Occupational Safety

Ride-On Lawnmowers

The hazards of overturning

By Melvin L. Myers

IN 2007, the California Occupational Safety and Health Standards Board (OSHSB) considered a petition to require rollover protective structures (ROPS) and seatbelts on powered ride-on lawnmowers. The petition was brought by parents whose son was mowing grounds as a gardener when the mower hit a rock and overturned off a ledge. He flipped off the machine, which then landed on him. He was fatally injured and his parents claimed his life may have been spared had the mower been outfitted with a ROPS and seatbelt. California OSHSB (2007) granted the petition with a review of state rules to address the request.

Bureau of Labor Statistics' national Census of Fatal Occupational Injuries reported that 169 employees in the landscaping industry were killed at work in 2006. Of a total of 116 mower-related occupational fatalities that included tractors from 2003 to 2006, 66 (57%) workers were fatality injured while they operated a ride-on lawnmower. Figure 1 shows fatalities in private industry and not public entities such as city park employment.

Consumer Product Safety Commission (CPSC) has found that mower overturns were more frequent in 2003 than they were in 1993 (Adler & Schroeder, 2004). This increase in frequency may have been related to an increase in the use of ride-on lawnmowers. A 2002 profile by the Outdoor Power Equipment Industry (OPEI) of the sale of ride-on commercial rotary mowers showed an increase of 121% in the previous 4 years. This was an average increase of more than 20% per year (Comer, Ayers, Wang, et al., 2003). Also, there appeared to be a trend of increased incidence of lawnmower-related injuries with a lack of the awareness of lawnmower hazards (Costilla & Bishhai, 2006). Industry representatives indicated that overturns occur primarily in grassy areas such as golf courses, community parks and sports fields, and not when mowing residential lawns (OSHSB, 2007).

Melvin L. Myers, Capt. (retired), *U.S. Public Health Service, served 9 years with EPA and 18 years with NIOSH. Myers holds a B.S. in Engineering from the University of Idaho, and a Master's of Public Affairs from Indiana University. He is an associate professor at the University of Kentucky in the College of Public Health and an associate professor (adjunct) at Emory University, Rollins School of Public Health.*

The classification of mower types has been complex (Scarlet, Reed, Semple, et al., 2006). The traditional type of mower, used along roadsides, was of a sickle or rotary-type that was attached to a utility tractor, which has an engine with less than engine 90 hp (67 kW). Smaller mowers have evolved into lawn tractors or zero turn radius (ZTR) mowers—(Photos 1 and 2), according to Consumer Reports (2008). ANSI (2003) divided ride-on lawnmowers into consumer use—a concern for CPSC—and commercial use (ANSI, 2004)—a concern for OSHA—that were marketed to homeowners and employers, respectively.

The purpose of this study was to describe the factors associated with the overturn hazard of the ride-on lawnmower, which was defined as a self-propelled machine, designed and advertised for mowing lawns (ASABE, 2005). These factors included characteristics inherent with the mower design that included rollover protection, environmental conditions and human factors that spanned the time frame from prior or incipient circumstances through the overturn event to postevent actions. The study used existing public data, which was biased toward serious injuries or fatalities that were reported or investigated and excluded successes of interventions that protected the operators from injury.

Background: The Overturn Hazard

Overturns may be to the rear (longitudinal) or to the side (lateral). The problem of equipment overturns began in 1914 with the first mass-produced small gasoline engine tractor. Manufactured by M. Hartsough and named the Little Bull, the tractor would overturn to the rear on a slope when it was turned uphill because of its unique design (Myers, 2003).

In 1954, OPEI petitioned the American Standards Association (renamed ANSI in 1969) to develop safety standards for the lawnmower manufacturing industry. The standards that resulted were ANSI B.71.1 in 1972. In 1968, President Lyndon Johnson established a National Commission on Product Safety, which evaluated lawnmower safety (Alexander, 1990).

Congress established CPSC in 1973, which selected Consumers' Union (CU) as the "offeror" to recommend lawnmower standards in 1974. Based on the CU recommended standard of 1975, CPSC published a proposed standard in 1977 that included the prevention of injuries from ride-on lawnmowers (Adler, 1993). However, CPSC withdrew that portion of the proposed standard that applied to ride-on lawnmowers (Moore & Magat, 1996) based on OPEI plans to upgrade the voluntary ANSI B71.1 standard (Adler, 1993).

A 1988 CPSC report found that half of 96 reported ride-on lawnmower-related deaths from 1983 through 1986 were associated with the hazards of tipping or sliding and walls or banks. Factors that contributed to initial tipping or sliding were terrain transition (15%), damp or wet grass (14%), uneven terrain (12%), and turn (10%); more than one factor may contribute to a tip or slide. Figure 2 (p. 54) shows the incipient factors to the mower as it became unstable and the factors that contributed to the overturn. CPSC investigated 15 slope-related overturns, half of which occurred on inclines greater than 15º. The majority of operator deaths occurred near a sharp drop in terrain where the decedent was found under an overturned mower (Smith, 1988).

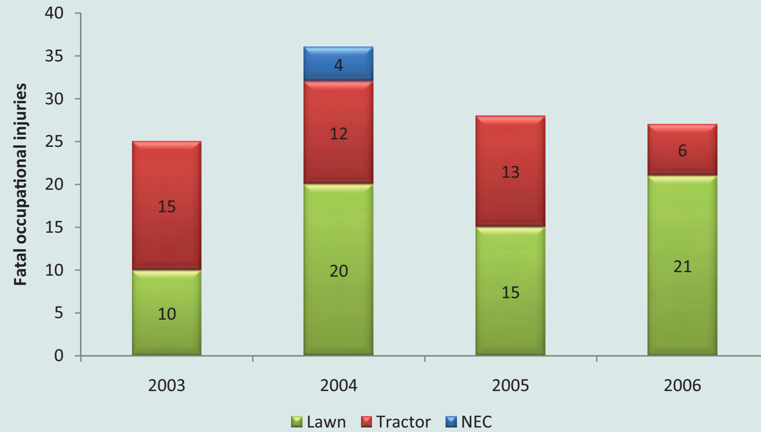
In 1987, CPSC recommended that tractor/mower operators drive up and down slopes and not across them to reduce the chance of overturn; this recommendation preceded a rise in use of ZTR mowers (CPSC, 1987). CPSC conducted another study of deaths and injuries associated with ride-on mowers for the period 1987 through 1990 (David, 1993). It estimated 150 deaths per year, which excluded farming or industrial products, with 60 of those associated with ride-on mowers; the remainder of the 90 deaths was associated with tractors and mowers not otherwise specified.

A primary hazard was to tip or slide the mower, which usually resulted in an overturn, or a fall over a wall or embankment. Overturns contributed to 59% of the fatalities. Forty percent of the overturns were associated with an incline such as a hill, slope or embankment.

In 1988, CPSC evaluated ride-on lawnmower dynamics on slopes that ranged from 10° to 25° (Eilbert, 1988). A rear-engine and a front-engine mower were tested. Modes of instability tested were pitch (longitudinal), roll (lateral), loss of traction, freewheeling (wheels roll with the engine off), and combinations of these modes and mower velocity.

Figure 1

Fatal Occupational Injuries in Mowing Operations



Note. *Fatal occupational injuries associated with mowing operations by primary source (tractor operated, lawnmower and not elsewhere classified) for private industry in the U.S., 2003-2006, Census of Fatal Occupational Injuries (excludes public employees and consumers).*

Further study was recommended for longitudinal stability related to sudden traction uphill with some rollback, maneuvers for lateral stability, and loss of traction and control.

In 1991, CPSC conducted field tests on grass slopes of the dynamic stability of mowers (Whitfield, 1992). The tests were conducted on three ride-on lawnmowers, and the results indicated that wheel liftoff (the measure of instability used) increased as either the speed, the slope angle or a combination of both increased. CPSC recommended that tests be conducted on both 15° and 20° slopes. The characteristics of the three mowers used in this test are shown in Table 1 (p. 54).

A study of tractive performance on lawn and garden tractors found that drive wheel slip was greater on dry grass than wet grass (Tompkins, Freeland, Wilhelm, et al., 1991). Four different tire designs consistently spunout at a 15º uphill pitch. Moreover, the study found the slip to be greater on the wheel that supported the greater load (e.g., downhill wheel).

CPSC conducted an analysis of hazards associated with ride-on mowers in 1993 (Adler, 1993). Mower instability was one hazard pattern associated with 2,200 injuries (13%) and 440 hospitalizations (20%) of a total of 17,000 injuries and 1,916 hospitalizations in the sample for the years 1987 through 1990. An additional 500 injuries (3%) and 125 hospitalizations (25%) were associated with a drop over a bank or wall.

Factors that contributed to instability included the design of the machine (e.g., brake pedal), the environment (e.g., slope) and operator actions (e.g., oversteering). This analysis concluded that the mower landed on top of the operator in about 75% of the overturns, and the mower initially faced uphill on a slope in about 50% of the overturns. In overturn-related spinouts that included free-

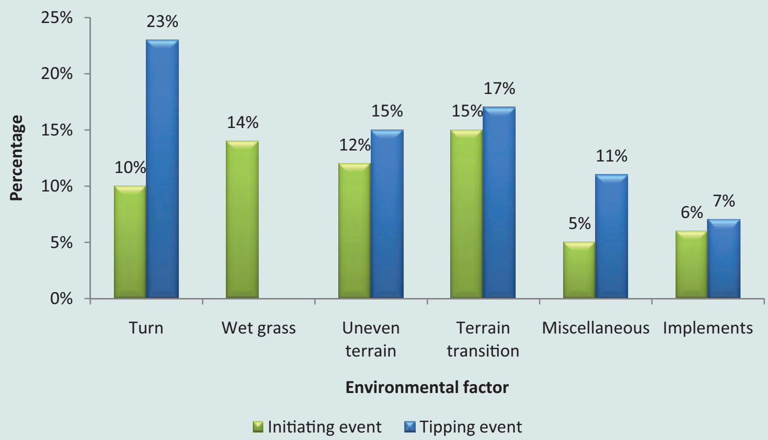

From left: Photos 1 and 2 show a lawn tractor and a zero turn radius (ZTR) mower.

PHOTOS COURTESY CPSC

Abstract: *Powered ride-on lawnmowers present risks of serious injury from overturns, yet the public is largely unaware of this hazard, its causes and the potential for overturn-related injuries. This study collected information on overturn-related injuries from various sources and analyzed it using the Haddon Matrix, which classifies risk factors by the machine, environment and operator, and by the circumstances that preceded the overturn, the overturn event and actions taken or conditions that followed the overturn.*

Figure 2

Mower Overturns: Contributing Factors



Note. *Contributing factors to the initiating and the tipping events of mower overturns, 1988.*

wheeling, about 89% occurred on wet grass-covered slopes with an average angle of 23º.

CPSC completed a hazard investigation of yard and garden equipment for injuries reported in 2001 (Rutherford, Marcy & Mills, 2003). In this study, 44 deaths, 13,280 emergency room visits and 37,730 medically treated injuries were reported—of which 10% of the medically treated patients were hospitalized. This study found that as much as 61% of the injuries could be addressed by equipment enhancements.

In 2003, CPSC estimated the annual number of injuries related to ride-on lawnmowers at 35,922, and during the 6-month period of April 1, 2003, to Aug. 31, 2003, CPSC estimated 8,000 injuries from overturn hazards (Adler & Schroeder, 2004). Most injuries were serious and caused by the weight of the mower as it came down on the operator. About 68% of the injuries were associated with mowing on a slope, hill or embankment. Another 28% occurred when the mower hit a root, bump, hole or fence and overturned.

Another study found that as the slope became steeper, steering control and traction on ZTR mowers was lost when one wheel reached 100% slip (spin-out) (Besselink & Fielke, 2003). Moreover, on slippery terrain, the loss of traction on one wheel caused a sudden steering deviation. Users of ZTR mowers contacted in a survey all responded that the slope limit should be 15º when mowing (Scarlet, et al., 2006).

National Safety Council, in collaboration with two ride-on lawnmower companies, initiated a mower safety training program in 2005 that covered the prevention of overturns (Wisniewski, 2005). In addition, three OSHA regional offices established local emphasis programs to educate landscape and horticultural service workers on how to reduce or eliminate risks, including the overturn hazard.

The programs were launched in Region II (which covers New York and New Jersey); Region III (focused on military reservations in Norfolk, VA); and Region IV (which covers North and South Carolina, Georgia, Florida, Alabama, Mississippi, Tennessee and Kentucky) (OSHA, 2007).

Rollover Protection

A ROPS is a structure designed to reduce the possibility of an operator being crushed or otherwise injured in the event of an off-road vehicle overturn. A seatbelt worn in conjunction with a ROPS may provide additional protection in the event of an overturn (ANSI, 2004). In addition, if a mower overturns into water, the ROPS may protect the operator from being pinned under the water. ROPS were designed to absorb energy in a vehicle overturn and also provide a spring response against the overturn force (Sommer, Nichol & Murphy, 2006). Furthermore, the

Table 1

Physical Lawnmower Characteristics

Vehicle	Model year	Engine location	hp (kW)	Weight lb (kg) Mower	Weight lb (kg) + 200 lb	Static stability Uphill	Static stability Right side	Static stability Left side
A	1983	Front	11 (8.2)	395 (180)	595 (270)	27°	27°	28°
L	1988	Rear	10 (7.5)	350 (159)	550 (250)	40°	26°	25°
M	1988	Rear	12 (9.0)	630 (286)	830 (377)	42°	27.5°	30.5°

Note. *Physical lawnmower characteristics used in the 1991 CPSC stability field tests. Analysis of dynamic tests on grass slopes using riding mowers A, L, and M. Adapted from* Analysis of Dynamic Tests on Grass Slopes Using Riding Mowers A, L and M, *by T. Whitfield, 1992, Washington, DC: CPSC, Directorate for Engineering Sciences.*

ROPS frame can yield and absorb energy to reduce the load transmitted to the mounting bolts and tractor body (The State of Queensland, 2006).

As far back as 1974, a patent was issued to Hoffmeyer and Heth (1974) for the invention of a ROPS for small ride-on tractors used for mowing, and a ROPS was present on a grass-cutting mower in 1994 (Dai, Zhang & Clark, 1994). Operator zone protection was recognized as the first step in the design of a ROPS (Teaford, 1993)—not only must the operator be protected within that zone, but the operator must be restrained within that zone by devices such as a lap belt. However, equipment manufacturers have long held that personal restraints should not be installed or used on equipment that lacks a ROPS so that the operator has a chance to jump clear in the event of an overturn (Myers, Cole & Westneat, 2006).

Society of Automotive Engineers' (SAE) standard J2194 has been used to comply with the OSHA ROPS standard for wheeled agricultural tractors (ASABE, 2002). OSHA required that ROPS be provided by the employer for each tractor of more than 20 engine hp (14.9 kW) operated by an employee (OSHA, 1976a). However, the standard exempted low-profile tractors where the vertical clearance was insufficient to allow a ROPS-equipped tractor to operate.

ANSI B71.4-2004 standard provided a procedure for longitudinal and lateral stability tests for ride-on mowers and turf tractors. The standard specified that if a machine's mass was less than 1,436 lb (655 kg)—as shown in the sidebar at right—then an operator's protective device, which may be a ROPS, would not be required; however, if that mass was greater and the tip angle was less than 40°, then the machine should be outfitted with a protective device to minimize a crushing injury in the event of a lateral overturn. The standard's rationale for the mass limit was based on limited information on injury severity from overturns; the limited accident data available showed that the injury severity under the weight limit was low.

Ayers, Conger, Comer, et al. (2003) calculated the critical (tip) stability angles for four lawn tractor models and four ZTR mower models when unloaded and loaded with a 200-lb (91 kg) operator. Table 2 shows the average lateral and longitudinal tip angles from these calculations.

The ANSI (2004) mass limits referenced two other standards: Organization of Economic Cooperation and Development (OECD) codes 6 and 7 (OECD, 2008a; 2008b); and Australian standards AS 1636.2 and 1636.3 (1996). The ANSI standard claimed exemption from OSHA 1928.51 because of overhead clearance problems encountered while mowing.

OECD codes 6 and 7 relate to narrow track agricultural and forestry tractors to test the ROPS, respectively, for rear- and front-mounted ROPS. They apply to tractors with a lower mass limit of 1,323 lb (600 kg) without the weight of the ROPS.

The Australian standards were intended for designers, manufacturers and testers of mid-mounted and rear-mounted ROPS for narrow-track, wheeled tractors. They describe two different methods of ROPS testing. Static tests use a technique that applies loads to the ROPS apparatus by direct contact in a laboratory on machines that weighed more than 1,235 lb (560 kg). Dynamic tests use kinetic loads to impact the ROPS apparatus.

In Australia, the State of Queensland (2006) has rules that require compliance with AS 1636 for ROPS testing, which exempt tractors that weigh less than 1,235 lb (560 kg). However, this standard states that there are no circumstances of operation in which a tractor is safe from overturning. The rules provide that an exempt tractor should not be used unless all proposed activities have been assessed for safety risks and all reasonable actions have been taken to

Standards for ROPS

OSHA 1928.51[a] (OSHA, 1976a) & 1928.52 (OSHA, 1976b)
Machine: Agricultural tractors
ROPS application by machine characteristics: ≥ 20 engine hp (14.9 kW)

ANSI B71.4
Machine: Riding mowers
ROPS application by machine characteristics: > 1,436 lb (655 kg)

OECD 6 Rear-Mounted ROPS
Machine: Narrow track tractors
ROPS application by machine characteristics: 1,323 to 6,614 lb (600-3,000 kg) unladen with ROPS

OECD 7 Front-Mounted ROPS
Machine: Narrow track tractors
ROPS application by machine characteristics: 1,323 lb (≥ 600 kg) unladen with ROPS

AS 1636 2 Mid-Mounted ROPS
Machine: Narrow track tractors
ROPS application by machine characteristics: Dynamic test: 1,764 to 6,614 lb (800 to 3,000 kg); Static test: 1,235 to 6,614 lb (560 to 3,000 kg)

AS 1636 3 Rear-Mounted ROPS
Machine: Narrow track tractors
ROPS application by machine characteristics: Dynamic test: 1,764 to 13,228 lb (800 to 6,000 kg); Static test: 1,235 to 13,228 lb (560 to 6,000 kg)

Note. *Standards that relate to ROPS use on ride-on lawnmowers either directly or by reference. [a]Not OSHA 1928.57 (OSHA, 1976c), as cited in ANSI. B71.4, p. 73.*

Table 2

Average Tip Angles

Vehicle type	Lateral tip angle Unloaded	Lateral tip angle Loaded	Longitudinal tip angle Unloaded	Longitudinal tip angle Loaded
Lawn tractors	44.5°	37.2°	55.3°	44.4°
ZTR mowers	51.5°	44.2°	37.6°	33.2°

Note. *Average tip angles for four lawn tractor models and four ZTR mower models.*

Photos 3 and 4: A continuous lateral overturn on a 35° slope as observed during a field test of a ROPS on a triplex mower.

prevent or control these risks. The rules also stated that a fold-down ROPS may be used in operations inside buildings or near trees, and the ROPS design should reduce the likelihood of continuous overturn and protect the operator.

A recent American Society of Agricultural and Biological Engineers (ASABE) standard established a tipover protective structure (TOPS) standard for front-wheel-drive ride-on lawnmowers, which stated that an overturn must not allow the mower to roll onto its top. Investigators have evaluated this standard for the influence of deck size in its effectiveness to stop a continuous roll (ASABE, 2002). They found that deck size, yaw and slide downhill must be considered in ROPS design (Wang & Ayers, 2006; Wang, Ayers, Womac, et al., 2007). These tests concluded that OECD code 6 was insufficient to prevent a continuous lateral overturn as shown (Photos 3 and 4) and the mower deck needs to be factored into the design to prevent a continuous overturn (Ayers, 2006). As a result of these tests, ASABE withdrew the TOPS standard. In the meantime manufacturers produced mowers per OSHA 1928.52 for the U.S. while international standard harmonization via ISO 21299 progressed (ASABE, 2007).

The ride-on mower industry, which includes ZTR manufacturers, has indicated that the ROPS standards applied to its vehicles may be overdesigned. However, a study in England concluded that the ROPS standards currently used were adequate for ride-on mowers (Scarlet, et al., 2006).

An ASABE standard (2005) was established to be consistent with a safety specification for commercial turf equipment from ANSI (2004). An annex to an ASABE standard for agricultural rotary mower safety recommended that the tractor be equipped with a ROPS (ASABE, 2004). A draft International Organization for Standardization (ISO, 2007) standard provided for tests of structures for operator protection against injury from overturns of ride-on turf-care equipment.

In its letter to landscape operators in May 2005, OSHA's Tampa Area Office warned of the hazard of ZTR mower operations on steep slopes and near drop-offs or water, and expressed the need for ROPS on ZTR lawnmowers. As a result, eight other area offices mailed similar letters to 2,925 employers in Alabama, Florida, Georgia and Mississippi. This effort was augmented by one mower manufacturer that offered to retrofit a ROPS free-of-charge to any of a line of ZTR mowers and free training materials on ZTR safety (OSHA, 2006).

NIOSH has developed an automatically deployable ROPS (AutoROPS) that can provide protection to the operator in the event of an overturn and that allows the machine to be operated in low-clearance areas. NIOSH has partnered with a ROPS manufacturer and a mower manufacturer to equip a ZTR mower with an AutoROPS (Etherton, McKenzie & Powers, 2004).

Method of Analysis

A two-step method was used in this study. The first step was to identify cases from three sources of ride-on lawnmower overturn incidents. The first source was newspaper reports, the second was narratives from CPSC's National Electronic Injury Surveillance System (NEISS), and the third was investigation summaries and reports by OSHA and NIOSH. The news reports included serious events (e.g., deaths or unusual circumstances, such as the operator pinned for hours prior to rescue). These reports were identified through a 2007 search of Google and NewsBank with the keywords of *mower* and *accident*. The narratives from the NEISS reported cases that were treated in hospitals. In 2006, NEISS recorded a sample of 274 emergency room-related injuries related to ride-on lawnmowers, which CPSC extrapolated to 12,768 nationally for that year. The OSHA cases included

Table 3

Example of a Haddon Matrix Analysis

Factor	Preevent	Event	Postevent
Vehicle (zero-turn-radius mower)	Pointed uphill Wheels spinout	Overturned to rear No ROPS and seatbelt	Upside down Bent steering arm Throttle at full power ROPS and seatbelt retrofitted
Environmental (park)	13° to 19° slope Grass on moist soil	4.5-ft bank 3-ft-deep creek Rock bottom	Sand and mud cleared 5 minutes after stirring
Human (operator)	23-year-old female Drove onto slope Full power uphill away from hazard[a]	Pinned under mower	Drowned 45 to 90 minutes under water Three responders lift mower off

Note. *An example of a Haddon Matrix analysis of a mower overturn incident. Data from Marble Falls Police Department, TX, Report No. MFPD0590167.6, 2.24.2005.* [a]*A human behavior noted in ANSI B74.4-2004, p. 73.*

For complete tables, visit www.asse.org/psextras for lists of cases and detailed information.

PHOTOS COURTESY HIGH PLAINS CENTER FOR AGRICULTURAL HEALTH AND SAFETY those from a search of the investigations on OSHA's website (2007).

The second step was to use the Haddon Matrix (Haddon, 1972; 1980) to analyze those cases for which data could be collected. The news reports contained some data as did the NEISS narratives, but the most detailed data (e.g., angle of slope) were provided by incident investigation reports. These reports included investigations conducted by OSHA, a police report and a NIOSH Fatality Assessment and Control Evaluation report.

The Haddon Matrix has been used to evaluate all-terrain-vehicle-related deaths (Hargarten, 1991); highway crash injuries (Albertson, Bjornstig & Falkemer, 2003); logging fatalities (Myers, Manwaring, Kennedy, et al., 1993); commercial fishing deaths (NIOSH, 1997); and road compactor/roller incidents (Myers, 2004). The matrix provides an epidemiology framework (Table 3) used to analyze data and suggest countermeasures.

Qualitative data were separated into the appropriate cells in the two dimensions by the risk factor—vehicle, environmental and human factors—and the phase of the injury-causing event—preevent, event and postevent. The matrix was used to identify circumstances before, during and following the overturn event. Against these three phases, it was used to identify risk factors—the circumstances—associated with the event and its consequences. These risk factors can be targeted to reduce the risk of an overturn event, or given that event, to protect the operator from injury.

Table 4

Risk Factors: Newspaper Reports

Factor	Preoverturn	Overturn	Postoverturn
Consumer lawnmowers (n = 80)			
Lawnmower	spin-out (7), slide (1), towing (2)	overturn (75)	
Environment	pond (2), incline (5), bank (11), creek (1), stump (1), gravel (1), hill (4), wall (2), ditch (3), drain (1), cliff (2), lake (1)	home (70), lot (1), residence (1), roadside (1), road (1), neighbor (1)	
Operator	ages 3-89 years, male (81%), female (18%) unknown (1%), into shed (1), turn (2), extra rider (1)	fall (2), mishap (1)	asphyxia (5), fire dead (3), drown (8), additional dead (52), critical (3), minor (1), cut (2), burned (1), guarded (1), rescued (3)
Commercial lawnmowers (n = 42)			
Lawnmower	spin-out (2), slide (1), runaway (1)	overturn (38), runover (2), fall off (2)	
Environment	shoulder (1), hill (2), bank (8), slope (2), lake (4), edge (3), pond (4), ditch (1), lagoon (2), lake (2), bog (1), ledge (1), muddy (1), wet grass (1)	airport (1), roadside (3), road (1), lawn (6), hospital (1), golf (8), condos (1), park (7), subdivision (1), stable (1), lodge (1), canal (1), cold (1)	
Operator	ages 3-89 years male (100%),), hit wall (1), turn (1)	exposure (1)	asphyxia (1), drown (16), additional dead (18), critical (2), rescued (2), arm loss (1), serious (1)
Consumer or commercial mowers (indeterminate from the news reports) (n = 12)			
Lawnmower	spinout (2)	roll (1), overturn (9)	
Environment	bank (3), incline (2), ditch (1), hill (1)	roadside (1), lawn (1)	
Operator	ages 45-66 years male (92%) female (8%)		asphyxia (1), fire dead (1), additional dead (8), minor (1), arm loss (1)

Note. *Risk factors from news reports associated with ride-on lawnmower overturns classified by the risk factor and overturn event phase. The numbers shown with parentheses count the number of reports that identified the risk factor.*

Results of Analysis

Newspaper Reports

Table 4 lists the results of a newspaper search on the Internet. Many of the circumstances were absent from these reports, but some circumstances of ride-on lawnmower instability, environmental conditions and injury victim characteristics were reported. In most cases, the author was able to determine whether the lawnmower was used in a consumer or commercial setting.

Fatalities dominated the newspaper case reports. The cause of these deaths included drowning, fire deaths and asphyxia. Drowning resulted when an operator was pinned under water by an overturned mower, and a fire death occurred when the operator was pinned under a mower that spilled gasoline from the fuel tank (because of a dislodged fuel cap) and ignited. Asphyxia resulted from

Application

How the Haddon Matrix Was Used to Identify Ride-On Lawnmower Overturn Hazards

Factor	*Identified risk factors*
Machine	•Static stability: tip angle to the side (lateral) and to the rear (longitudinal), overturn. •Dynamic stability: uphill spinout, sliding, turning, runaways, loading or unloading. •Protection: no rollover protection, no personal restraints, potential fuel leaks and ignition.
Environment	•Steep slopes, embankments, slippery surfaces (muddy, wet grass), drop offs, water (creeks, ponds, lakes, canals), obstacles (trees, ledge), ditches, visibility (nighttime, drop-offs obscured by high grass).
Operator	•Turns, fell off, jumped, ejected, seatbelt use, untrained, lost control, pinned.

Table 5

Circumstances Reported by Hospitals

Factor	Preoverturn	Overturn	Postoverturn
Lawnmower	slid (1), loading or unloading (4)	turned over (7), rollover (18), flipped (13), tipped over (4), rolled backwards (4)	
Environment	embankment (6), incline (6), edge (2), ledge (1)	home (7)	
Operator	jumped (3), fell off (5)	pinned leg (1)	concussion (3), contusion or abrasion (15), dislocation (1), fracture (10), hematoma (3), internal organ injury (3), laceration (6), ankle (1), back (4), sprain and strain (8)

Note. *Circumstances reported by hospitals to CPSC associated with ride-on lawnmower overturns classified by the risk factor and overturn event phase in 2006,* n *= 53. The numbers shown with parentheses count the number of reports that identified the risk factor.*

the weight of the overturned mower as it compressed the operator's chest. Other deaths occurred as a result of trauma (e.g., crushing injuries).

The injured operators of ride-on lawnmower overturns were predominately male. Even though some young operators were injured, many were older. Rescues reported involved operators pinned under an overturned mower, sometimes for hours. In one case, bystanders were able to rescue a man trapped underwater within 1 minute. In another case, the mower pinned the operator's legs overnight and he died of exposure.

Newspapers reported inclines, water bodies, embankments and ditches as environmental risk factors. Striking objects such as tree trunks or wet conditions was incipient to some overturns. In some cases, drop-offs such as seawalls were a hazard. Of the 134 incidents reviewed, 80 involved consumer mowing and 42 involved commercial activity; the activity could not be determined in the remaining 12 incidents. These incidents occurred in 32 states, with the highest number occurring in Florida (19), North Carolina (11), Ohio and Pennsylvania (10 each), Indiana (9), Illinois and Iowa (8 each), and Wisconsin (6).

Eighty consumer incidents were identified as shown in Table 4. These incidents occurred between 1989 and 2007. Operators ranged in age from 3 to 89 years. Fifteen were female and 64 were male, including one toddler extra-rider. The incident was described as an overturn in 74 cases, with two described as a fall over a cliff, one as a mishap and one as a loss of control; two cases had no descriptors but may have been overturns.

The home was described as the location of the incident in 64 cases and two at a road. Fatalities occurred in 68 of the cases that included drowning, asphyxia and fire death. Three operators were rescued; the rest were described as suffering a minor injury or burn, or as being in guarded or critical condition with the outcome unknown. The environment included embankments, ditches, walls, hills, creeks, tree stumps and gravel. Reports of dangerous maneuvers by the operator included towing and turning.

Of the 134 reports involved, 42 could be identified as commercial (Table 4, p. 57). OSHA could have investigated the incidents, but it lacks authority over incidents that involve public employees (e.g., city park workers) unless a state-based OSHA program included public-sector employees within its jurisdiction. These incidents occurred in the years 1990 to 2007, and the ages of the injured operators (all males) ranged from 19 to 78 years. Two incidents were described as runovers after a fall from a mower; 39 were described as overturns; and one lacked description but could have been an overturn. Two operators survived and were rescued; one had an amputation; and three others were described as in critical or in serious condition with their outcome unknown.

In the other 36 cases, the operators were killed; this included at least 16 drownings, one by asphyxia and one from fire. The location of these incidents included golf courses, parks and roadsides, as well as lawns at various residences and commercial locations. The environment included shoulders, hills, embankments, slopes, drop-offs and water bodies. Incipient events included spinouts, slides (mud or wet grass), turns, runaways and collisions with objects.

Table 4 also shows 12 cases reported by newspapers that lacked descriptors to identify whether the mowing operation was consumer or commercial. These incidents spanned the years 1998 to 2007, and the injured operators, one female and 11 males, ranged in age from 45 to 66. Ten were killed, which included by fire or asphyxia, but two survived, one with an amputation and another with minor injuries. Ten of the incidents were overturns (including one described as a "roll") plus two more that may have been overturns. The incidents occurred on embankments, inclines, hills, ditches or roadsides.

NEISS Narratives

Table 5 shows in Haddon Matrix format the overturn-related injuries reported through NEISS for the year 2006 for the product category riding lawnmowers (product no. 1422). Through a search of the narratives related to the sample collected by this system, nine different injury diagnoses were identified as the result of a lawnmower overturn: concussion, contusion or abrasion, dislocation, fracture, hematoma, internal organ injury, laceration, sprain and strain, and other.

The principle hazards that preceded the overturns were inclines, embankments or ledges, loading or unloading for transport, and falling or jumping as the mower tipped. All concussions were related to overturns on embankments. Contusions and abrasions resulted from overturns on inclines such as hills, ramps and embankments. Fractures included circumstances that were described as "flipped over," and one involved an operator who jumped from the mower as it overturned. Internal organ injury involved overturns while the mower was loaded for transport and on an embankment. Lacerations occurred either when an operator jumped from a lawnmower as it overturned or the mower overturned on an embankment or ledge. The other injury categories also involved overturns on inclines as well as ramps and hills.

crushed (9), asphyxiated (3), heart attack (1), amputation (1) and trauma (head and massive). When the overturns ended in water, drownings occurred at depths as shallow as 8 in.

The incipient event included runaways or freewheeling, edges that included sand traps, spinout or slide, and an elevated center of gravity. Of the 37 mowers involved, 19 were identified as ZTRs, one of which involved a runover rather than an overturn.

Three fatal overturns involved mowers with a ROPS. In one, the ROPS on a triplex mower (three rotary blades) collapsed (OSHA Investigation No. 305871295). In two others—a ZTR mower (No. 310210638) and a tractor-mounted mower, the only utility tractor included in this analysis (No. 310214408)—the operators had not worn their seat-

Incident Investigation Reports

Table 6 shows the results from the Haddon Matrix of 17 OSHA summary statements and 37 investigation reports. The first part of the table classifies the keywords that OSHA associated with each overturn incident; these served as an indicator of risk factors associated with overturns. Prior to the overturns, machine factors identified included reverse operation, unstable position, slips, failures of hydraulic lines or brakes, or counterbalance (weight to oppose tipping). Environmental factors included steep grade, embankment, slope and slippery surface. The operator factors included lost control, work rules and no training.

At the overturn event, factors included no ROPS or seatbelt on the machine. The environmental factors included water, tree and ditch. The operator was pinned, ejected, struck against or fell. After the overturn, the cause of injury or death included asphyxia, drowning, crushed, burn, fracture, heart attack or laceration. The parts of body injured included chest, head, pelvis, arm and leg.

Table 6 also shows risk factors drawn from 37 investigation reports that covered incidents from 1986 to 2007. These data include a turf-care truck in addition to ride-on lawnmowers. Most reported that slopes exceeded 15° with the steepest slopes reported to be 60°. The environment included hills, trees, slopes, drop-offs (e.g., sea walls), culverts, ditches, washouts, embankments, berms, roadsides and sand traps. Many overturns occurred on golf courses.

Of the 37 cases, 34 were fatal. Two decedents were female and 33 were male; the gender of two was unknown. The decedents' ages ranged from 19 to 71 years. The injuries included drowned (15),

Table 6

Information Collected From OSHA Investigations

Factor	Preoverturn	Overturn	Postoverturn
OSHA investigation keywords associated with ride-on lawnmower overturns, *n* = 17			
Lawnmower	backing up (1) unstable position (3) slip (1) hydraulic line (1) counterbalance (1) brake (1)	roll-over/overturn (14) no ROPS (4) no seatbelt (3)	
Environment	steep grade (3) embankment (3) slope (9) slippery surface (3)	water (3) tree (1) ditch (1)	
Operator	lost control (4) work rules (4) untrained (1)	pin, pinned (8) ejected (1) struck against (1) fall (2)	chest (2) asphyxiate ()d (1) heart attack (1) crushed (3) drown (4) burn (1) head (1) pelvis (1) arm (1) fracture (1) heart attack (1) laceration(1) leg (2)
OSHA investigation reports associated with ride-on lawnmower overturns, *n* = 37			
Lawnmower	ZTR (19), triplex (5), tractor (1), run-away (5), spinout (5), freewheel (1), slide (5), skid (1), deflated tire (1), object (1), tree (1), ROPS (2), no ROPS (24), sprayer (1)	overturn (33), jumped (1), collision (1), runover (2)	
Environment	edge (4), lake (4), pond (5), canal (1), creek (1), hill (1), nighttime (1), tree (2), ditch (2)	golf (13), sandtrap (2), bank (3), culvert (1), washout (1), slope (5), berm (1), wet grass or ground (2), drop-off (4), roadside (1)	
Operator	ages 19-66 years seatbelt off (2), female (2), male (33), U-turn (1)		dead (34), nonfatal injury (3), drowned (15), crushed (9), concussion (2), asphysia (3), amputation (1), fracture (1), head trauma (1), internal injuries (1), massive trauma (1)

Note. *Information collected from OSHA investigations associated with ride-on lawnmower overturns classified by the risk factor and overturn event phase. The numbers shown with parentheses count the number of reports that identified the risk factor.*

(Clockwise from left) Photo 5: NIOSH's AutoROPS on a commercial mower. Photo 6 shows the device retracted while Photo 7 shows it deployed.

PHOTOS COURTESY NIOSH

belt and were pinned under water and drowned. Both of the latter vehicles overturned 270°.

One incident investigated by OSHA (No. 303642235) involved a 690-lb (313 kg) ZTR lawnmower outfitted with a 500-lb (227 kg) sprayer that overturned, pinned the operator and spilled herbicide onto his head. He died of a heart attack. The investigators concluded that a ROPS and seatbelt would have prevented the operator from being pinned. In another inspection (No. 126591494) of a drowning that resulted from a mower overturn, investigators concluded that the death may have been prevented had the machine been equipped with a ROPS and seatbelt.

An OSHA inspection (No. 302367453) of an overturn from a ledge noted that the ZTR mower was not equipped with a ROPS and that the manufacturer did not provide a ROPS for that type of machine. In another investigation (No. 308434273), OSHA proffered to an employer the installation of a ROPS and seatbelt as part of the abatement settlement; the employer complied and installed a ROPS on his ZTR mower. In an OSHA investigation (No. 305871295) of a drowning that resulted from an overturn of a reel-type mower, the investigator observed that high grass may have obscured the edge of an 8 ft (2.4 m) deep ditch. The lack of tread on the tires may also have contributed to a slide and the overturn. The mower landed upside down on the operator, and a photograph shows a bar, perhaps a ROPS, behind the seat that collapsed. No mention was made of this bar in the report.

An OSHA investigation (No. 112898408) of an overturn of a 25 hp (18.6 kW) lawnmower concluded, citing the general duty clause, that an employer did not provide a place of employment free from recognized hazards since the machine lacked a ROPS. This inspection involved a runaway mower; it prompted the employer to retrofit its mowers with ROPS based on citations under 1928.51 (b)1 (agriculture standard) and 1926.1002 (construction standard). Another OSHA inspection (No. 306499336) cited the employer under 1928.51 (b)1 for no ROPS on the mower based on the classification of lawn mowing services as included under agricultural services. Two other OSHA inspections (No. 306499336 and No. 302024633) observed that the mower was not equipped with a ROPS and seatbelt.

Discussion

Overturns are a significant hazard associated with the operation of both consumer and commercial ride-on lawnmowers. The injuries that result from these overturns can be severe and many result in death. Comprehensive surveillance of ride-on lawnmower overturn-related injuries is needed to integrate data related to consumer and commercial mowers, public and private employment, and fatal and nonfatal injuries. Such a system would better estimate the risk of injury from mower overturns to mower operators and the circumstances associated with these events.

The OSHA standard applies to agricultural tractors with more than 20 engine hp (14.9 kW), but the ANSI standard applies to lawnmowers that are delimited by weight. There is a need to address which measure should be used. Furthermore, ROPS test standards need to be developed for vehicles that have less power or less weight than provided in these standards. Surveillance efforts should gather data to better understand the measures and limits to be used.

Two problems exist with regard to OSHA jurisdiction. One problem is the lack of coverage by federal OSHA over public employees, many of whom are engaged in mowing operations. The other jurisdiction problem is to identify the appropriate ROPS standard for mowers. Under the Standard Industrial Classification system, lawn mowing services are included under agricultural services, thus the ROPS standard for agriculture can apply to lawnmowers. However, OSHA now uses the North American Industry Classification System, which classifies lawn mowing service under services rather than agriculture.

ROPS and seatbelts are a known guard against serious injury in the event of an overturn and should be considered as standard equipment. Indeed, Lutz & McKenzie (2005) observed that a ROPS was a critical safety addition to ZTR mowers.

One necessity of lawn care has been to cut grass on slopes, which has resulted in the deaths of operators from continuous rolls (> 90º) (Wang, et al., 2005). Antiroll bar technology designed to stop continuous overturns was developed in New Zealand in the late 1950s (Crosbie, 1961). In 1961, the North Dakota Highway Department designed and installed antiroll bars on tractors used for roadside mowing that virtually eliminated severe and fatal injuries—followed 95 overturn-related fatalities from 1947 to 1960 (Hanson, 1962). The State of Illinois followed suit with reductions in serious and fatal injuries with the use of antiroll bars (Kuhns, 1966). Bucher (1966) of John Deere stated, "In most cases, when the tractor upset is limited to a 90° roll, the operator is seldom crushed." National Safety Council (1966) published data with the aim to use antiroll bars to restrict tractor overturns to 90°.

Photo 8: Removal of a mower that overturned to the rear into a creek and fatally pinned the operator underwater.

PHOTO BY MARBLE FALLS (TX) POLICE DEPARTMENT

A survey in Nebraska for the period Jan. 1, 1966, to Jan. 1, 1972, compiled data for 175 tractor overturns. Thirty overturns occurred on inclines, 26 of the total occurred to the rear, and the remainder to the side. Overall, overturns to 180° (upside down) resulted in a mortality rate of 50% whereas 90° overturns resulted in a mortality rate of 27%. No fatalities occurred on the tractors equipped with ROPS (Schnieder & Baker, 1972).

Although the TOPS standard would have been a benchmark for ROPS design for ride-on lawnmowers, the failure of the OECD ROPS standard to provide protection against a continuous roll has brought the TOPS approach into question. Nonetheless, on some machines, continuous overturns to the side are prevented by ROPS (Myers, 2008). Moreover, continuous overturns to the rear may still be a viable goal as ROPS on tractors typically stop a rear overturn at 90°. A ROPS design to protect the operator from death or serious injury during a continuous overturn makes attention to the safety zone for the operator most important (Hsiao, Whitestone, Bradtmiller, et al., 2005).

An argument against ROPS is overhead obstructions, such as collisions with tree limbs. However, cases were observed of head injuries from mower operators' collisions with tree limbs but were not reported from the NEISS system herein. The adaptation of a foldable ROPS on mowers has been used as a solution to the tree limb obstruction problem. Nevertheless, foldable ROPS are problematic since they are easily left in a folded position. NIOSH has addressed this problem by developing AutoROPS (Photos 5, 6 and 7).

An argument continues with regard to dangerous equipment that inevitably results in injuries versus injuries as the result of the careless use of dangerous equipment. The former view relates to engineering-based performance standards while the latter view relates to behavioral approaches with regard to careful equipment operation (Alexander, 1990). In their study of CPSC's walk-behind mower standards, Moore and Magat (1996) concluded that the labeling requirement—a behavior-based technique—had no

References

Adler, P. (1993). *Ride-on mower hazard analysis (1987-1990).* Washington, DC: Consumer Product Safety Commission (CPSC).

Adler, P. & Schroeder, T. (2004). *Hazard analysis of power lawn mower studies calendar years 2003 and 1993.* Washington, DC: CPSC.

Albertsson, P., Bjornstig, U. & Falkmer T. (2003). The Haddon Matrix: A tool for investigating severe bus and coach crashes. *International Journal of Disaster Medicine, 2,* 109-119.

Alexander, D.L. (1990). An empirical investigation of lawn mower safety regulation. *Applied Economics, 22*(6), 795-804.

Consumer Reports. (2008, May). Best lawn gear: Top mowers and trimmers. *Consumer Reports, 73*(5), 22-28.

ANSI. (2003). Consumer turf care equipment walk-behind mowers and ride-on machines with mowers safety specification (ANSI B71.1-2003). New York: Author.

ANSI. (2004). American National Standard for commercial turf equipment—safety specification (ANSI B71.4-2004). New York: Author.

American Society of Agricultural and Biological Engineers (ASABE). (2002a). Roll-over protective structures (ROPS) for wheeled agricultural tractors (SAE J2194).. St. Joseph, MI: Author.

ASABE. (2002b). Tip-over protective structure (TOPS) for front wheel drive turf and landscape equipment (ANSI/ASAE S547). St. Joseph, MI: Author.

ASABE. (2004). Agricultural rotary mower safety (ASAE S474.1). St. Joseph, MI: Author.

ASABE. (2005a). Definitions of powered lawn and garden equipment [ANSI/ASAE S323.2(R2005)]. St. Joseph, MI: Author.

ASABE. (2005b). Safety for powered lawn and garden equipment (ASAE S440.3). St. Joseph, MI: Author.

ASABE. (2007). Cooperative Standards Program. St. Joseph, MI: Author.

Ayers, P., Conger, J.B., Comer, R., et al. (2003). Stability analysis of agricultural off-road vehicles. Presented at the 2003 Annual International Meeting of the American Society of Agricultural Engineers (ASAE Paper No. 038006). St. Joseph, MI: ASABE.

Ayers, P. (2006). ROPS design and testing for agricultural vehicles. Fort Collins, CO: Colorado State University, High Plains Intermountain Center for Agricultural Health and Safety. Retrieved April 10, 2009, from http://www.hicahs.colostate.edu/completed_prevention_projects/ROPStesting.htm.

Besselink, B.C. & Fielke, J.M. (2003). Improving tractive efficiency by integrating the steering and drive systems of four-wheeled vehicles (ASAE Paper No. 031058). St. Joseph, MI: ASABE.

Bucher, D.H. (1966). The design and evaluation of a protective canopy for agricultural tractors (ASAE Paper No. 66-625). St. Joseph, MI: ASABE.

California Occupational Safety and Health Standards Board (OSHSB). (2007). Proposed petition decision of the Occupational Safety and Health Standards Board (Petition File No. 494). Sacramento, CA: Author.

(References continued on page 62)

significant affect on injury reduction, whereas performance standards appear to have led to lower injury rates.

Early CPSC warnings with regard to ride-on lawnmowers—do not drive across slopes—is inconsistent with ZTR mower manufacturer warnings—drive across slopes—thus the characteristics of ZTR mower operations need to be studied to better protect the operator through design and training. Such studies also need to address inadvertent restraint by the steering bars in the event of an overturn so as to allow escape from an overturned machine in water. An exemplar warning label *danger* was suggested in 1984 to be affixed to tractors, including those in the 10 to 20 hp (7.5 to 14.9 kW) range, which warned of the overturn hazard (Schmitt & Sevart, 1984b).

Compact tractor overturns result from towing, rear-axle torque, centrifugal force or gravity during grounds care (Gasch, 2001), but incipient conditions lead to lawnmower overturns, and risk factors include slopes, uneven terrain, embankments, drop-offs and loss of traction—which are a safety challenge for landscape designers. Risk factors associated with overturn-related injuries include the weight of the machine, no rollover protection and restraint device, water bodies, fuel leaks and prompt extrication.

A focus on only static stability appears to under-characterize the danger of ride-on lawnmowers, whereas dynamic stability in the presence of environmental factors such as slopes, uneven terrain, water bodies, drop-offs and loss of traction can lead to instability of the machine. A factor incipient to an overturn is a spinout on grass that results in slides downhill and overturns off drop-offs or over embankments. Designs are needed that control these spinouts so the mower does not go out of control (e.g., control based on slip-sensing).

Furthermore, it is evident that lawnmowers are used on steep terrain. The common control—warning against operating on steep slopes—appears to be unheeded or not known. Warnings are not enough. Operator training is also needed. Nonetheless, ROPS and seatbelts are known and proven protective technologies. An alternative design is autonomous mowers for use on steep inclines (Wang & Ayers, 2008).

The incident shown in Table 3 (p. 56) demonstrates the escalation of hazards and postoverturn events that resulted in a death. The hazards that contributed to the overturn event were a steep slope, a water body with an unprotected edge at the bottom of the slope, moist soil under the grass, a mower that spunout when pointed uphill and slid backwards, a mower with handles that control three functions simultaneously (direction, braking and steering), an operator who drove onto the slope and uphill away from the hazard, no slope indicator or warning device on the machine, and warnings in the operator's manual that the operator (and perhaps the employer) likely never read. After the overturn, the events leading to the operator's death included a continuous overturn to the rear into the water that pinned the operator under water, a steering arm bent across one of the operator's legs, no ROPS or seatbelt protection, and no monitor to assist in a quick rescue. It took three men to lift the mower off the decedent. Photo 8 (p. 61) shows the removal of this mower after the overturn.

News stories of lawnmower overturns reported major injuries such as fatalities or unusual situations such as rescues. OSHA investigated fatalities and some serious injuries. CPSC sampled hospital emergency rooms for data, thus, it did not capture deaths that occurred or injuries treated outside of the hospital. None investigated the lives saved or injuries averted or reduced in severity by interventions.

There is a need to investigate close calls to better understand how an overturn event was averted or an injury was prevented. A coordinated surveillance system to report across the spectrum of injury severity as well as lawn mowing hazards would inform scientists and engineers about the magnitude of the problem and opportunities for prevention of mower overturns and associated injuries.

In addition, there is a need for research into interventions that range from inherently safer landscape design for mower operation to devices on mowers that can prevent spinout to rollover protection systems that will protect the operator in the event of an overturn. Attention is also needed regarding keeping foldable ROPS deployed in the absence of overhead obstructions, and machine designs that will allow submerged operators to escape from an overturned mower in water. Furthermore, informing the consumer and the commercial operators of lawn mowing hazards and safe equipment operation is worthy of effective education campaigns. ■

References *(continued from page 61)*

Comer, R.S, Ayers, P., Wang, X., et al. (2003). Evaluation of ASAE Standard S547 for the continuous roll testing on front driven mowers (ASAE Paper No. 038005). St. Joseph, MI: ASABE.

Costilla, V. & Bishhai, D.M. (2006) Lawnmower injuries in the U.S.: 1996 to 2004. *Injury Prevention, 47*(6), 567-573.

CPSC. (1987, June 4). Lawn mower safety [Press release No. 87-035]. Washington, DC: Author.

Crosbie, C.J. (1961, Jan.). Tractor safety devices. *New Zealand Journal of Agriculture,* 75-87.

Dai, J., Zhang, N. & Clark, S.J. (1994). Tractor and stability tests of a highway mower. (SAE Technical Paper Series No. 941701). Warrendale, PA: Society of Automotive Engineers.

David, J.A. (1993). *Deaths related to ride-on mowers: 1987-1990.* Washington, DC: CPSC.

Eilbert, M. (1988). *Evaluation and screening of riding mower dynamic maneuvers on slopes.* Washington, DC: CPSC, Directorate for Engineering Sciences.

Etherton, J.R., McKenzie, E.A. & Powers, J.R. (2004). Commercializing an automatically deployable rollover protective structure (AutoROPS) for a zero-turn riding mower: Initial product safety assessment criteria. *Proceedings of the International Mechanical Engineering Congress and Exposition, Anaheim, CA, USA.*

Gasch, R.J. (2001). Safety management for landscapers, grounds-care businesses and golf courses. Moline, IL: Deere & Co.

Haddon, W. (1972). A logical framework for categorizing highway safety phenomena and activity. *Journal of Trauma, 12,* 193-207.

Haddon, W. (1980). Advances in the epidemiology of injuries as a basis for public policy. *Public Health Reports, 95*(5), 411-421.

Hanson, W.I. (1962). Antiroll bars on wheel tractors and mowers: The North Dakota picture (ASAE Paper No. 62-658). St. Joseph, MI: ASABE.

Hargarten, S.W. (1991). All-terrain vehicle mortality in Wisconsin: A case study in injury control. *American Journal of Emergency Medicine, 9*(2), 149-152.

Hoffmeyer, K.H. & Heth, S.C. (1974, July 30). Riding tractor U.S. Patent 3,826,530.

Hsiao, H., Whitestone, J., Bradtmiller, B., et al. (2005). Anthropometric criteria for the design of tractor cabs and protection frames. *Ergonomics, 48*(4), 323-353.

International Organization for Standardization (ISO). (2007). Powered ride-on turf equipment rollover protective structures (ROPS): Test procedures and acceptance criteria (draft ISO/TC 23/SC 13). Geneva, Switzerland: Author.

Kuhns, G.F. (1966, Mar. 9). Experiences with antiroll bar equipped tractors. Engineering seminar sponsored by the Farm and Industrial Equipment Institute, National Institute for Farm Safety.

Lutz, T.J. & McKenzie, E.A. (2005). Remote controls on a zero-turn commercial lawn mower to conduct SAE J2194 rollover tests (ASAE Paper No. 055004). St. Joseph, MI: ASABE.

Moore, M.J. & Magat, W.A. (1996). Labeling and performance standards for product safety: The case of CPSC's lawn mower standards. *Managerial and Decision Economics, 17*(5), 509-516.

Myers, M.L. (2003). NIOSH agricultural research centers update for Summer 2003. *AgConnections, 1*(3), 1.

Myers, M.L. (2004). Compactor overturns and rollover protective structures. Silver Spring, MD: Center to Protect Workers' Rights.

Myers, M.L. (2008). Continuous overturn control of compactors/rollers by rollover protective structures. International *Journal of Vehicle Safety, 3*(1), 45-59.

Myers, M.L., Cole, H.P, & Westneat, S.C. (2006). Seatbelt use during tractor overturns. *Journal of Agricultural Safety and Health, 12*(1), 43-49.

Myers, M.L., Manwaring, J.C., Kennedy, R.D., et al. (1993, Aug.). Logging-related fatalities in Alaska, 1990-92. Poster at NIOSH Symposium on Efforts to Prevent Injury and Disease among Agricultural Workers. Lexington, KY, USA.

NIOSH. (2007). *Commercial fishing fatalities in Alaska: Risk factors and prevention strategies* (NIOSH Publication No. 97-163). Cincinnati, OH: U.S. Department of Health and Human Services, CDC, Author.

National Safety Council. (1966, Sept.). Tractor operation and antiroll bars (Datasheet 587). *National Safety News, 94*(3), 50-55.

Organization for Economic Cooperation and Development (OECD). (2008a). OECD standard code for the official testing of mid-mounted rollover protective structures on narrow-track wheeled agricultural and forestry tractors (OECD Code 6). Paris, France: Author. Retrieved March 10, 2008, from http://www.oecd.org/dataoecd/1/35/40221170.pdf.

OECD. (2008b). OECD standard code for the official testing of mid-mounted rollover protective structures on narrow-track wheeled agricultural and forestry tractors (OECD Code 7). Paris, France: Author. Retrieved March 10, 2008, from http://www.oecd.org/dataoecd/1/36/40221188.pdf.

OSHA. (1976a). Rollover protective structures (ROPS) for tractors used in agricultural operations (29 CFR 1928.51). Washington, DC: U.S. Department of Labor, Author.

OSHA. (1976b). Protective frames for wheel-type agricultural tractors: Test procedures and performance requirements (29 CFR 1928.52). Washington, DC: U.S. Department of Labor, Author.

OSHA. (1976c). Guarding of farm field equipment, farmstead equipment and cotton gins (29 CFR 1928.57). Washington, DC: U.S. Department of Labor, Author.

OSHA. (2006). OSHA's Region IV seeks to reduce fatalities in the landscaping and horticultural services industry. Washington, DC: U.S. Department of Labor, Author. Retrieved April 6, 2009, from http://www.osha.gov/dcsp/success_stories/compliance_assistance/reg4_landscapers.html.

OSHA. (2007, Aug. 23). Local emphasis programs. Washington, DC: U.S. Department of Labor, Author, Directorate of Enforcement Programs. Retrieved March 10, 2008, from http://www.osha.gov/dep/local_emphasis_programs.html.

Rutherford, G., Marcy, N. & Mills, A. (2003). *Hazard screening report yard and garden equipment* (Product Codes 1400-1464). Washington, DC: CPSC.

Scarlet, A.J., Reed, J.N., Semple, D.A., et al. (2006). Operator rollover protection on small vehicles (HSE Research Report 432). Bedford, U.K.: Health and Safety Executive.

Schmitt, L.D. & Sevart, J.B. (1981). The design of ROPS for small tractors in the ten to twenty horsepower range (ASAE Paper No. MCR-81-402). St. Joseph, MI: ASABE.

Schmitt, L.D. & Sevart, J.B. (1984a). Repeatability of results for performance requirements of ROPS for tractors in the ten to twenty horsepower range (ASAE Paper No. MCR-84-193). St. Joseph, MI: ASABE.

Schmitt, L.D. & Sevart, J.B. (1984b). Updating the ROPS and FOPS standards for agricultural tractors (ASAE Paper No. MCR-84-192). St. Joseph, MI: ASABE.

Schnieder, R.D. & Baker, L.D. (1972). Prevention of injury or death from tractor overturns (ASAE Paper No. 72-604). St. Joseph, MI: ASABE.

Smith, E. (1988). *Hazard analysis: Ride-on mowers.* Washington, DC: CPSC.

Sommer, H.J., Nichol, C.I. & Murphy, D.J. (2006). MEMS sensors to prevent side and rear overturn of agricultural tractors (ASAE Paper No. 061153). St. Joseph, MI: ASABE.

Standards Australia. (1996). Tractors: Rollover protective structures. Criteria and tests: Rear-mounted for narrow-track tractors (AS 1636.2-1996). Sydney, Australia: Author.

Standards Australia. (1996). Tractors: Rollover protective structures. Criteria and tests: Mid-mounted for narrow-track tractors (AS 1636.3-1996). Sydney, Australia: Author.

The State of Queensland, Department of Employment & Industrial Relations. (2006). 2.1 Rollover protective structures (ROPS). Queensland, Australia: Author. Retrieved April 6, 2009, from http://www.deir.qld.gov.au/workplace/law/codes/tractors/safety/rops/index.htm.

Teaford, W.J. (1993, Dec. 3-11). Rollover protective structures (ROPS) for wheeled agricultural tractors (ASAE Distinguished Lecture Series). St. Joseph, MI: ASABE.

Tompkins, F.D., Freeland, R.S., Wilhelm, L.R., et al. (1991). Tractor performance of ride-on lawn and garden tractor tires during tractor operation on turf (SAE Paper No. 911240). Warrendale, PA: Society of Automotive Engineers.

Wang, X. & Ayers, P. (2006). The influence of deck size on the continuous roll behavior of front-drive mowers. *Transactions of the American Society of Agricultural and Biological Engineers, 49*(6), 1677-1685.

Wang, X. & Ayers, P.D. (2008). Study of driverless mowers. St. Joseph, MI: ASABE.

Wang, X., Ayers, P. & Comer, R.S. (2005). Modification and evaluation of continuous prediction model for front drive mowers (ASAE Paper No. 055003). St. Joseph, MI: ASABE.

Wang, X., Ayers, P.D., Womac, A.R., et al. (2007). Sensitivity analysis and validation of continuous roll prediction model for front drive mowers. *Applied Engineering in Agriculture, 23*(4), 455-461.

Whitfield, T. (1992). *Analysis of dynamic tests on grass slopes using riding mowers A, L and M.* Washington, DC: CPSC, Directorate for Engineering Sciences.

Wisniewski, N. (2005, Nov. 11). National Safety Council, Toro and Exmark launch zero radius turn mower safety training program. Grounds Maintenance. Retrieved April 6, 2009, from http://lawnandlandscape.texterity.com/lawnandlandscape/200512/?pg=19.

Acknowledgments

The author thanks Teresa Donovan of the University of Kentucky, College of Public Health, for editorial assistance. CPSC was helpful in providing copies of its research reports for this analysis and several OSHA area offices provided copies of their investigation reports for the study. The Austin, TX, firm of Byrd Davis Furman LLP is acknowledged for supporting the initial collection of information that led to this study.