate vehicle velocities by applying conservation of momentum. The momentum for two colliding vehicles before a crash must be equal to that after a collision:

$$(W_1V_1) + (W_2V_2) = (W_3V_3) + (W_4V_4), \tag{14-2}$$

where

W is the weight (pounds),

V is the velocity (miles per hour),

subscripts 1 and 2 represent the two vehicles before the crash, and

subscripts 3 and 4 represent the two vehicles after the crash.

One must know vehicle weights and vehicle speed before or after the crash to solve this equation.

Example 14-1 Consider a rear-end collision between two vehicles. Vehicle 1 weighs 3,500 lb and vehicle 2 weighs 2,800 lb. Vehicle 1 is standing still at a stop light and the driver has the brakes fully engaged. Vehicle 2 crashes into it. Just at the point of impact, the second vehicle begins to skid. The two vehicles skid 25 ft beyond the point of impact, with all wheels locked. Assume the coefficient of friction between the dry pavement and tires is 0.85. How fast was the second vehicle going before the accident?

The velocity of vehicle 1 is 0 before the crash and there is no change in the weight of the vehicles from before to after the crash. Using Equation 14-4,

$$(3{,}500 \times 0) + (2{,}800 \times V_2) = (3500 + 2800)V_3,$$

V_3 is determined from Equation 14-1:

$$V_3 = (30 \times 0.85 \times 25)^{1/2} = 25.25 \text{ mi/hr}.$$

Then

$$V_2 = \frac{6{,}300(25.25)}{2{,}800} = 56.8 \text{ mi/hr}.$$

14-4 OTHER FORMS OF TRANSPORTATION

Railroads

Since their emergence in the mid 1800s, railroads have faced safety problems. In the rush to complete the transcontinental railroad in 1867, safety received limited attention. In 1888, 315 passengers were killed and 2,138 were injured. In the same year, 2,070 employees were killed and 20,148 were injured. One citizen, a farmer from Iowa named Lorenzo Coffin, was so irate that he launched his own campaign for railroad safety. After being elected to Congress, he was responsible for enactment of the Rail Safety Appliance Act of 1893. The act required the use of two inventions: the Westinghouse air brake, which replaced manual brakes on each car, and the Janney coupling, which replaced the oval links and pins. After several years, railroad employee accidents were reduced by 60%. Soon the railroads learned that safety of employees and passengers paid dividends in cash and good will.[3]

Another significant improvement was an automatic block signal system that kept trains from colliding on the same track. Also, boiler overpressure valves prevented steam engines from exploding.

Hazards The record of railroads has improved and the hazards have shifted. Today, derailments pose significant hazards from the transported materials, including explosions, fires, and releases of toxic materials. Most rail deaths and injuries now result from grade-crossing accidents with motor vehicles.

Controls Today's railroad cars incorporate many safety features. Ladders have rungs that prevent feet from sliding off. There are grab bars at climbing transition points and slip-resistant walkways and handrails. Thermally insulated tank cars prevent heat buildup and explosions from fires in adjacent cars. Cars carrying hazardous materials have interlocking couplings. Locomotives have dead-man controls to prevent runaway trains should an engineer become incapacitated. Cars containing hazardous materials have placards indicating contents and type of hazard. Automatic sensors placed strategically along main lines detect overheated bearings.

Based on traffic at crossings, more and more grade crossings are being protected by barrier gates and signals. Sensors that detect the speed of a train activate some gates and ensure adequate lead time for gates to close. Major highways avoid grade crossings with underpasses and bridges. Some cities are diverting main line rail traffic from the inner cities where dangerous traffic conflicts exist.

Aviation

The aviation industry in the United States has grown during this century to the point where millions of passengers travel each year by air. Most propeller-driven aircraft have given way to much larger jet-powered aircraft. Airways have grown more crowded. In the past decade, the number of takeoffs and landings has nearly doubled.

Hazards Aircraft must take off and land without incident. Because airspace in some areas is very crowded, sophisticated electronic gear helps fly the aircraft and control traffic in the highways of the air. Aviation hazards have changed with aircraft scale, speed, and altitude. Structural loads are greater, requiring exotic metals, like fiber-reinforced titanium. Structures face expansion and contraction from repeated loading, pressurization and depressurization, and thermal expansion and shrinkage.

A large portion of an aircraft's takeoff weight is fuel. Leaking fuel tanks and ignition can be disastrous. Icing of wings and loss of lift is still a danger in severe weather. Designing emergency exiting for as many as 450 passengers is a challenge. Detecting and avoiding wind shear, particularly in clear weather, also remains a challenge.

Controls The newest aircraft have on-board computers and instruments for navigation, flight control and management, fuel management, fire detection and extinguishment, collision avoidance, pressurization control, and many other functions. Some even have the capability for automated landing. Air traffic control systems are upgraded continually to handle increased traffic. Without these systems, aviation would not be possible or as safe as it is.

Federal Aviation Administration regulations set design standards and control air worthiness of the aircraft and its engines. Flight and maintenance logs help ensure that equipment is in good condition. Regulation of pilot training and certification place qualified crews in charge of flight. Standards for air traffic controllers are essential, too. Airlines and aviation employee unions set standards for employee qualifications. Strict management and enforcement of flight and operation regulations and procedures contribute to aviation safety.

Pipelines

Pipelines transport gases and liquids. Most materials transported by pipeline are fuels, including natural gas, liquified natural gas, and other petroleum products, although other hazardous materials, like anhydrous ammonia, move through pipelines, too. Department of Transportation regulations govern pipelines.

Other piping systems transport water, storm runoff, sanitary waste, and other wastes. Codes for water and waste fall under Environmental Protection Agency (EPA) regulations and state and local codes.

Hazards Because most pipelines are located underground, there are hazards related to materials handling and excavation during construction. For pipelines carrying fuels and hazardous materials, pumping systems move contents from sources to processing and use locations. Fire and explosion are major concerns for fuels and flammables. A leak in a pipe, fitting, valve, pump, or other component of the pipeline could produce disastrous results. During maintenance, segments being repaired must be depressurized, blocked off, and purged so that any residual fuel does not ignite. Valves must be closed and locked before flanges are worked on. If the material in the pipeline is corrosive or toxic, there are dangers of contact and inhalation. Gaskets and packings in valves are common failure points.

Most special facilities, like pumping stations, storage tanks, collection stations, and transfer stations, are above ground and part of the pipeline systems. Physical damage, corrosion, and component failures can lead to major disasters. Opening the wrong valve and not knowing what is in a system are common errors.

A failure in a pressurized water system will not have nearly the same results as piping systems for flammable or toxic materials. Storm and sanitary systems depend on gravity to move the contents. Leaks may contaminate underground water sources and leaking material may leach to the surface or into water supplies and create health hazards. The EPA has regulations for underground storage tanks.

Controls Pipelines and related components and facilities for fuels and hazardous materials that are under pressure must meet strict design standards of the DOT. Standards vary for different pipe materials and different materials transported. Pipeline and piping components are pressure tested following strict procedures before use. DOT also specifies detailed requirements for operation, maintenance, inspection, and reporting procedures. DOT standards related to pipelines incorporate the reference standards of many other organizations, including the American Society of Mechanical Engineers (ASME), the American Petroleum Institute (API), and the American Society for Testing and Materials (ASTM).

Piping and components should have labels to prevent errors in contents and what each component does. There are standards for pipe labeling. Maintenance of pipelines, components, and facilities requires detailed planning, communication among workers, and application of many safety procedures. For example, failure to remove the pressure from a pipeline and to purge residual fuels can lead to explosion, severe injury, and fire. Welding in the presence of residual fuels is dangerous. A box or hood placed on valve stems can prevent injury when a valve packing blows. Workers at some distance from a compressor used to pressure test a line must be in close communication with the compressor operator because they need to know what the pressure is at all times during the test procedure.

14-5 TRANSPORTATION OF HAZARDOUS MATERIALS

The Transportation Safety Act of 1974 recognized the dangers to life and property that can result from transportation of a variety of hazardous materials. In the event of an accident, a spill of materials could create significant harm for passengers, other vehicles nearby, and people living near the accident. The act applies to transportation, shipping, packaging, and labeling of materials defined as hazardous, and it provides for penalties for violations. Estimates suggest that there are more than 250,000 hazardous material shipments every day in the United States. Estimates also suggest that approximately 400 shipments per year are involved in injury accidents.

Hazards

The Transportation Safety Act defines several classes of hazardous materials, including explosives, radioactive material, flammable liquids or solids, combustible liquids or solids, oxidizing or corrosive materials, compressed gases, poisons, etiologic agents (hazardous biological materials), irritating materials, and other regulated materials (ORM). The act excludes firearms and ammunition. Other chapters in this book discuss hazards associated with some of these materials.

Controls

To minimize the danger to life and property, controls for hazards fall into several categories. Controls include defining and recognizing hazardous materials, excluding certain materials from particular transportation modes, limiting quantities, controlling placement, design and selection of packaging, labelling of containers, restricting transportation routes, and using shipping manifests, incident reporting, and training.

Definition and Recognition The DOT defines what materials are hazardous. They work with other agencies to maintain a list of hazardous materials. Table 14-3 lists DOT definitions for hazardous materials. Hazardous materials and information about them are listed in 49 CFR Part 172. Changes to the list are published in the *Federal Register*.

Those who transport or use hazardous materials must know which materials are hazardous. Training and labeling help convey this information.

Excluding and Isolating Materials No one is allowed to carry or ship radioactive material by aircraft. Certain materials cannot be transported on passenger aircraft or passenger railroad cars. Certain hazardous materials cannot be transported in the same shipment with certain other hazardous materials.

Limiting Quantities Another way to limit the dangers of hazardous materials is to limit the quantity present in containers or in transport. For example, one may carry very small quantities of certain materials on passenger aircraft. Regulations permit larger amounts on cargo aircraft and even greater amounts by rail, truck, or water vessels. Fines for violations can be large. Consider a case in which an employee of a chemical company carried a small container of nitric acid in his luggage. The acid spilled and damaged the aircraft baggage compartment. The company was fined $15,000.

Storage Rules Hazards of some materials increase if they come into contact with other materials. For example, a fire involving flammable materials will greatly intensify in the presence of an oxidizer other than air. Some chemicals will react violently when mixed. Because of this, hazardous materials tables give guidance on placement of materials. Some should not be placed in locations where people are normally present; some should always

TABLE 14-3 Department of Transportation Hazardous Materials Definitions[a]

Hazard Class	Definition
Explosive	Any chemical compound, mixture, or device, the primary or common purpose of which is to function by explosion.
Explosive A	Detonation or otherwise of maximum hazard.
Explosive B	In general, function by rapid combustion rather than detonation. *Flammable hazard.*
Explosive C	Certain types of manufactured articles containing class A or class B explosives in restricted quantities. *Minimum hazard*.
Blasting agents	A material designed for blasting that has been tested and found to be so insensitive that there is very little probability of accidental initiation of explosion or of transition from deflagration to detonation.
Combustible liquids	Any liquid having a flash point of more than 100°F and less than 200°F.
Corrosive material	Any liquid or solid that causes visible destruction of human skin tissue or a liquid that has a severe corrosion rate on steel.
Flammable liquid	Any liquid having a flash point less than 100°F. *Pyroforic liquid*—Any liquid that ignites spontaneously in dry or moist air at or less than 130°F. *Compressed gas*—Any materials or mixture having in the container a pressure exceeding 40 lb/in^2 absolute at 70°F or a pressure exceeding 104 lb/in^2 absolute at 130°F, or any liquid flammable material having a vapor pressure exceeding 40 lb/in^2 absolute at 100°F.
Flammable gas	Any compressed gas meeting the requirements for lower flammability limit, flammability limit range, flame projection, or flame propagation criteria of DOT.
Nonflammable gas	Any compressed gas other than a flammable compressed gas.
Flammable solid	Any solid material, other than an explosive, that is liable to cause fires through friction or retained heat from manufacturing or processing or that can be ignited readily and when ignited burns so vigorously and persistently as to create a serious transportation hazard.
Organic peroxide	An organic compound containing the bivalent –O–O– structure and that may be considered a derivative of hydrogen peroxide where one or more of the hydrogen atoms has been replaced by organic radicals. (Some exceptions)
Oxidizer	A substance such as chlorate, permanganate, inorganic peroxide, or a nitrate that yields oxygen readily to stimulate the combustion of organic matter.
Poison A	*Extremely dangerous poisons*—Poisonous gases or liquids of such nature that a very small amount of the gas, or vapor of the liquid, mixed with air is *dangerous to life*.
Poison B	*Less dangerous poisons*—Substances, liquids, or solids (including pastes and semisolids), other than class A or irritating materials that are known to be so toxic to humans as to afford a hazard to health during transportation, or that, in the absence of adequate data on human toxicity, are presumed to be *toxic to humans.*
Irritating material	A liquid or solid substance that on contact with fire or when exposed to air, gives off dangerous or intensely irritating fumes, but not including any poisonous (class A) material.
Etiologic agent	A viable microorganism, or its toxin, that causes or may cause human disease.
Radioactive material	Any material or combination of materials that spontaneously emits ionizing radiation and has a specific activity greater than 0.002 μCi/g.

TABLE 14-3 continued

Hazard Class	Definition
ORM (Other regulated materials)	Any material that does not meet the definition of a hazardous material, other than a combustible liquid in packaging having a capacity of 110 gal or less, and is specified as an ORM material or that possesses one or more of the characteristics of specific ORM classes of materials.
ORM A	A material that has an anesthetic, irritating, noxious, toxic, or other similar property and that can cause extreme annoyance or discomfort to passengers and crew in the event of leakage during transport.
ORM B	A material (including a solid when wet with water) capable of causing significant damage to a transport vehicle or vessel from leakage during transportation. Materials meeting one or both of the following criteria are ORM B materials: (1) a liquid substance that has a corrosion rate exceeding 0.250 in/yr on aluminum (nonclad 7075-T6) at a test temperature of 130°F; (2) specifically designated by name by DOT.
ORM C	A material that has other inherent characteristics not described as an ORM A or ORM B but that make it unsuitable for shipment, unless properly identified and prepared for transportation. ORM C materials are specifically named by DOT.
ORM D	A material such as a consumer commodity (packaged or distributed in a form intended and suitable for retail sale for consumption by individuals for personal care or household use, including drugs and medicines) that, although otherwise subject to the regulations of this subchapter, presents a limited hazard during transportation because of its form, quantity, and packaging. They must be materials for which exceptions in DOT regulations are provided.
ORM E	A material that is not included in any other hazard class, but is subject to DOT regulations. Included are hazardous waste and hazardous substance named by DOT in this class.

[a] See also 49 CFR 171–173.

be separated from other materials during storage and transit; others must be kept dry, cool, away from sunlight or heat, or meet other restrictions.

Packaging Design and Selection DOT has many standards for the design of packaging. Regulations specify strength, dimensions, and other properties for fiberboard boxes and drums, glass carboys, steel drums and liners, tank trucks, rail tank cars, and many other containers. Regulations also specify what type of container to use for each hazardous materials. The major purpose of these design standards is to minimize the release of hazardous materials, even if the packaging is in an accident. To dramatize the value of hazardous material packaging, the British government placed a shipping container for nuclear fuel rods on a railroad track and crashed a train into it at 100 mi/hr. The container withstood the crash without a leak.

Labeling Serious errors in the transport and handling of hazardous materials could occur when one does not know what is in containers. DOT has many regulations regarding labeling of particular materials. Typically, the label indicates what material is inside the container and gives warnings for handling and transport, DOT hazard class, and special information. In many cases, empty containers must have an "EMPTY" label. For some materials, there are dangers for an empty container that do not exist when it is full.

As part of the labeling, DOT requires a standard warning placard. Motor vehicles, freight containers, and rail cars must have placards listing the class of hazardous material by name and symbol. For some materials, a placard also must list the name of the material and a DOT identifying number. A United Nations Hazard Class Number[4] also may be displayed. Figure 14-7 gives examples of DOT warning placards.

Restricted Transportation Routes Some states have laws that restrict the highways over which certain hazardous materials can travel. Restrictions are typical for areas where there are high densities of people and highly traveled or critical tunnels and bridges. In addition, there may be local ordinances that restrict transportation of hazardous materials. Some of these restrictions resulted from public reaction to disasters. For example, a railroad tank car containing LP gas caught fire and exploded in Crescent City, Illinois, in 1970. This disaster occurred as the train was passing through the town and the explosion destroyed most of the businesses.

Shipping Papers DOT regulations require that a shipping order, bill of lading, manifest, or other document used to initiate a shipment must describe any hazardous material offered for shipment. The description must include the name of the material, the DOT hazard class, the amount being shipped, and the number and type of containers. The document must separate hazardous materials from other materials. The shipping papers must certify that hazardous materials are packaged and labeled properly. There are additional requirements for hazardous waste.

Incident Reports During transportation, a carrier must report to DOT any unintentional release of a hazardous material. When an incident involves death, serious injury, major property damage, or certain releases of radioactive and etiologic agents, the carrier must make an immediate telephone report. DOT regulations detail these reporting procedures.

Training To help minimize the release of hazardous materials, people in the entire chain must receive training. Designers of packaging, preparers of shipments, managers of ship-

Figure 14-7. Examples of DOT warning placards.

ping and handling, drivers, operators, and handlers need to know the dangers of the materials and the procedures to ensure safety. DOT requires that each person who offers hazardous materials for transportation must instruct officers, agents, and employees about applicable regulations.

EXERCISES

1. A car skids to a stop. At the start of the skid, the car was traveling at 50 mi/hr. What was the stopping distance if the coefficient of friction between the tires and the pavement was 0.71?
2. An investigator finds skid marks 90 ft long. If the skid brought the car to a stop, what was the initial velocity of the car? Assume a coefficient of friction of 0.65 between the tires and the pavement.
3. For the situation in Problem 2, what was the initial velocity if only two wheels were sliding and the braking efficiency was 0.5?
4. For the situation in Problem 2, what was the total stopping distance if the driver's combined perception and reaction time was 0.65 s? Assume the vehicle weights 1,000 lb.
5. Car 1 is stopped with brakes locked. Car 2 skids and strikes car 1 in the rear. If, after the collision, both cars skid 60 ft to a stop and the coefficient of friction is 0.45 for a wet pavement, what was the velocity of car 2 at the time of impact? Car 1 weighs 2,500 lb and car 2 weighs 3,800 lb.
6. A forklift industrial truck turns a corner with a 1,000-lb load on the forks. The forks are raised 3 ft above the floor. The center of gravity for the forklift with driver is 38 in above the floor with empty forks at the floor. The center of gravity of the load is 22 in above the floor when it sets on the floor. The forklift weighs 2,800 lb. Its wheels are 48 in between lateral outside edges. If the radius of turn is 25 ft, the speed of the forklift is 8 mi/hr, and the coefficient of friction between tires and floor is 0.67, will the forklift turn over, skid, or negotiate the turn?
7. Locate consensus or government safety standards for each of the following. Select one design feature that contributes to safety for each and describe its function.
   - **(a)** motor vehicles
   - **(b)** school buses
   - **(c)** truck tractors
   - **(d)** truck trailers
   - **(e)** highways
   - **(f)** railroad cars
   - **(g)** railroad traffic controls
   - **(h)** aircraft
   - **(i)** pipelines
8. Review the current regulations related to transportation of hazardous materials issued by the Department of Transportation. Identify key requirements for each mode of transportation.
9. Conduct a review of the safety standards for the pipeline industry issued by the American Petroleum Institute.

REVIEW QUESTIONS

1. Approximately how many people die each year on United States highways?
2. What is the leading cause of occupational injuries and work-related deaths?
3. The motor vehicle death rate is highest for what age groups?
4. What portion of drivers involved in fatal crashes have blood alcohol content (BAC) of 0.10 or more?
5. Describe the crash sequence for vehicle and passenger in
   (a) a frontal crash
   (b) in a rear-end collision
6. What is the "second crash"?
7. Describe the concept of crashworthiness.
8. What is meant by integrity of the passenger compartment?
9. What organizations publish standards for motor vehicles?
10. Describe a safety feature built into a motor vehicle.
11. Describe a driver characteristic important for motor vehicle safety.
12. Describe a design standard for highways that reduces injury or death.
13. Describe an environmental factor that contributes to motor vehicle safety.
14. What is accident reconstruction?
15. Name two hazards in rail transportation today.
16. Name four safety design features in railroad cars.
17. Name four factors that contribute to aviation safety.
18. Identify four controls for hazards of pipelines and related facilities.
19. What types of controls reduce the dangers associated with transportation of hazardous materials?

NOTES

1 Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC, 20402.

2 AASHTO, Suite 249, 444 North Capitol Street NW, Washington, DC 20001.

3 Holbrook, S. H., *The Story of the American Railroads,* Crown Publishers, New York, 1947.

4 "Transport of Hazardous Goods," United Nations Recommendation, United Nations, New York, 1970.

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