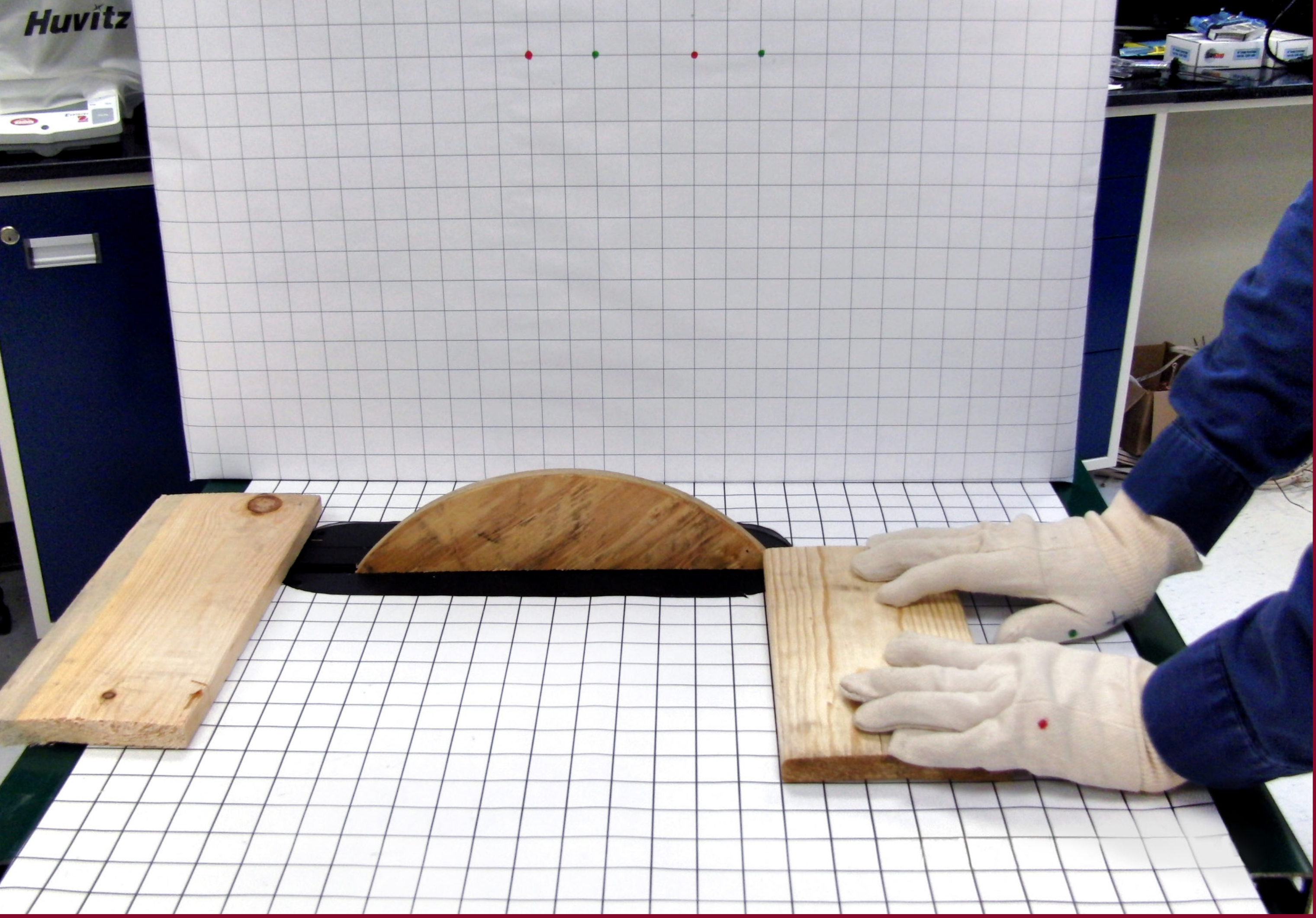

Table Saw Hazard Study on Finger Injuries Due to Blade Contact

JANUARY 2014

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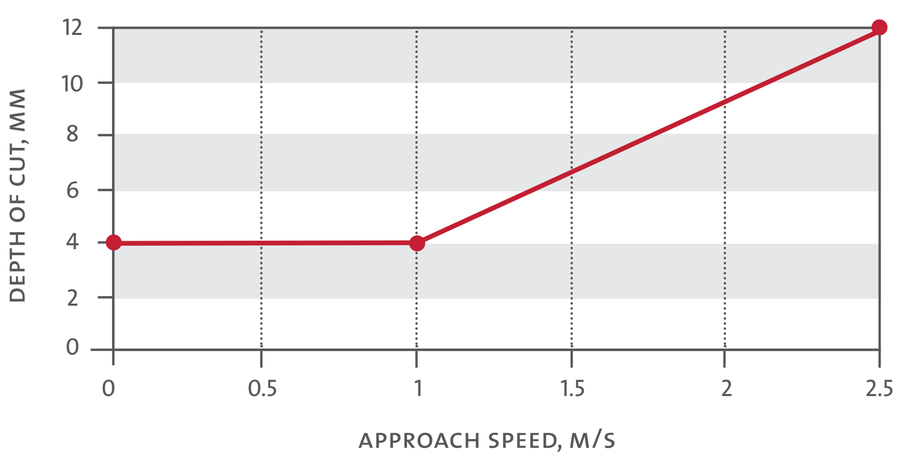
Executive Summary

The intent of this research was to understand the circumstances that may lead to hand/finger contact injuries for operators of table saws and help identify critical parameters that would define the hazard level. For the specific hazard of hand/finger coming into contact with a spinning saw blade, two critical parameters were identified: first, hand approach velocity, as an appropriate metric for the movement of the hand/finger toward the spinning blade; and second, a medically guided estimate of maximum cut depth of the finger that would help distinguish between simple and complex lacerations and provide a positive impact on reducing the severity of hand/finger injuries. Based on the research described within this report and the intent of reducing hand/finger blade contact injuries for table saw operators, the following relationship between approach speed and depth of cut (Figure 1) is recommended:

Figure 1: Recommended approach speed versus depth-of-cut relationship



- Finger contact with a table saw should not result in a depth of cut of more than 4 mm (0.157 inches) at any approach speeds equal to or less than 1 m/s (3.28 ft/s).
- The table saw should be tested at a lower approach speed to ensure that the performance of the safety technology does not degrade. This lower approach speed can be based on the operational details of the safety technology or else set to a value of 0.1 m/s (0.33 ft/s).
- In addition, the depth of cut should remain proportional to approach speeds beyond 1 m/s (3.28 ft/s). An upper approach speed limit of 2.5 m/s (8.2 ft/s) is recommended. Therefore, at this approach speed, the acceptable depth of cut should be 12 mm (0.47 inches) or less.[1]

Note: The approach speed described above is the linear speed of a surrogate finger that is traveling parallel to the table saw surface toward the midpoint of the exposed portion of a blade set to a standard height.

Note: The depth of cut should be measured on a surrogate finger. The surrogate finger must possess the key properties that trigger the safety device and allow for repeatable depth-of-cut measurements.

The research described within this report provides the rationale for these recommendations and is summarized next.

- For the depth of cut, it was necessary to find a quantitative threshold that might serve as a reasonable boundary between simple and complex lacerations. This prescribed value was based on measurements of key anatomical features within the human finger and an understanding of the surgical and treatment implications as the depth of cut increases. Since the focus of the finger injury research was on depth of cut, specifics of blade width, tooth profile and other factors were ignored. However, depth of cut is a primary factor in determining the injury severity, and reducing the depth of cut will still help tremendously in addressing blade contact injuries regardless of these other factors.
- Based on the approach speed estimates derived from the SawStop customer injury database, the set point of 1 m/s (3.28 ft/s) was selected as typical of cases where the injury might be considered a simple laceration. Though this database covers only cabinet and contractor saws, all table saws use the same safety technology. Some of the entries are based on self-reporting by users, yet the database tries to capture a wide array of details about an incident involving blade contact injury. Moreover,

1 Includes a 20% buffer above the proportional value.

the database is unique by virtue of the data extracted from an electronic cartridge that is part of the safety system, and so the SawStop database is the key source for the approach-speed set point recommendation of 1 m/s (3.28 ft/s). However, extended analysis of the database for more serious treatments,[2] limitations of the database, the experiments conducted in this research simulating reach-over and the incident narratives suggest that injuries could also be occurring at higher speeds. For example, one study found that amateur status was a significant predictor of tool-related injuries for woodworkers (Becker et al., 1996). Incident narratives where a person "noticed a wood panel falling off the edge of his table' and then 'lunged to catch it' when 'his right forearm got caught on the blade" suggest higher approach speeds than walking speeds for the person coming into contact with the blade.[3] Another parallel exists with OSHA[4] standards covering mechanical power presses (29 CFR-1910.217). Though the standard prescribed a hand movement of 1.6 m/s (63 in/s), research showed that there were groups of users that exceeded these movements at speeds more than twice that stated in the standard (NIOSH, 1987). Based on the simple experiments of this research on reach-over, approach speeds in the range of 2.5-3 m/s (8.2-9.8 ft/s) may be possible in the general population of table saw users, and any system that can mitigate hand/finger blade contact injuries at speeds greater than 1 m/s will most likely have a substantive impact on injury rates. Also, workpieces can be propelled at very high speeds during kickback; however, the challenges with operator safety prevented actual hand approach-speed measurements during this research program. Thus, in the area of kickback, the effect of hand approach speeds still remains unresolved.[5] However, to impose a 4 mm (0.157 inches) depth-of-cut limit for speeds over 1 m/s (3.28 ft/s) may create an undue constraint on safety technologies for table saws, and so instead a speed-dependent cut threshold is recommended.

It is recognized that this research provides a reasonable, first-order estimate for two critical parameters addressing the specific hazard of hand/finger blade contact with table saws. As such, further research should be encouraged to build on this work and to improve understanding of the circumstances in which table saw injuries occur, to the end that significant findings can be compared against the analysis presented in this work and fill in the gaps that advance public discussions, product development, policy decisions and safety standards.

2 The SawStop manual states that "it is possible to be seriously injured even with the SawStop system.

3 Emotionally and financially, "it's devastating." – Adam Thull, in an article by Lily Fowler on Fairwarning.org, May 16, 2013.

4 US Occupational Safety and Health Administration.

5 Of the 1,316 entries in the SawStop customer injury database (provided in 2011), 172 were labeled as yes in the kickback question.

Introduction

The US Consumer Product Safety Commission (CPSC) maintains a national database (NEISS: National Electronic Injury Surveillance System[6]) of patient information collected from participating 24-hour hospital emergency rooms to help investigate consumer product-related injuries. In 2009, the CPSC conducted a special follow-up study of the NEISS database focused on stationary table saw-related injuries treated in 2007 and 2008 (Chowdhury & Paul, 2011). The study involved an analysis of the NEISS data on table saw injuries along with follow-up phone interviews to gather information about the characteristics of the saws and other factors related to the injury incident.[7] The study estimated that 79,500 US hospital-treated injuries related to table/bench saws occurred in 2007-2008. Further breakdown of the data and survey results indicated that in 95.7% of all cases, the operator of the saw was injured. In 88% of the cases where the operator of the saw was injured, the injury was incurred from contact with a blade. Because in 94.5% of all cases the motor was running, and 91.2% of all cases involved cutting of a wooden board, it can be assumed that most injuries cited are due to contact with a rotating blade while cutting wood. In 89.1% of all cases, the finger was the injured body part, followed by the hand in 6.8% of all cases. The injuries were classified as lacerations in 64.8%, fractures in 12.2% and amputations in 10.5% of all cases.

In a search of other publicly available literature[8] on the topic of table saw injuries[9, 10, 11] a paper was found that also analyzed data from NEISS over a time period extending from 1990-2007 and covering adults and children (Shields et al., 2010). This paper basically reached a similar conclusion: most table saw-related injuries were a result of hand/finger/thumb contact with the saw blade. One study (McGonegal, 2012)[12] estimates that the number of table saw injuries during 2007-2008 was lower than that provided by the CPSC study.

6 http://www.cpsc.gov/cpscpub/pubs/3002.html

7 See Appendix B for sample narratives.

8 Literature reviews based on Google search engine using English-language sources.

9 http://www.hospital-data.com/accidents/841-bench-or-table-saws/index.html#b is one website that claims to graphically display data on bench or table saw accidents taken from NEISS.

10 http://www.sawaccidents.com/p1.htm is a website claiming to collect data from visitors on table saw accidents.

11 SawStop, a table saw manufacturer, collects data from its customers who experience blade contact accidents (over 1,300 incidents) and has provided this data to the CPSC as part of its response to an ANPR on table saw blade contact injuries; http://www.regulations.gov/#!documentDetail;D=CPSC-2011-0074-1106.

12 This document was provided by Power Tool Institute and can be accessed at http://www.regulations.gov/#!documentDetail;D=CPSC-2011-0074-1081.

Looking at the total number of table saws in the US, the CPSC – based on information provided by the Power Tool Institute – estimates that there were about 9.5 million units in 2007/2008 with lifetimes ranging from six years (consumer-grade bench saw) to 17 years (contractor saw) to 24 years (cabinet saw) (CPSC, 2011). As an estimate on the economic impact of table saw injuries, the CPSC (CPSC, 2011) and others (Hoxie et al., 2009; McGonegal, 2012) have calculated societal costs in the range of $30,000 to $40,000 per incident.[13]

Currently, table saws in the US market are certified in accordance with the Standard for Stationary and Fixed Electric Tools, UL 987. This ANSI-approved, voluntary, consensus-based safety standard has been updated several times since its inception in 1971, with new requirements for safety features such as guards and riving knives, and was most recently updated in 2009. However, the standard does not presently require table saws to incorporate safety devices that might mitigate injuries once a hand/finger is in contact with a rotating blade.

In September 2011, UL started a research project and formed a Working Group (WG) by inviting a group of outside experts on table saw operation, table saw safety and table saw injuries. The scope of the research project was to develop a set of performance requirements for active safety technologies through a rational process to help update safety standards for table saws.

These performance requirements would define the conditions covering a specific hazardous condition and would serve as the prerequisites for any new test protocols for the table saw safety standard. In this research, focusing on the specific hazard of a hand/finger coming into contact with a moving saw blade, the performance requirements would be based on two building blocks: one would be an understanding of the circumstances in which the hand/finger of the operator could come into contact with the blade and use a single parameter, hand approach velocity, as an appropriate metric; the other would require some medically guided estimate of maximum cut depth of the hand/finger that would help distinguish between simple and complex lacerations and provide a positive impact on reducing the severity of hand/finger injuries.

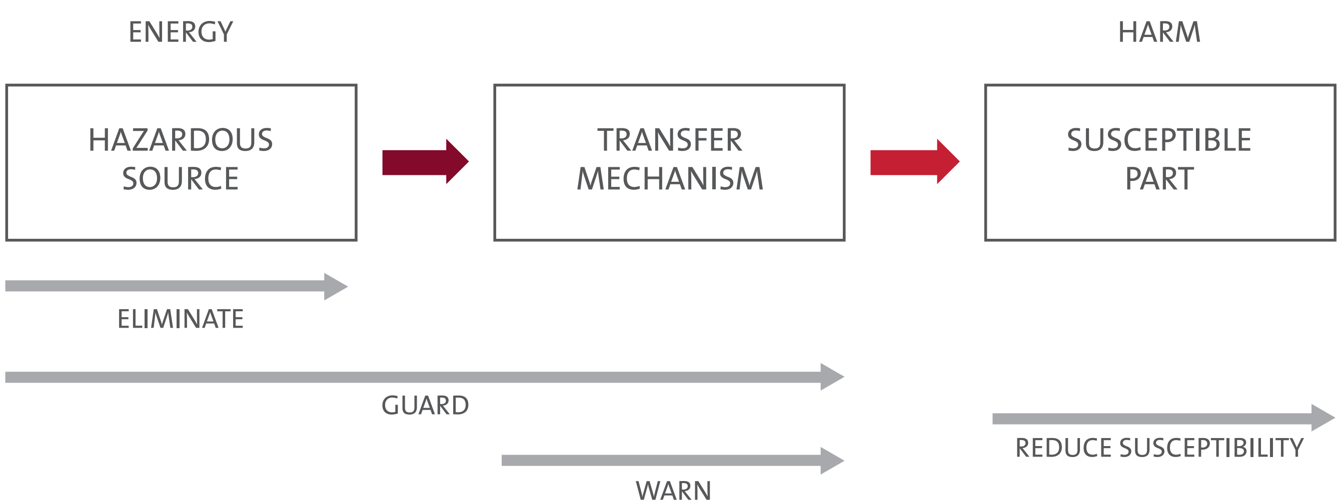
13 This report does not attempt to critique or evaluate any analyses conducted on injury rates due to table saws or the economic impact of such injury rates. The starting point of this research is simply that there are well-documented hazards involving table saws whereby the hand/finger of the operator can come into contact with a rotating blade.

Hazard Analysis

To properly investigate a hazard, it is important to follow a methodology grounded on established engineering and risk analysis principles. For this reason, the first step of the project involved using some specialized tools and techniques to analyze and document harm from hazards and protections against hazards within a well-defined scope. Figure 2 displays the general framework for any hazard whereby energy is transferred to a susceptible body part, resulting in harm. For example, when a hand is approaching a moving blade, physical contact is the transfer mechanism that generates harm (injury) to the susceptible part (hand/finger) from the hazardous source (rotating blade). Though it is not being addressed in the current work, the diagram demonstrates how the first and most effective step is prevention of energy transfer or elimination of the hazardous source. Another possible strategy is guarding, preventing the transfer mechanism from acting on the susceptible part. For the hazard of a hand/finger coming in contact with a moving blade, reducing the susceptibility is one means of reducing the risk of serious harm.

For hazard analysis of the table saw, the Fault Tree Analysis (FTA) tool was selected. The FTA is a deductive process starting with a high-level failure and working through the sequence of events to determine possible root causes (Vesely, 2002). The approach relies on a treelike graphical representation to visually communicate the linkages between the different layers of analysis. The FTA captures the current state of knowledge regarding the root causes for a hazard and should be viewed as a working document.

Figure 2: Hazard-based safety engineering conceptual diagram



Fault Tree Analysis for Blade Contact Injury

In developing an FTA, it is necessary to first identify the key functional components and interactions between the components that help define the scope and boundaries of the analysis. Figure 3 shows a detailed part breakdown for a particular commercial table saw. This level of detail is unnecessary for the purposes of this research. However, selectively simplifying and grouping the components of a product to extract the key features is an important first step. The outcome of this process is captured in a simplified functional block diagram (FBD), Figure 4, for a generic table saw with the key components and connections that will help guide the subsequent FTA based on a scope covering hand/finger contact with the blade.

The main components of a table saw include a motor, table/base, power switch and blade, along with passive safety features. Energy (mechanical or electrical) is transferred among the components represented by solid lines in the FBD. For example, the motor drives the rotation of the blade and, when the saw is in use, an operator would be pushing against a work-piece along the table surface as it is being cut by the rotating blade. The purpose of the riving knife, required by UL 987, is to reduce the probability of kickback.15 In the FBD, a solid line connects the operator to the wood sample and with another solid line connects the wood sample to the blade, indicating energy transfer during the cutting action. The riving knife is shown acting between the wood sample and the blade (tip of the object labeled "Riving Knife" in Figure 4). This represents the role of the riving knife in trying to reduce the probability of kickback during cutting of the work-piece.

The presence of a guard, required by UL 987, affords some protection against contact, mainly from the top, back and side of the blade. In the FBD, a solid line is shown directly connecting the operator to the blade, with the guard shown intervening in the middle (tip of the arrow labeled "Guard" in Figure 4). This graphic represents the role of the

Figure 3: Components of a commercial table saw[14]

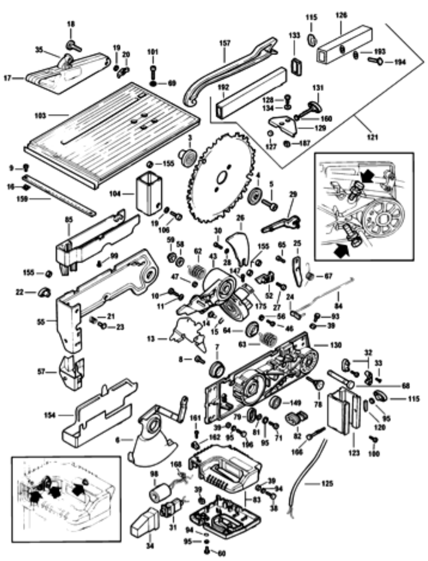
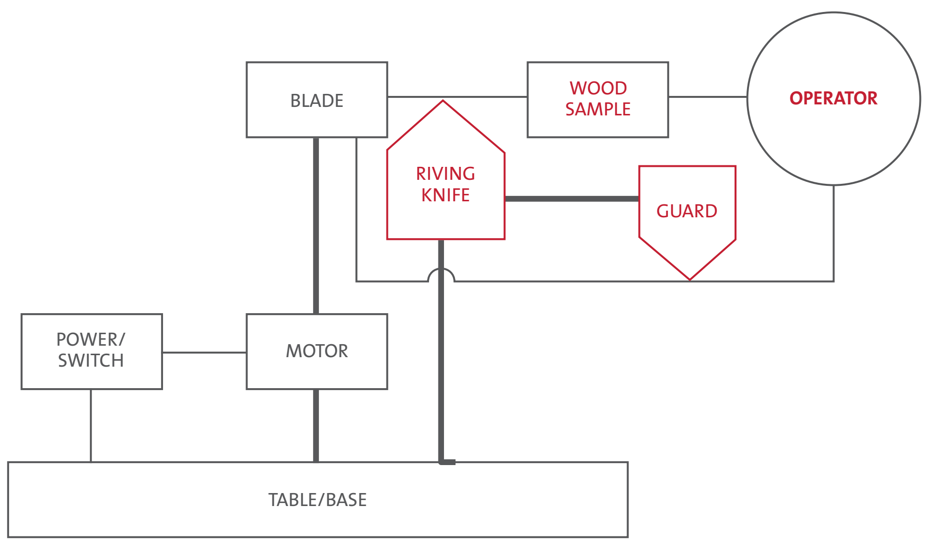


Figure 4: Simplified functional block diagram for generic table saw



14 http://www.toolsandpartsdirect.co.uk/Elu-EMTS711-Type-1-Table-Saw-Spare-Parts__p-5574.aspx.

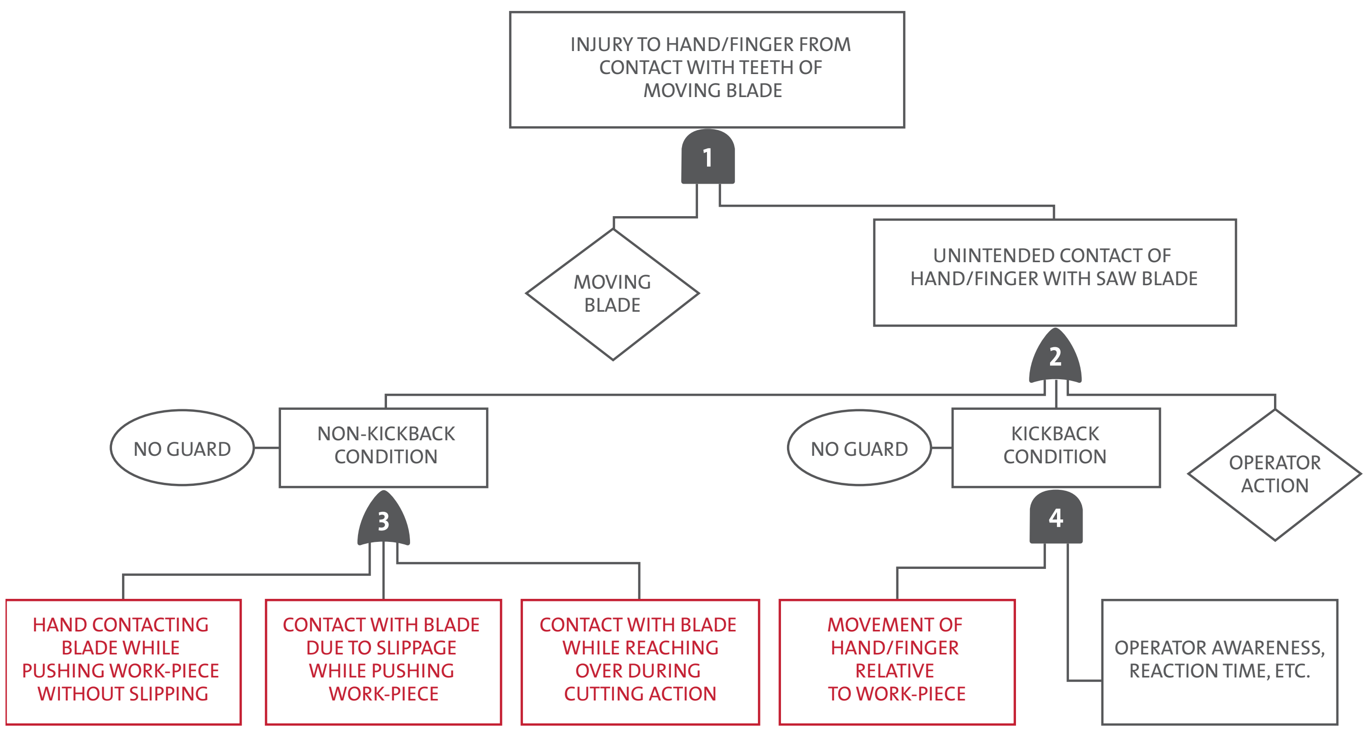
15 The definition of kickback, according to UL 987, is "sudden reaction to a pinched, bound or misaligned work-piece with respect to the saw blade, which causes the work-piece to be propelled by the blade."

guard in passively shielding the operator from contact injury with the blade in some circumstances. As noted in the CPSC study (Chowdhury & Paul, 2011), a guard was present in 34.3% of the cases involving blade contact injuries. This shows that, even with a guard present, based on current designs, blade contact injury is possible. However, since most blade contact injury cases cited in the CPSC study were with no guard present, the no- guard scenario is considered to be more comprehensive for the purposes of this hazard analysis.

With the FBD completed, the scope for the next step, developing the FTA, covers the hazardous condition in which an operator's hand/finger is coming into contact with a moving blade during a cutting operation of wood stock without the presence of a guard. Details such as the type of cut, state of the blade and others were not deemed pertinent for this analysis.

One of the key challenges in trying to understand table saw injuries is knowledge of the diverse behavior of a human operator at a home, work or other setting where there are no independent records of the circumstances and the measurements of key parameters during the incident (like that provided by flight data recorders in airplanes). The CPSC survey (Chowdhury & Paul, 2011) noted earlier did provide some descriptive summaries of numerous incidents and helped serve as background for discussions by the WG on the possible scenarios that could lead to a blade contact injury. Of course, post-incident interviews and self-reporting surveys of people involved in injurious events (such as those conducted by the CPSC and SawStop), can be valuable in a hazard analysis, but they must be carefully analyzed and sometimes require corrections.[16] The potential limitations of self-reporting and the effect of recall duration for interviews should be understood when designing such surveys and analyzing any subsequent data (Landen et al., 1995).

Figure 5: FTA of generic table saw with top-level hazard involving hand or finger blade contact injury



16 An analysis of data recorders from Prius vehicles involved in "sudden acceleration" accidents where drivers stated they had applied the brakes has shown no evidence of braking and suggests some faulty recall of actions during the inciden;: http://www.nhtsa.gov/PR/DOT-16-11.

The building of the FTA starts with a high- level hazard: an injury from a hand/finger coming into contact with a moving blade (Figure 5). Below this top event is the first gate (an AND gate labeled as '1'), which requires that all items feeding into it from the immediate lower level of the fault tree occur for the high-level hazard to be realized. So, for a blade contact hand/finger injury to occur, both "unintended contact of hand/finger with saw blade" AND a "moving blade" are required. The 'moving blade' event is not developed further as it would not provide further insight into the injuries for these purposes. Of course, injuries can still occur with a stationary blade as noted in one of the incidents in Appendix B. Already, one can see the challenges in trying to capture circumstances that cover a wide range of ways in which the operator of a table saw could be injured through contact with a blade. One can always imagine a circumstance where an operator might slam his or her hand/fingers onto a stationary blade. The question that must continually be asked at each stage of the FTA is whether a circumstance would help inform the hazard analysis and not put undue requirements on safety systems for table saws. However, the other event under the AND gate 1, "unintended contact of hand/finger with saw blade", needs to be developed further to help capture the circumstances leading to the specified hazard.

The gate labeled 2 is an OR gate, and indicates that any one of the immediate lower events leading into it are sufficient for the event above it to occur. Therefore, the "unintended contact of hand/finger with saw blade" event could have one of three immediate causes. The first event, "operator action," leading into this gate could simply mean that the blade is rotating and, without any cutting of stock, the operator inadvertently brings his hand/finger in contact with the blade. Other researchers have looked into this issue and have cited reasons such as "being in a hurry, not realizing the hand was in a hazardous area, misjudging time and distance to avoid an injury, shifting work materials or tools and attention not fully on task" (Sorock et al., 2001) that would fall under this general event. This item will not be developed further as the analysis by the CPSC summarized in the introduction indicated that most injuries occur during cutting operations. It is also likely that some aspects of operator action will show up in other branches as the FTA is further developed.

The two other events, kickback and non-kickback conditions, describe two general categories that cover work-piece cutting operations when the hand/finger of the operator could come into contact with the blade. The choice of these categories was an attempt to develop a more tractable analysis. To list every conceivable way in which an operator could be coming into contact with a blade would create a very complex tree without necessarily improving the analysis outcome. One revelation when discussing the scenarios with the WG was the difficulty in describing a "representative" circumstance for blade contact injuries with high confidence. But this is not really surprising, considering how the state of the operator plays a large role in these incidents.

For the kickback and non-kickback events, there is an adjoining oval with the label "No Guard." This oval indicates that the event occurs under the conditions described in the oval. This simply reflects the scope of the analysis described earlier in this section. The kickback and non-kickback events are considered to be taking place without the presence of a guard.[17]

For the kickback condition, both "movement of hand/finger relative to the work-piece"[18] that is being kicked back and (Gate 4) the "operator awareness of and reaction" to the sudden change in movement of the work-piece determine how fast the hand is moving and whether it contacts the blade. These events under the kickback condition are not developed further for reasons to be discussed in the Approach Speed Experiments section.

For the non-kickback condition, there are basically three general circumstances in which the hand/finger could contact the saw blade. First condition: an operator is pushing a work-piece into the blade during a cutting process, and it is possible that the operator is unaware of his/her hand moving very close to the blade until there is contact. Second condition: an operator is pushing a work-piece into the blade during a cutting process, and it is possible that the hand will slip and move toward the saw blade at a speed faster than the work-piece speed. Third condition: during a cutting operation, the operator is reaching over the saw blade and being distracted in the process so that a hand/finger comes into contact with the rotating saw blade. Notice in all conditions that operator awareness and reaction influence the motion of the hand/fingers.

With an initial FTA completed, and having identified four different general circumstances (highlighted in red in Figure 5) in which an operator of a table saw may experience an injury of the hand/fingers due to blade contact, the next step is to attempt to simulate these circumstances and record/analyze the needed measurements that would help provide quantitative estimates of the key metric, hand approach velocity. Standard EN 999:1998, Safety of Machinery,[19] which cites a value of 1,600-2,000 mm/s as the typical walking speed and hand/arm approach speed, is used to determine distance thresholds for "sensing or actuating devices of protective equipment in a danger zone". Yet, it was not known how well walking speed might represent hand movement during wood-cutting operations. So a series of experiments was designed and run to simulate some of the conditions identified in the FTA. In addition, a customer incident database for table saws by one manufacturer was analyzed. This database was provided by SawStop LLC, which sells a table saw system that "detects when someone accidentally contacts the spinning blade and then stops the blade in milliseconds."[20] Both the experiments and the injury database were examined in detail as they relate to approach velocity for hand/fingers. However, the next section first covers the classification of injuries and how it informs a possible injury threshold.

17 It is still possible for injuries to occur even with the presence of the passive safety devices.

18 This can include the case where the relative movement is zero; that is, the hand is moving with the work-piece without slippage.

19 This standard is now superseded by EN ISO 13855.

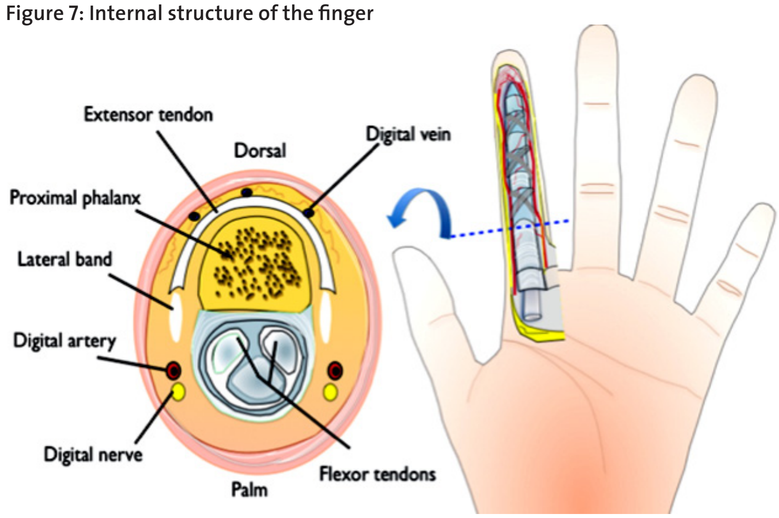
20 http://www.sawstop.com/wp-content/uploads/sawstop_whitepaper.pdf.

Injury Classification[21]

Table saw injuries can involve lacerations of varying depth in fingers, and owing to their distal location (Figure 6) and small size, fingers are especially prone to injury. Finger lacerations can be grouped according to structure damage: simple lacerations or complex lacerations, which include tendon, nerve or vascular involvement and amputation (Figure 7). Simple lacerations that damage only the epidermis and dermis can usually be treated at home with simple wound care, but may require emergency department attention. In either case, simple lacerations generally heal uneventfully. The exception is fingertip lacerations associated with injury to the fingernail bed. Careful reconstruction must be undertaken to avoid fingernail bed scarring that can lead to painful or deformed finger nail regrowth. Deeper lacerations along the length of the finger disrupt more-vital structures. Severed tendons, nerves and, vessels require skilled microsurgery to ensure optimal functional and aesthetic results. Surgery may require a hospital stay and lengthy occupational therapy.

Figure 6: Phalanges of the human finger

Figure 7: Internal structure of the finger



21 This section is extracted with some modifications from a full report: "Table Saw Injuries: epidemiology and a proposal for preventive measures," by Dr. Kevin Chung and Melissa Shauver, Department of Surgery, University of Michigan. This work was commissioned and funded by UL. Furthermore, this work has been accepted for publication in a peer-reviewed medical journal, *Plastic and Reconstructive Surgery.*

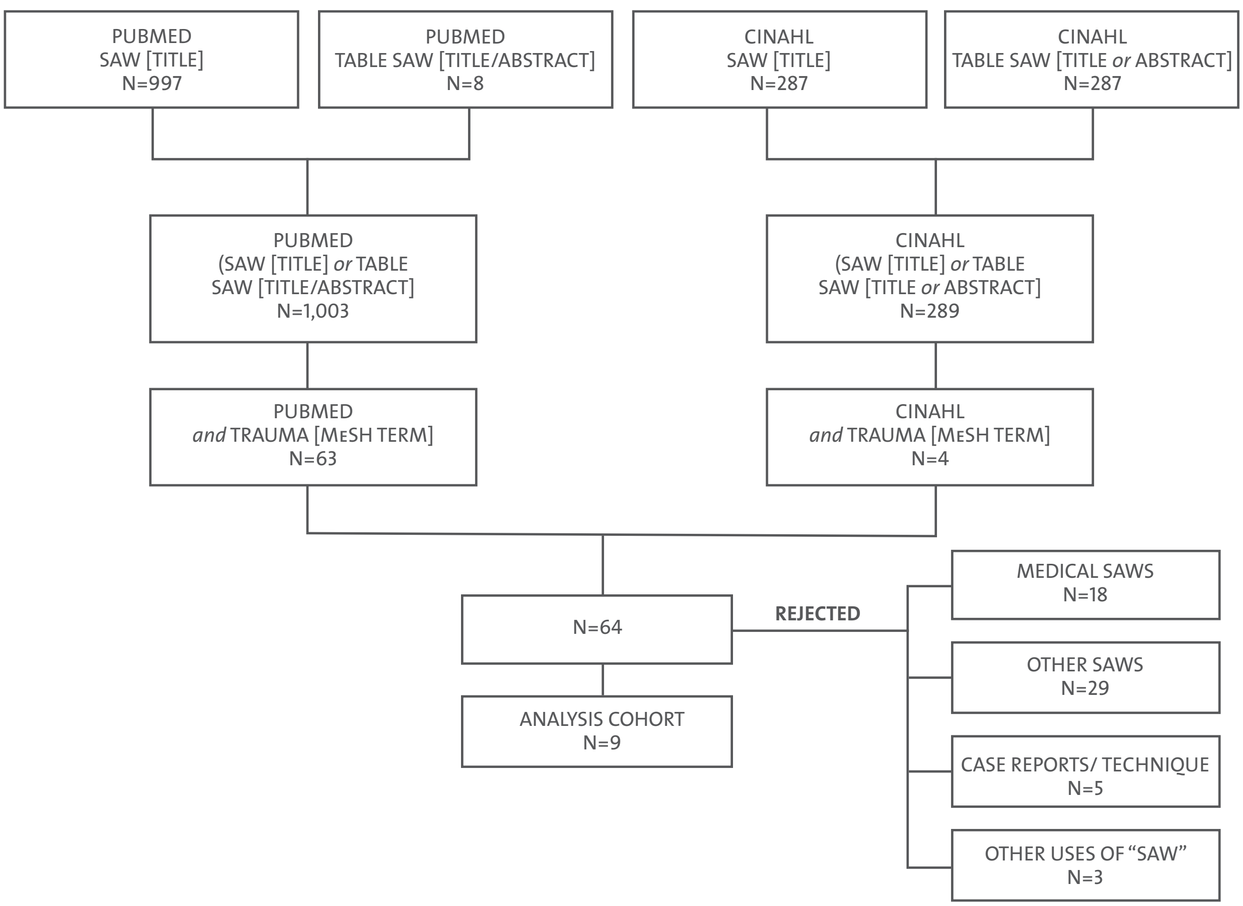
Review of Medical Literature

Using CINAHL and PubMed databases to search the English-language literature for articles with the keywords "saw" or "table saw" in the title or abstract resulted in the following: after filtering the searches and removing duplicates, the list comprised 64 citations consisting of articles about table saw injuries, specifically to the upper extremities. If an article included several types of saws or tools, the data regarding table saws had to be extractable. Case reports or articles about repair technique after table saw injuries were also eliminated, leading to a much-shortened list of citations (Figure 8).

One study (Al-Qattan, 2012) followed 16 patients who had saw injuries for a mean of 16 weeks (range: 14-25 weeks). The patients' injuries could be described in one of two injury groups caused by a saw. The first group sustained phalangeal neck fractures with concurrent extensor tendon injury. The second group also sustained fractures and tendon injury, but additionally sustained nerve transection. None of the patients recovered full range of motion at the distal interphalangeal joint. In the first group, final range of motion was 54% of that of the normal finger (range: 29%-78%). In the more severely injured second group, range of motion was 32% of the normal finger (range: 14%-57%).

A 2002 nationwide study found that 20% of nonoccupational amputation could be attributed to table saws, more than any other consumer product, anything sold for the personal use or consumption of consumers in a nonoccupational setting (Conn et al., 2005). A nationwide survey dispersed in a woodworking magazine

Figure 8: Literature search and screening process



found that 42% of reported injuries were caused by a table saw, and it was the cause of the highest proportion of amputations (39%) (Justis, 1987). A survey of Albuquerque-area professional and amateur woodworkers reported that the table saw was involved in for 31% of injuries and was responsible for the highest proportion of injuries requiring medical attention (21%) (Becker et al., 1996). Table saw injuries resulted in hospitalization 7% of the time; the mean for all consumer products is 4% (CPSC, 2011).

Individuals injured while using a table saw can be grouped into three broad categories. The first two are occupational and nonoccupational injuries. Both of these groups are overwhelmingly male. The percentage of injuries sustained at work ranges from 31% to 46% (Becker et al., 1996; Justis, 1987; Waller, 1990). Injured workers had a mean age of 40 years. Hobbyist or amateur woodworkers tend to be older than professionals (mean age approximately 50 years). A Poisson regression controlling for age, experience, type of woodworking activity and training found that amateur status was a significant predictor of injury ($p<0.0001$) (Becker et al., 1996). Despite this, work-related and non-work-related injuries have a similar injury pattern, recovery course, and costs of care (Hoxie et al., 2009).

The third and most notable group injured by table saws is minors injured in school woodshop courses. In a longitudinal sample of nonoccupational table saw injuries, only 3% of the samples were minors, but more than half of them were injured at school (Shields et al., 2010). This is especially interesting in light of the fact that per US Department of Labor regulations, minors are not permitted to use power-driven woodworking tools or saws, metal-forming machinery, or punching machines in the workplace.[22] Yet this equipment is regularly used by children as young as 11 years old in middle-school and high-school shop and industrial arts classes. A Utah statewide examination of injuries at schools found that 7% of injuries occurred in shop and that 31% of injuries were caused by saws (table saw and band saw 12% each and 7% by other saws) (Knight et al., 2000). Improper equipment use was cited in 38% of cases. Injured students were primarily in grades 8 and 9 (42%) and were mostly male (87%). The average time missed from school was one-half day (range: 0-36). Fingers and thumbs were the most frequently injured body parts (64%) followed by hands/wrists (13%) and eyes (6%). Lacerations were the most common injury (71%). Burns (6%) and abrasions (5%) were also experienced (Knight et al., 2000). Twenty-seven percent of injured students were treated at an emergency department (ED) (Knight et al., 2000). Table saws were involved in 15% of injuries requiring ED treatment. This is a higher proportion than the proportion of injuries caused by table saws, indicating that table saws cause more serious injuries than do other types of equipment. Seven students were admitted to the hospital following a shop class injury. Six of those students were using table saws, and in four of the six cases, improper use of the table saw was cited as the cause of the injury. Two patients sustained a finger amputation and one patient sustained a thumb amputation; the other three patients sustained hand or finger lacerations with tendon, nerve and/or bone involvement.

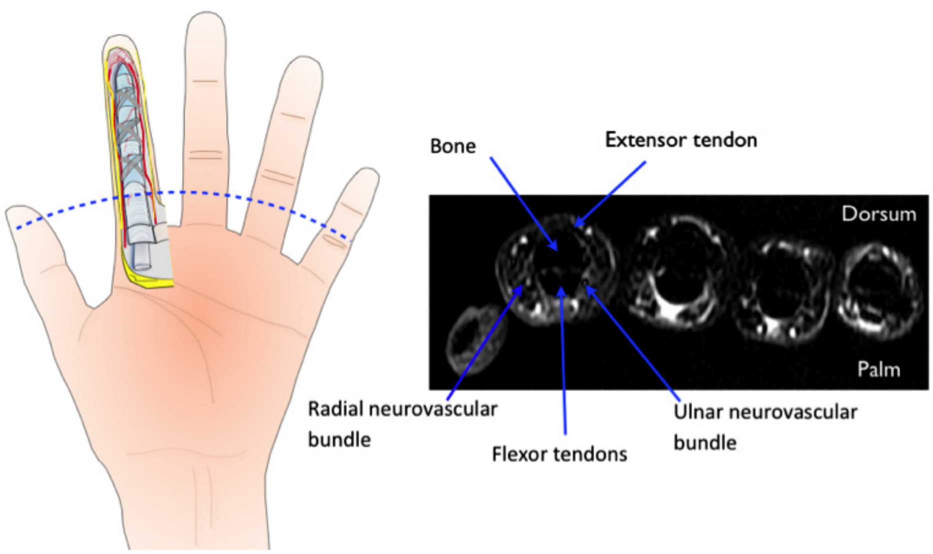
Another study (Beavis et al., 2006) specifically looked at hand injuries that occurred in shop class. All the patients were male, with a mean age of 16 years (range: 12-18 years). Sixty percent of the injuries were caused by table saws, resulting in two index finger amputations, one index and long finger amputation, and lacerations and/or abrasions of various degrees of severity. The outcome of treatment was assessed at an average of 22 weeks (range: 3-66 weeks) and revealed sensory and range of motion deficits in patients who had tendon, nerve or artery repair and sensitivity in patients treated with revision amputation.

22 Child Labor Provisions for Nonagricultural Occupations Under the Fair Labor Standards Act in: US Department of Labor Wages and Hours Division, ed.; 2010.

Measurements on Finger Structure

Because the depth of finger laceration has a direct effect on the structures injured, it is important to understand the depth of key anatomic structures relative to the skin's surface. In an extensive review of the literature, no sources were found providing anatomic measurements quantifying the relationship of vital structures in the fingers to the skin. Therefore, results were generated for this research by examining magnetic resonance imaging (MRI) scans from five patients from the Department of Surgery at the University of Michigan hand surgery practice who had undergone MRI scans for a hand condition unrelated to the fingers. Patients were selected for their similarity to the average sufferer of a table saw-related hand injury: middle-aged males (Becker et al., 1996; Shields et al., 2010; CPSC, 2011). Patients were male, with a mean age of 54 years (range: 42-74). MRI was of the dominant hand in two cases and of the nondominant hand in one case. In two cases hand dominance was not known. Using PACS radiology software, the distance from the surface of the skin to the neurovascular bundle, flexor tendon and bone was measured for each digit from both the radial and ulnar side. Measurements were taken at the midpoint of each phalanx (Figure 9) and the mean and standard deviation were calculated.

Figure 9: Sample MRI image of human fingers with anatomical structures labeled on the index finger



Generally, structures were deepest at the proximal phalanx of the long finger and most shallow at the distal phalanx of the little finger. The neurovascular bundle, which contains the nerves and arteries, is the structure closest to the skin's surface (Table 1). Its depth ranged from 4.3 mm at the distal phalanx of the little finger to 7.1 mm at the proximal phalanx of the index finger. Tendon depth ranged from 4.6 mm to 7.1 mm (Table 2), whereas bone was located at 6.3 mm to 13.5 mm (Table 3) in depth. Figure 10 shows graphically the meaning of these measurements based on data from one patient.

Table 1: Mean (+/- standard deviation) distance from skin's surface to neurovascular bundle measured at the phalanx midpoint (mm)

	Proximal		Middle		Distal	
	RADIAL	ULNAR	RADIAL	ULNAR	RADIAL	ULNAR
Thumb	4.8 ± 0.6	5.1 ± 0.8	--	--	4.4 ± 0.3	5.8 ± 0.7
Index	7.1 ± 0.5	6.2 ± 1.1	6.2 ± 0.3	5.4 ± 0.3	4.6 ± 0.7	4.3 ± 0.9
Long	6.5 ± 0.7	6.5 ± 0.6	5.8 ± 0.7	6.1 ± 0.4	4.9 ± 0.4	4.4 ± 0.7
Ring	6.5 ± 0.6	5.1 ± 0.8	4.9 ± 0.5	4.8 ± 0.4	4.6 ± 0.3	4.8 ± 1.2
Little	4.6 ± 0.9	4.8 ± 0.6	4.5 ± 0.3	4.4 ± 0.6	4.7 ± 0.6	4.3 ± 0.6

Table 2: Mean (+/- standard deviation) distance from skin's surface to flexor tendon measured at phalanx midpoint (mm)

	Proximal	Middle	Distal
Thumb	5.1 ± 1.0	--	6.7 ± 1.6
Index	7.1 ± 1.3	5.8 ± 0.5	5.2 ± 1.4
Long	7.1 ± 1.4	6.9 ± 0.6	6.3 ± 0.5
Ring	6.5 ± 0.7	6.0 ± 1.1	5.4 ± 0.9
Little	5.1 ± 0.7	4.6 ± 0.6	4.7 ± 0.4

Table 3: Mean (+/- standard deviation) distance from skin's surface to bone measured at the phalanx midpoint (mm)

	Proximal	Middle	Distal
Thumb	11.3 ± 1.7	--	8.8 ± 2.9
Index	13.2 ± 1.3	10.8 ± 0.6	6.6 ± 1.5
Long	13.5 ± 0.7	11.9 ± 1.0	9.6 ± 0.7
Ring	12.3 ± 1.2	10.7 ± 0.8	8.6 ± 0.8
Little	10.0 ± 1.0	7.7 ± 1.6	6.3 ± 0.7

Because it is virtually impossible to make contact with a rapidly rotating saw blade and avoid any injury at all, a simple finger laceration may be an acceptable goal for a saw injury; these injuries can be managed in the ED with little expertise or may require only simple home wound care because these cuts generally heal uneventfully. A deeper cut will need surgery to repair the structures damaged, requiring increasing levels of skill at increasing cost. Based on the measurements presented in this research, a depth of 4 mm (0.16 inches) is the maximum depth for a cut to a finger before serious injury is sustained.

Figure 10: Cross section of the human index finger with anatomical structures labeled. Distances are from the skin's surface at the midpoint of the distal phalanx for a single patient (mean +/- standard deviation).

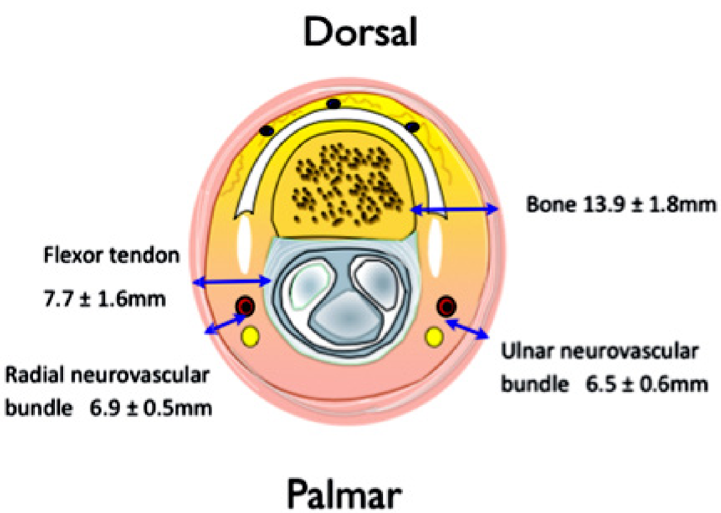
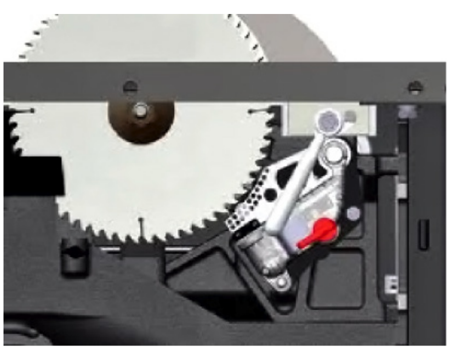


Table Saw Injury Database

One table saw manufacturer, SawStop, has been selling table saws equipped with a capacitance-based sensing system for many years (Figure 11). The SawStop product line includes contractor saws and industrial and professional cabinet saws but no bench table saws. During this time, SawStop has encouraged customers to fill out a survey and return the safety system cartridge whenever they experience an incident triggering the safety system. The cartridge records the electrical signature of the triggering event. Information in the database is a combination of processed data (extracted from the electronic cartridge) and customer responses.[23] The database in this study included 1,316 incidents since 2005.[24]

The database contains information about table saw incidents based on a survey filled out and returned by SawStop customers. However, as noted previously, post-incident surveys can suffer from errors, and the database has not been analyzed in detail to assess the validity of its entries. Instead, the database is used to estimate the hand approach speed, making clear where data is extracted directly from the database and where assumptions are made.

Figure 11: Illustration of SawStop safety device



Analysis: To use the database to estimate hand approach speeds, two sets of data are required: depth of cut and "total time" (TT). The TT is defined as the time from when the hand first contacts the blade to when the system is able to remove the hazardous condition. For the depth of cut, the database does not provide any quantitative information but instead provides some general categories. So, as a starting point, database entries are first filtered according to the description of the treatment type. SawStop uses the following categories to describe the treatment required for the injury incurred from contacting the saw blade and activating the safety mechanism:

1. None
2. Cleaned
3. Antiseptic
4. Band-Aid
5. Bandage
6. Bandaged at hospital or clinic
7. Stitches
8. In-house/first aid
9. Doctor visit
10. Doctor amputated finger tip
11. Not specified

In the Injury Classification section, a 4 mm depth of cut was recommended as a possible threshold value distinguishing between simple and complex lacerations. So only data where the treatment description might suggest a simple laceration (items 1-8 in the list above) is analyzed and a 4 mm depth of cut is assumed for each case. Of the 1,316 entries, 124 had unspecified treatment.

Next consider how to calculate TT. Again, the SawStop database does not directly provide all the information needed for TT, but does provide one of its components. This component, called "time between contact and detection" in the database, represents the time interval between initial changes to the signal that are likely due to first contact (or soon after) of the hand/finger (or any object) with the blade and when contact is finally confirmed by the SawStop algorithm. This value is based on processing of the cartridge data. Once object/blade contact is established by the SawStop algorithm, then the system activates a metal brake that stops the blade from rotating. Therefore, TT is the sum of the "time between contact and detection" and the time it takes to stop the blade from presenting a hazard.[25]

Continuing on, the data column labeled "time between contact and detection" is examined and another filter is applied to remove the empty entries. The final outcome is shown in Figure 12, a histogram of the "time between

23 A copy of the header information from the database is included in Appendix A.

24 These numbers are based on the number of entries in the database provided to the WG by Steve Gass (SawStop LLC) in October 2011.

25 The total time is affected by approach speed up to the limits of the electronics.

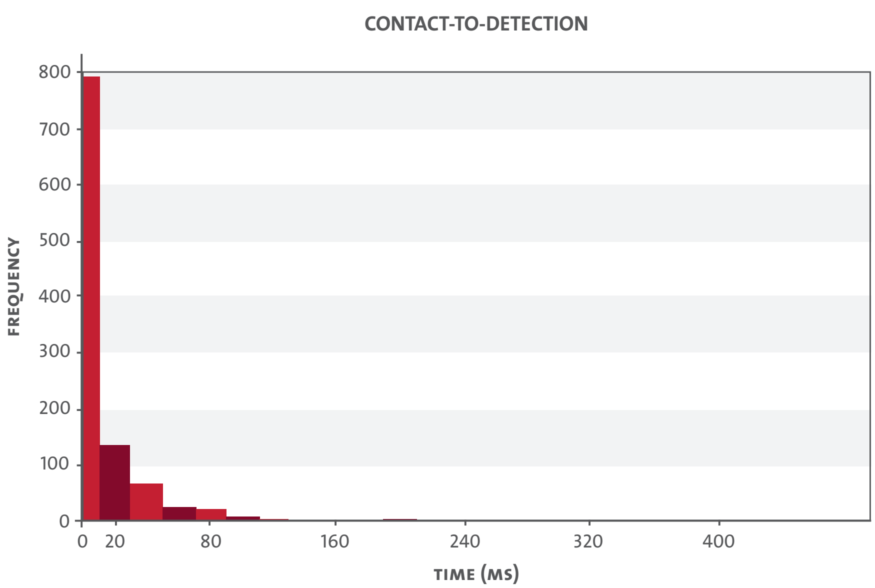
contact and detection" for the category of treatment that might be considered a simple laceration. Most of the time data is 10 ms or less. Assuming a fixed depth of cut, a lower value of TT will lead to a more conservative (higher) estimate of approach velocity. Examining the data in more detail, Figure 13, it appears that 1 ms could be a reasonable conservative threshold time that would cover most of these cases.

Now to estimate TT, the additional time for the brake mechanism to activate and stop the blade is needed. This time interval is not available in the database, and only a single value of 3 ms has been provided by SawStop.[26] Assuming that all these cases involve a simple laceration defined by a 4mm depth of cut and that the "total time" for this system to remove the hazard is (1 ms + 3 ms) 4 ms, then the estimated hand approach speed would be 1 m/s (3.3 ft/s) for incidents involving SawStop customer injuries for the selected treatment categories.

Since there is only a single value for the braking time, and it was not from the electronic cartridge, it is important to consider how the hand approach speed might change based on a variation in the braking time. If a lower limit of 2 ms for the braking time (as increased braking time only results in lower approach speeds) and system linearity are assumed, then the estimated approach speed would be 1.3 m/s (4.3 ft/s).

To develop the above analysis a bit further, consider treatment categories that might suggest a cut deeper than 4 mm. This would include categories 6, 7, 9 and 10. In these cases (69 entries), it may be possible that the cut extended up to the neurovascular bundle. Referring to Table 1, the possible depth of cut without damaging this bundle could be as high as 7 mm for the index finger, a finger that is typically injured. Figure 14 shows the time data for these selected treatment categories, and once again 1 ms is a fair estimate for "time between contact and detection". Assuming a "total time" of 4 ms and a depth of cut between 6-7 mm leads to estimated approach speeds in the range of 1.5-1.75 m/s (4.9-5.7 ft/s).[27]

Figure 12: Histogram of contact-to-detection times of filtered SawStop customer injury database



26 The SawStop owner's manual (10" Professional Cabinet Saw Model PCS31230) states that "an improperly positioned brake could increase the time required to stop the blade in the event of accidental contact." The same manual also states that the "blade will be stopped in about 3-5 milliseconds (coarse-toothed blades stop more quickly than fine-toothed blades such as plywood blades)."

27 There was a single case labeled "doctor amputated finger" with a "time between contact and detection" of 0.2 ms. The amputated finger was the left ring finger.

Figure 13: Close-up of data in Figure 12

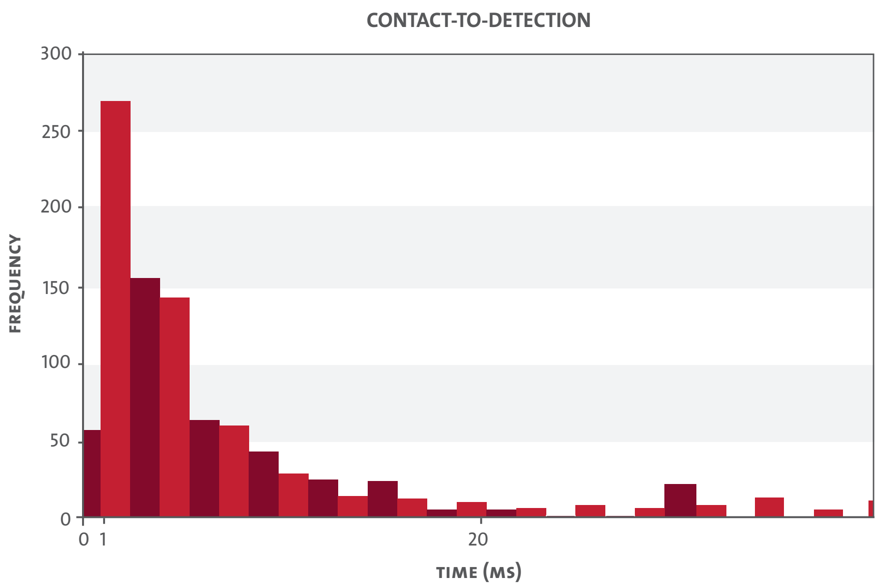
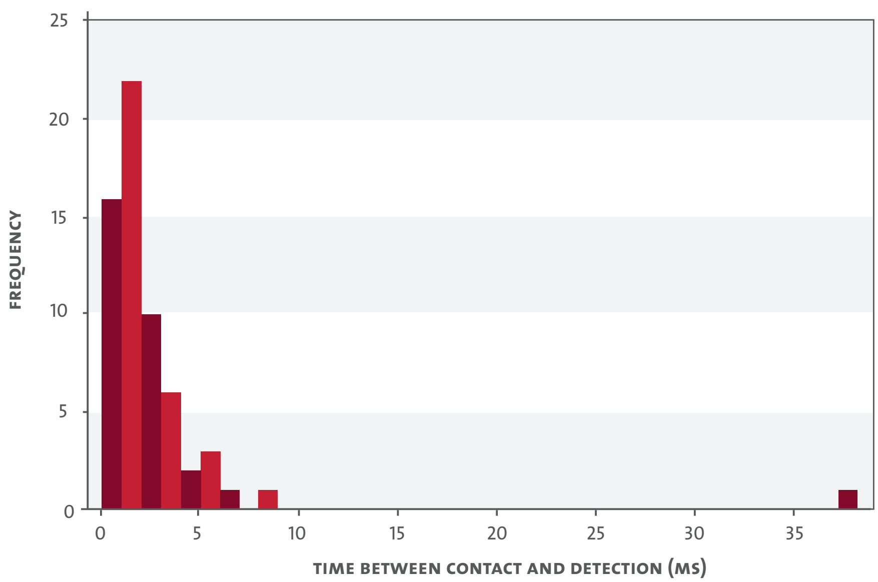


Figure 14: Histogram of time between contact and detection for the treatment categories 6, 7, 9 and 10



Discussion

Before this section ends, some possible caveats of the database are discussed. Approach speeds presented in this section are estimates, and not direct measurements, with assumptions identified at each step. Another possible limitation in extending these results to cover the general table saw user population is that the current SawStop product line does not include bench table saws.[29] Most of the incidents in the database occur at a "workplace or school," since "most SawStop table saws are sold to professionals, schools and government entities."[30] As noted before, one study found that amateur status was a significant predictor of injury ($p<0.0001$) (Becker et al., 1996). There is the possibility that amateur woodworkers, who (according to the CPSC report (CPSC, 2011)) are likely to include owners of bench table saws, "may discover dangerous and difficult operations only by actually experiencing near accidents or problems." This might mean an increased probability of injury and/or higher injury severity. The latter assumption would imply that amateur table saw users could contact the blade under higher approach speeds than those of professional users, the typical owners of cabinet and contractor saws.

Nevertheless, despite these remarks, the database is a very helpful piece of the puzzle in framing performance requirements. However, this database does not preclude the need for the hazard analysis and experiments to simulate circumstances in which an operator of a table saw may contact the blade, to possibly help define reasonable upper limits for approach speeds. The next section details experiments designed to simulate some of the circumstances captured in the FTA and hopefully advance knowledge about table saw safety and contribute to the discussions and updating of the table saw safety standards.

28 Analysis by SawStop of the CPSC survey results suggests that a majority of injuries occurred on bench table saws. See Comments and Information Responsive to the ANPR for Table Saw Blade Contact Injuries by SawStop, LLC, US CPSC, Docket No. CPSC-2011-0074, March 16, 2012.

29 Ibid.

Approach Speed Experiments

From the hazard analysis, four general scenarios were identified in which a table saw operator's hand/finger may come into contact with a moving blade; these require further study:

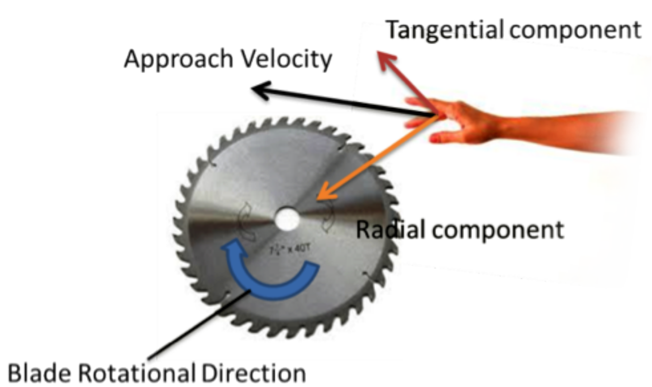
1. Slippage of the hand that is pushing a work-piece toward the rotating blade
2. Hand that is pushing (without slip) a work-piece toward the rotating blade
3. Saw blade reach-over by the operator
4. Movement of hand toward the blade during a kickback condition

In each of these scenarios, one key determinant of the degree of hazard posed to an operator's hand/finger is the approach velocity. Using the center of the blade as a reference point, as the hand/finger contacts the blade, the approach velocity can be broken down into two components (Figure 15): one component tangential to the circumference of the blade, and another component directed toward the center of the blade (radial). When the hand/finger contacts the blade, it is mainly the radial component of the approach velocity that drives the hand/finger deeper into the blade and determines the injury level.

One key challenge is that the simulation must include the realities of human cognitive awareness and reaction times. In any incident reconstruction, the operator reaction time is an important factor. Therefore, human subjects must be used, but in a test where minimal instruction is given that might prime the candidate to react differently. Also the simulation must not present a hazard to the test subject.

To ensure a safe test protocol in running the experiments to simulate hazardous conditions, the following was decided: for the slippage and reach-over experiments, no blade should be present, and for the kickback experiment, no human subject should be in contact with or in proximity of the work-piece. Within these safety boundaries, a series to experiments was designed in an attempt to simulate the motion of the human hand in a way that might provide a reasonable estimate of hand speeds during certain conditions. The intent of estimating approach speeds is to help inform the understanding of the conditions under which most injuries might occur and, in turn, contribute toward the development of performance requirements. However, for practical reasons, it was difficult to run a full demographic study of the population of table saw users. Instead, a small sample of table saw users was selected based on access and availability.[30] As a final economy in the test plan, scenarios 1 and 2 were not included. Scenario 2 would certainly result in lower speeds than scenario 1. Furthermore, scenario 1 was expected to have lower speeds than Scenario 3. So scenarios 3 and 4 were chosen as reasonable and representative conditions to provide quantitative estimates of the upper limits of hand approach speeds.

Figure 15: Different components of approach velocity



30 Since the testing was conducted at the UL research laboratory in Northbrook, Illinois, the test subjects were selected from the pool of employees at the campus. Some effort was made to select candidates across a range of physical attributes and age.

Table Saws

For these experiments, two commercially available table saws were purchased from a national hardware retailer. One table saw was representative of "contractor" type table saws (Figure 16). This table saw was belt-driven, incorporated integral legs and once assembled is not typically moved around. The motor label listed the following specifications: 120/240 V, 14/7 A, 3450 rpm (full load) and 1.75 HP. For this phase of the project, this table saw was used during the reach-over experiments. Though the table saw was not operational during the experiments described in this section, using an actual table saw helped provide proper dimensioning for the experimental setup.

The other table saw was a direct-drive design, was relatively light in weight and, although it had attached legs, could be considered a portable table saw (Figure 17). The motor label listed the following specifications: 120 V, 60 Hz, 15 A and 5,000 rpm (no load). This table saw was used to run the kickback experiments.

Figure 16: Photograph of belt-driven table saw used in experiments

Figure 17: Photograph of direct-drive table saw used in experiments

Experimental Setup

Figure 18 is a photograph of the experimental setup. As the key variable to be measured was velocity, a background grid was designed to aid in measurements. The background grid consisted of 1 inch x 1 inch (25.4 mm x 25.4 mm) grids covering a vertical board set against the table-top edge. Color marks at select grid points were generated to account forright- and left-side side testing (dominant versus nondominant hand effects). Participants would wore gloves with color marking to help track hand movement. Video of each experimental setup for every participant was recorded using a high-speed Olympus model i-SPEED 3 camera. The frame rate was set to 2,000 frames/s for the reach-over experiments and to 5,000 frames/s for the kickback experiments.

Figure 19 shows how the video was processed by selecting frames that covered approximately 2 inches (51 mm) of hand displacement centered on the appropriate colored grids. In this picture, the test subject is moving his left hand from the front side of the table to the back side (based on cutting action). Points are selected on the hand over the specified distance, and with the measured time duration, velocity of the hand over that portion of the travel path is calculated.

Figure 18: Experimental setup

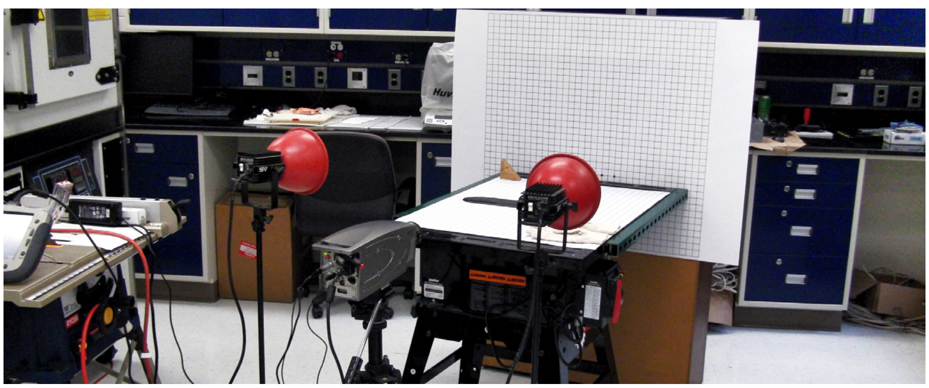
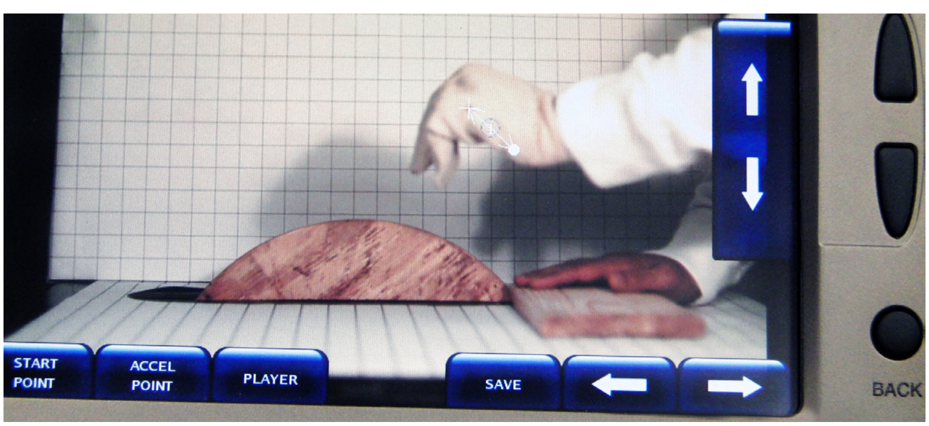


Figure 19: View on high-speed camera screen used to measure velocities



Reach-over Experiments

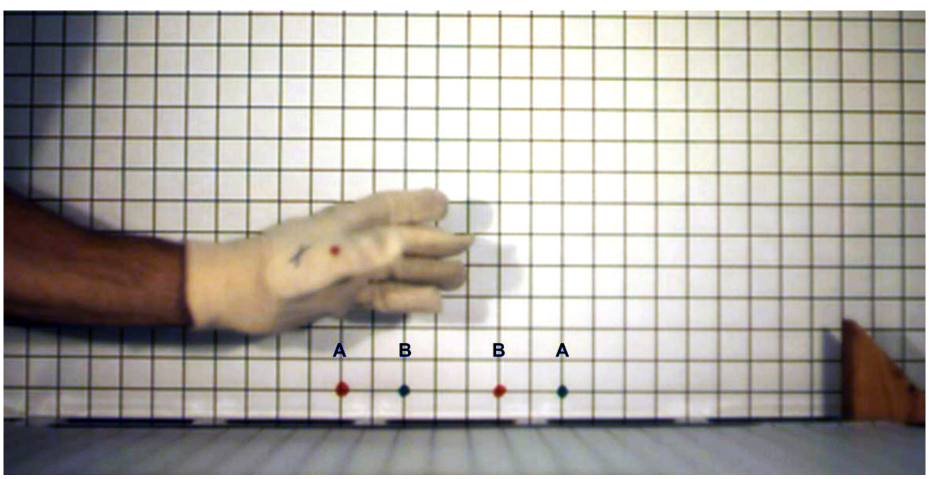
Description: For the simulation of reach-over conditions, an experimental procedure was designed to measure the speed of a person's hand when reaching across the table saw and grabbing a stationary piece of wood with no intervening obstacle (Figure 20). The tests were set up to allow for reach-over with both the left and right hand, regardless of hand dominance. The test subject would stand at one edge of the table and place both hands on the edge. Upon a signal from the experimenter, the test subject would reach over and grab the stationary piece of wood. For each subject, the test was carried out with the person's left and right hand. The intent of these experiments was to quantify hand velocities that could be seen if a person had to suddenly reach for an item without attention to any other objects.

For this experimental run, a total of 12 people were tested with the following characteristics:

a. Three women and nine men
b. Ages ranging from 31 to 60 years
c. Heights ranging from 5'4" to 6'4" (1.63-1.93m)
d. Arm spans ranging from 64.5 to 78 inches (1.64-1.98 m)
e. Dominant hand: 14 right-handed and one left-handed
f. Experience ranging from "beginner" to "intermediate" to "expert" based on self-assessment

Results: For each test subject and each hand, the experiment was run three times. As participants were instructed to simply reach over and grab the piece of wood over a distance of 36 inches (0.91 m), it was noted that some subjects were clearly attempting to go as fast as possible though no such instruction was given. From these experiments, the overall average velocity for the 12 participants was 12.7 ft/s (3.87 m/s) for position A (leading edge of the blade) and 13.8 ft/s (4.21 m/s) for position B (middle of the blade).[31] This suggests that the hand was still accelerating as it passed the leading edge of the blade. The maximum speed was 22.9 ft/s (6.98 m/s) for position A and 24.9 ft/s (7.59 m/s) for position B. The minimum speed was 8.2 ft/s (2.5 m/s) for position A and 8.5 ft/s (2.59 m/s) for position B. Though the minimum speeds cited were for two different test subjects, the maximum speed for both positions was achieved from the same test subject. Table 4 and Table 5 show individual measurements calculated for the 12 test subjects.

Figure 20: Photograph of one test subject during reach-over experiment



31 The red-colored dots were used for tracking the reach-over using the right hand and the blue-colored dots were used for tracking the reach-over using the left hand.

Table 4

		LOCATION A			LOCATION B		
Subject Number	Hand	Distance (in)	Rate (ft/s)	Avg. Rate (ft/s)	Distance (in)	Rate (ft/s)	Avg. Rate (ft/s)
1	R	2.03	10.24		2.07	10.78	
		1.91	9.96		2.03	10.56	
		1.98	10.33		2.03	12.06	
				10.18			11.13
	L	2.02	10.88		2.04	11.71	
		2.01	11.55		2.06	13.76	
		1.91	10.95		2.02	12.05	
				11.13			12.51
2	R	2.18	10.66		2.02	11.24	
		1.98	12.24		2.06	12.24	
		2.07	11.87		2.12	12.64	
				11.59			12.04
	L	2.03	12.08		2.11	13.03	
		1.94	11.99		2.07	11.15	
		1.99	10.68		2.02	10.22	
				11.58			11.47
3	R	2.07	8.85		2.08	8.47	
		1.95	12.47		2.06	13.76	
		2.06	14.96		2.06	14.95	
				12.09			12.39
	L	2.01	11.24		2.04	11.74	
		2.02	12.97		2.08	13.32	
		2.10	13.49		2.03	13.01	
				12.57			12.69
4	R	2.11	13.03		1.97	13.13	
		2.00	11.92		2.11	13.50	
		2.11	13.04		2.11	14.65	
				12.66			13.76
	L	2.07	12.79		1.98	13.78	
		1.95	14.79		1.94	16.18	
		2.03	14.73		2.06	17.20	
				14.10			15.72
5	R	1.99	10.05		2.11	12.53	
		2.07	13.82		2.06	16.31	
		2.07	11.51		2.11	14.64	
				11.79			14.49
	L	2.02	12.49		2.10	14.55	
		2.02	9.88		1.97	10.59	
		2.06	9.56		2.07	10.47	
				10.64			11.87
6	R	1.96	15.53		2.02	16.86	
		2.01	16.74		2.06	19.11	
		2.06	22.93		1.94	24.91	
				18.40			20.29
	L	2.02	13.49		2.00	15.17	
		1.98	14.97		2.07	17.23	
		1.98	18.36		2.11	20.72	
				15.61			17.71

Table 5

Subject Number	Hand	LOCATION A Distance (in)	Rate (ft/s)	Avg. Rate (ft/s)	LOCATION B Distance (in)	Rate (ft/s)	Avg. Rate (ft/s)
7	R	1.97	12.64		2.12	16.08	
		2.05	14.87		2.03	16.88	
		1.97	14.28		2.07	19.15	
				13.93			17.37
	L	1.96	12.55		2.09	14.53	
		2.12	13.11		2.18	18.15	
		2.05	15.54		2.15	18.87	
				13.73			17.18
8	R	1.98	8.26		2.02	8.65	
		2.03	10.90		2.02	11.24	
		2.03	12.10		2.06	12.74	
				10.42			10.88
	L	1.96	9.91		2.02	9.92	
		2.06	12.28		1.99	12.28	
		2.07	12.80		2.02	12.97	
				11.66			11.72
9	R	2.20	12.70		2.02	13.49	
		2.04	9.72		2.07	11.10	
		1.90	12.69		2.15	14.96	
				11.70			13.18
	L	2.01	10.16		2.13	10.75	
		1.99	12.28		1.98	12.25	
		2.01	9.05		2.02	10.22	
				10.50			11.07
10	R	2.01	10.82		2.06	11.08	
		2.04	10.95		2.05	10.69	
		1.97	12.19		2.09	12.91	
				11.32			11.56
	L	1.99	9.76		2.03	9.93	
		1.98	10.01		1.97	10.60	
		2.03	10.58		2.04	10.95	
				10.12			10.49
11	R	2.00	11.10		1.99	11.41	
		1.97	14.31		2.24	17.79	
		1.94	12.94		2.11	14.67	
				12.78			14.62
	L	1.97	11.34		2.11	12.14	
		1.97	15.66		2.03	14.07	
		2.10	17.50		2.09	15.82	
				14.83			14.01
12	R	2.04	13.10		2.02	14.65	
		2.02	17.72		1.99	18.44	
		2.09	20.50		2.06	20.21	
				17.11			17.77
	L	2.00	15.16		2.03	16.88	
		1.98	14.36		2.14	17.00	
		2.03	16.08		2.03	17.77	

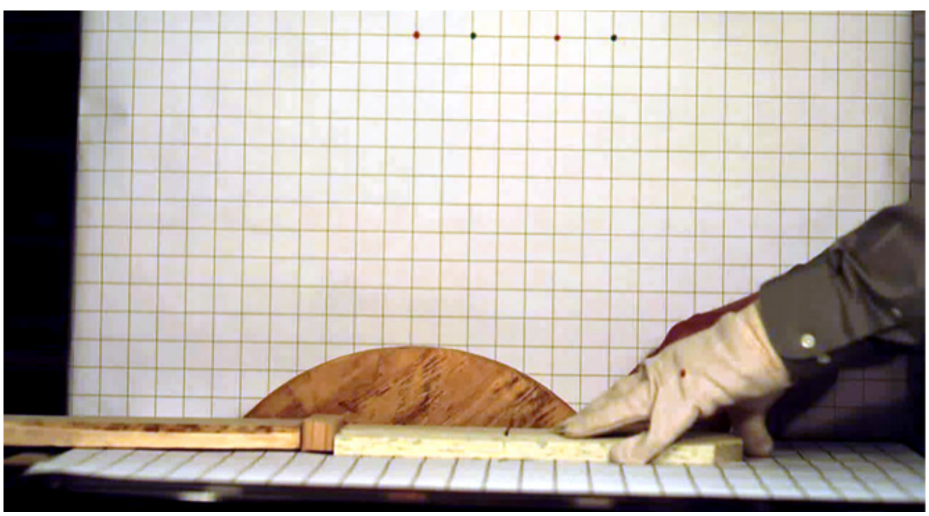
Redesigned Reach-over Experiments

Procedure: In order to create an experimental condition closer to what was described in the narratives, a variation on the previous reach-over test was developed. For these experimental runs, the test subject was asked to push a piece of wood (representing a work-piece) in parallel to a surrogate blade (Figure 21) with both hands. This work-piece, in turn, pressed against another separate piece of board (representing the cut work-piece) which would at some point begin to tip over the end of the table top. The test subject was instructed to push the work-piece, mimicking the action of an operator cutting a board and, upon noticing the second piece of board tipping over, to reach over and grab it.

The design of the test mimics several of the narratives found in the CPSC survey: "Near the end of the cut when the wood started to fall. Victim reached for the wood and put his left hand into the blade and cut 2 of his fingers"and "Completed a cut when wood started to fall. Victim reached with his left hand." For each test subject, two trials were conducted. The first case was as described previously while, in the second case, the piece of board representing the cut work-piece had a weighted end. The purpose of the weighted end was to minimize the effect of the operator knowing when a board would fall.

Results: Though this test was only run on a small subset of the original group for the first reach-over tests, the results revealed

Figure 21: Reach-over test with falling board (left-most piece)



Discussion

The first obvious shortcoming is the small population of test subjects. This is a common constraint for most formalized studies requiring human subjects. Of course, delving into the details of human reaction, especially for accident reconstruction, is a complex and situationally dependent phenomenon and is beyond the scope of this research. The literature review showed a large and varied body of research on measuring human reaction times and the different influencers. From the literature, the tests in this report would be considered simple reaction time experiments, as there is only a single (visual) stimulus and a single response. The effect of influencers on reaction time, such as fatigue, age and drug use (Kosinski, 2012), was not studied. In the redesigned reach-over experiments, the number of runs per subject was minimized as studies have shown that when subjects are new to a reaction time task, their reaction times show greater variability and are slower. With practice, reaction times become faster. For table saw injury incidents, one can assume that the operator has not had much practice in the action that resulted in the injury ("near misses"). However, some instructions were provided to the subject, and this would be considered a "warning of impending stimuli." Research on this topic seems to indicate that reaction times are faster when the test subject has been warned that a stimulus will arrive (Jakobs et al., 2009).

that for three out of four test subjects, the measured speeds were slower than for the first reach-over test procedure (Table 6). For subject 2, the measured speeds actually increased. The average speed for this smaller group was approximately 10 ft/s (3.05 m/s). Another tracked variable was the minimum distance of the hand from the blade as the hand moved toward the end piece. For these runs, this distance ranged from 2 to 8 inches (0.05–0.2 m). In none of the cases were the test subjects able to catch the falling piece.

Table 6[32]

Subject Number	Location A Hand Rate (ft/s)	Location B Hand Rate (ft/s)
0	5.7	6.5
0	8.6	9.5
11	10.4	10.7
11	11.2	11.8
5	10.2	12.1
5	10.6	9.8
2	13.3	13.7

Discussion *continued*

It is difficult for a subject to maintain attention and muscle tension at a high level for more than a few seconds. Some research focuses on the concept of speed-accuracy trade-off (Fairbrother, 2010). This concept simply describes what is understood intuitively: at higher speeds you are more likely to miss your target, especially under time constraints. For table saw incidents, an operator is certainly trying to react quickly and so may be missing the target (falling work-piece) and, in the process, is also taking a path that brings the hand/finger in contact with the blade before reaching the work-piece. If the person did not feel an urgency to reach out quickly, then it is less likely that the operator response (in a favorable cognitive state) would lead to injury.

This entire discussion still does not inform about how much error there might be in the estimates of approach speeds. To consider the confounding influence of these many factors would be impractical and perhaps provide only incremental insights. The simplicity and design of these (redesigned reach-over) experiments satisfy the intent of having a reasonable first-order estimate for approach speeds during reach-over related to table saw injury incidents.

32 Subject 0 data was not shown in Table 1 (and 2) but measured an average speed of 9.8 ft/s for position A and 10.98 ft/s for position B.

Kickback Simulations

The kickback condition is believed to be the most severe in terms of work-piece speed. However, it is not clear how the reaction of an operator to sudden kickback would alter the motion of the hand relative to the work-piece. The worst case is that the hand simply remains fully coupled to the work-piece, as if it were glued, as the work-piece draws the hand/finger into the blade. This scenario was deemed to be very unlikely. The other extreme is that the work-piece moves without accelerating the hand (full slip condition). This is also very unlikely. As mentioned previously, for safety reasons, the simulation of kickback did not involve an operator's hand directly guiding a work-piece and required some additional panels to absorb any projectile motion of the work-piece (Figure 22). Despite this shortcoming, these experiments were intended to provide some idea of the speed of the work-piece during kickback and of a possible upper limit on any performance requirements recommended for table saws.

Figure 22: Experimental setup for kickback simulations

Procedure: For the kickback simulations, a single operator who was identified as "expert" was selected to run the tests. Two potential scenarios were explored. The first condition mimicked closing of the kerf slot at the completed side of the board during a rip-cut operation. The second condition represented the binding of a board between a rotating blade and a stationary guide fence during a cross-cut operation. The portable direct-drive table saw was used for these experiments. The saw was equipped with a 36-count carbide tooth general purpose blade. To avoid any injuries, the operator was positioned to be protected from a flying board. In all experiments the blade was in the fully raised 0 degree bevel position.

For the rip-cut experiments, a pine board measuring 1 x 2 x 19 inches (0.02 x 0.05 x 0.48 m) was precut with a kerf to extend beyond the blade contact region.

Two methods were followed to generate contact between the board and the blade in a manner to induce kickback. The first method employed a short pulse force at the edge of the work-piece to generate board/blade contact. The second method involved exerting a force, to close the kerf slot, through an elastic band wrapped at the end of the board. A wedge was inserted into the slot initially to prevent contact. Once the board was positioned over the blade and the motor was powered with the blade running at full speed, only then was the wedge quickly removed, allowing the board to bind to the blade.

For the cross-cut experiments, a softwood board was prepared by removing a portion of the edge of the board with two angled cuts at the corners (Figure 23). The board was then run through a cross-cut to form two pieces. The cut board remained in position, eventually binding to the blade.

Results: The first method for the rip-cut experiments did not generate a kickback condition. The second method did produce kickback with speeds ranging from 17 to 27 ft/s (5.18 to 8.22 m/s). Calculating the speed of the work-piece during kickback was challenging. The motion of the work-piece was not a simple in-plane motion but rather a combined in-plane and out-of-plane motion. To properly[34] identify the different components of velocity, three points on the work-piece were used. For the cross-cut experiments (Figure 24) the calculated work-piece speeds for the different components ranged from 26 to 80 ft/s (7.92 to 24.4 m/s).

33 In-plane refers to the two-dimensional plane that is the camera image.

Figure 23: Cross-cut experiment with work-piece

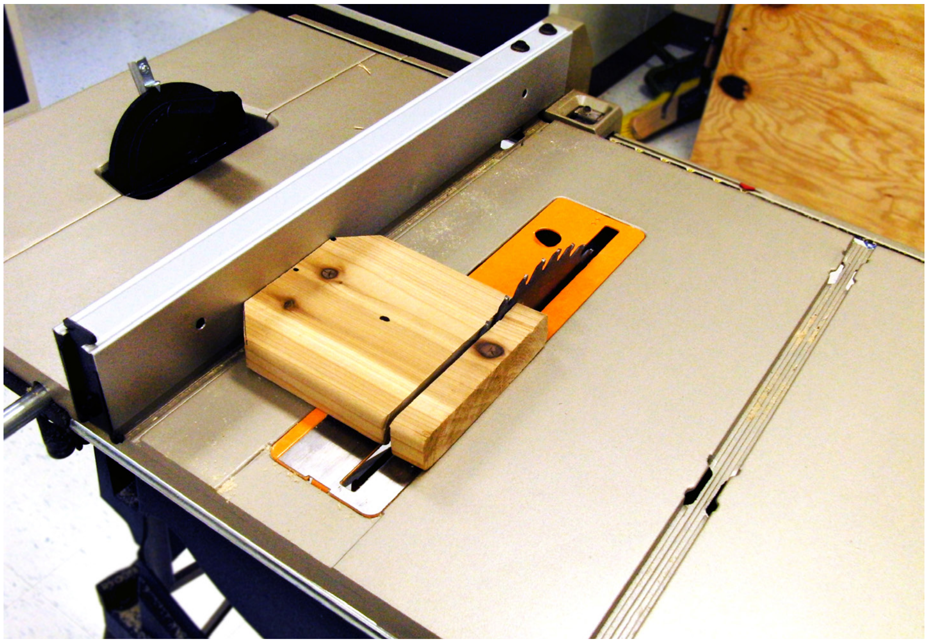
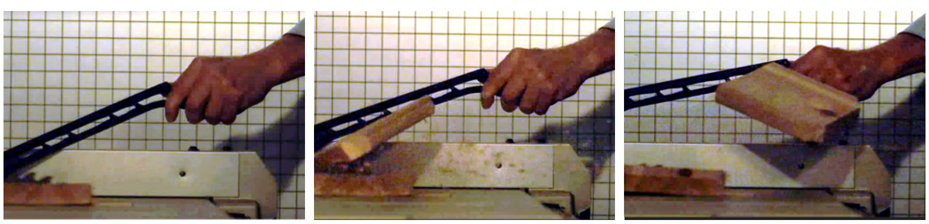


Figure 24: Kickback during cross-cut experiment at different time frames starting from the left-most image.



Discussion

In these experiments, no approach speeds were directly measured and so the only value that this data can provide is an upper limit to any discussions on approach speeds. Clearly, a higher value of approach speed will only increase the safety buffer, but this may come at a cost to public safety, with few or no technologies being able to comply with such approach speed requirements. For now, more research, possibly modeling,[34] could still be conducted to estimate hand approach speeds during kickback.

34 In early 2012, UL approached the Biosciences Group at the University of Michigan Transportation Research Institute for an opinion about using numerical modeling tools. They submitted a proposal that suggests that quantitative predictions of hand motions during kickback, as an outgrowth of modeling work in vehicle crash dummy modeling, using explicit nonlinear finite element methods, is entirely possible.

Disclaimer

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Works Cited

Al-Qattan, M. (2012). Saw injuries causing phalangeal neck fractures in adults. Annals of Plastic Surgery, 38-40.

Beavis, R., et al. (2006). Hand trauma in workshop. Journal of Pediatric Orthopedics, 36-38.

Becker, T., et al. (1996). Tool-related injuries among amateur and professional woodworkers. Journal of Occupational Environmental Medicine, 1032-1035.

Chowdhury, S., & Paul, C. (2011). Survey of Injuries Involving Stationary Saws: Table and Bench Saws 2007-2008. US CPSC.

Conn, J., et al. (2005). Non-work related finger amputations in the United States: 2001-2002. Annals of Emergency Medicine, 630-635.

CPSC. (2011). Table Saw Blade Contact Injuries; Advance Notice of Proposed Rulemaking; Request for Comments and Information. Federal Register/ Vol. 76, No. 6.

Fairbrother, J. (2010). Fundamentals of Motor Behavior.

Hoxie, S., et al. (2009). The economic impact of electric saw injuries to the hand. American Society for Surgery of the Hand.

Jakobs, O., et al. (2009). Effects of timing and movement uncertainty implicate the temporoparietal junction in the prediction of the forthcoming motor actions. NeuroImage.

Justis, E. (1987). Woodworking injuries: an epidemiological survey of injuries sustained using woodworking machinery and hand tools. Journal of Hand Surgery, 890-895.

Knight, S., et al. (2000). Injuries sustained by students in shop class. Pediatrics, 10-13.

Kosinski, R. (2012). A Literature Review on Reaction Time. Retrieved from Clemson University: http://biae.clemson.edu/bpc/bp/lab/110/reaction.html

Landen, D., et al. (1995). Effect of recall on reporting of at-work injuries. Public Health Reports.

McGonegal, S. (2012). Table Saw Operator Blade Contact Injuries: Review and Analysis of Injury and Societal Cost Estimates. Econometrica, Inc.

NIOSH. (1987). Injuries and Amputations Resulting from Work with Mechanical Power Presses. Current Intelligence Bulletin 49.

Shields, B., et al. (2010). Nonoccupational table saw related injuries treated in us emergency departments, 1990-2007. The Journal of Trauma Injury, Infection and Critical Care.

Sorock, G., et al. (2001). Epidemiology of occupational acute traumatic hand injuries: a literature review. Safety Science, 241-256.

Vesely, W. (2002). Fault Tree Handbook with Aerospace Applications. NASA Langley Research Center.

Waller, J. (1990). Disability, direct cost, and payment issues in injuries involving woodworking and wood-related construction. Accident Analysis and Prevention, 351-360.

Appendix A

This section shows the type of data contained in the customer injury database provided by SawStop. This is only a partial listing of the full database that was provided to UL, which contained 1,316 entries.

Saves	Finger Save Recount or Supporting Document Number	Date of Accident or Date of Repo	Time of Accident	Customer Name	Customer State	Customer Type
1	2340	3/15/2005		REDACTED	AR	Manufacturi
1	2341-42	3/22/2005		REDACTED	NC	Manufacturi
1	2343	4/23/2005		REDACTED	CT	Education
1	2360-61	5/5/2005		REDACTED	FL	Manufacturi
1	2344	5/9/2005		REDACTED	WI	Education
1	2332, 2345-46	5/10/2005	morning	REDACTED	AZ	Individuals
1	2348	6/13/2005		REDACTED	CO	Education
1	2349	6/24/2005		REDACTED	IL	Manufacturi
1	2347	7/22/2005		REDACTED	GA	Individuals
1	2351	8/19/2005		REDACTED	CA	Manufacturi
1	2336-39	8/24/2005		REDACTED	WA	Manufacturi
1	2350	9/2/2005		REDACTED	CA	Manufacturi
1	2352-53	9/28/2005		REDACTED	WA	Manufacturi

Customer Phon	Name of Person Filling out Form	Name of Person Who Touched the Blade	Saw Serial No.	Saw Typ	Saw Mode	Cartridge Serial N	Cartridge Data
REDACTED	REDACTED	REDACTED		CB		not stored	Yes
REDACTED	REDACTED	REDACTED		CB			No
REDACTED	REDACTED	REDACTED	04480033	CB	31230	0092-3304-A09	Yes
REDACTED	REDACTED	REDACTED		CB	53230	not stored	Yes
REDACTED	REDACTED	REDACTED	04480042	CB	31230		No
REDACTED	REDACTED	REDACTED	05060076	CB	31230		No
REDACTED	REDACTED	REDACTED	05110368	CB	51230	0306-0705-B01	Yes
REDACTED	REDACTED	REDACTED	05020161	CB	53230	0084-3704-A09	Yes
REDACTED	REDACTED	REDACTED	04450020	CB	51230	0124-0705-B01	Yes
REDACTED	REDACTED	REDACTED	05150459	CB	53230	0334-0805-B01	Yes
REDACTED	REDACTED	REDACTED	05210640	CB	51230	0169-1805-B02	Yes
REDACTED	REDACTED	REDACTED		CB	53480		No
REDACTED	REDACTED	REDACTED		CB	53230	0043-1905-B02	Yes

Cartridge Data Doc. No.	User's Years of Experienc	Body Part Contacted	Fingernail Contact	Visible Injury	Treatment	No. Stitche	Type of Material	Operation
C427		Unspecified Index Finger		Yes	None		Solid Wood	Not Specified
		Right Pinky Finger		Yes	Bandaid		Plywood	Rip / Straight
C418		Unspecified Multiple Fingers		Yes	Not Specified		Solid Wood	Not Specified
C438		Not Specified		Not Specifie	Not Specified		Not Specified	Trim Cut
		Right Thumb		Yes	Not Specified		Not Specified	Cross Cut
		Right Index Finger		Yes	Not Specified		Solid Wood	Dado
C420		Left Thumb		Yes	Not Specified		Not Specified	Rip / Straight
C419	10	Right Thumb	YES	Yes	Not Specified		Solid Wood	Rip / Straight
C421		Not Specified		Not Specifie	Not Specified		Not Specified	Not Specified
C423		Unspecified Middle Finger		Yes	Not Specified		Not Specified	Not Specified
C422		Unspecified Pinky Finger		Yes	Not Specified		Solid Wood	Not Specified
		Not Specified		No	Not Specified		Not Specified	Not Specified
C424		Not Specified		Not Specifie	Not Specified		Not Specified	Not Specified

Primary Safety Devices in Use	Secondary Safety Devices in Use	Blade Ty	No. Teeth on Blad	Wearing Gloves	Kickbac	Feed Speed
Not Specified	None/Not Specified	Not Specified		Not Specified	Not Specified	Not Specified
Not Specified	None/Not Specified	Not Specified		Not Specified	Not Specified	Not Specified
Not Specified	None/Not Specified	Not Specified		Not Specified	Not Specified	Not Specified
Not Specified	None/Not Specified	Not Specified		Not Specified	Not Specified	Not Specified
Not Specified	Miter Gauge	Not Specified		Not Specified	Yes	Not Specified
None	Push Block	8" Dado		Not Specified	Yes	Not Specified
Not Specified	Push Stick	Not Specified		Not Specified	No	Not Specified
Not Specified	None/Not Specified	Not Specified		Not Specified	No	Not Specified
Not Specified	None/Not Specified	Not Specified		Not Specified	Not Specified	Not Specified
Not Specified	None/Not Specified	Not Specified		Not Specified	Not Specified	Not Specified
Not Specified	None/Not Specified	Not Specified		Not Specified	Not Specified	Not Specified
Not Specified	None/Not Specified	Not Specified		Not Specified	No	Not Specified
Not Specified	None/Not Specified	Not Specified		Not Specified	Not Specified	Not Specified

In./Sec	Type of Contact	Estimate of Injury w/o SawStop	Dollar Valu	Testimonia	Can SawStop Use the Testimonia	Time Between Contact and Detection (ms)	Contact Typ
	Inadvertent Touch	Not Specified		Not Specified	Not Specified	50	Teeth
	Not Specified	Not Specified		Not Specified	Not Specified		
	Removing Material	Not Specified		Not Specified	Not Specified	3	Teeth
	Not Specified	Not Specified		Not Specified	Not Specified	16	Teeth
	Kickback	Not Specified		Not Specified	Not Specified		
	Kickback	Not Specified		Yes	Yes		
	Inadvertent Touch	Not Specified		Not Specified	Not Specified	1	Teeth
	Material shifted	Not Specified		Not Specified	Not Specified	1	Teeth
	Not Specified	Not Specified		Not Specified	Not Specified	4	Teeth
	Not Specified	Not Specified		Not Specified	Not Specified	1	Teeth
	Removing Material	Not Specified		Not Specified	Not Specified	3	Teeth
	Removing Material	Does Not Know		Not Specified	Not Specified		
	Not Specified	Not Specified		Not Specified	Not Specified	4	Teeth

Blade RPM	Motor-On Time (sec)	Coast Down (sec.)	Blade Loading	Fire Type	Data is Consistent or Inconsistent with Contact	
4000	135		103	Short Sum	Consistent	
					No Data	
4000	13		100	Short Sum	Consistent	
4000	102		100	Short Sum	Consistent	
					No Data	
					No Data	
Coast 0.8	30	0.8	100	Short Sum	Consistent	
4000	2659		101	Short Sum	Consistent	
Coast 2.8	96	2.8	100	Fall Off	Consistent	
Coast 9.8	45	9.8	102	Short Sum	Consistent	
4000	316		100	Short Sum	Consistent	
					No Data	
4000	136		101	Fall Off	Consistent	

Appendix B

This section lists some examples from the 862 narratives from the CPSC survey (Chowdhury & Paul, 2011). These narratives were obtained by UL via FOIA request and were received in August 2011. The information in the column on the left is the case number and the date of the accident (YYMMDD). The narrative summary in the right column is either full or an excerpts. Highlights were created by the authors of the report.

NUMBER	DATE	NARRATIVE SUMMARY
I0850027A	080427	...after the board kicked back and his left hand was dragged across the blade while he was using the saw.
N07C0005A	071114	14-year-old male had the tips of 3 fingers severed after he slipped on sawdust, falling and putting his fingers in the way of a table saw that was running. He was hospitalized.
I0910536A 100525CCC3695 I1054000A	081121	54-year-old man was using a table saw and the guard's design presents a greater danger. He was using the saw, the piece kicked and his hand made contact with the blade, severing his middle finger.
100517		A 40-year-old male victim was injured while using a table saw in garage. As the victim was ripping through an 8-foot long deck board, the board bound up and kicked back. Immediately the blade guard assembly detached from the table saw and struck the consumer in the face. The victim received minor lacerations and bruising to his face.
081203HEP6401	081122	The 54-year-old male sustained a partial amputation of his left middle finger. The victim was using his son's table saw when the wood hit a knot and kicked back. This pushed his hand into the blade. He cut and partially amputated his left middle finger.
060131HEP9001	060115	50-year-old male was using a table saw and completed a cut. When the victim reached for the wood, his left glove got caught in the blade and he amputated the tip of his left thumb.
060214HEP9011	060202	60-year-old male. The wood jumped as he was cutting and his left hand was pulled toward the blade. Victim cut 4 of his fingers....
060223HEP9008	060212	34-year-old male. Victim completed a cut and reached with his right hand for the wood. Victim was not concentrating and put his right thumb into the blade and amputated the tip.
060308HEP9005	060225	32-year-old male. Cut a small piece of wood. While cutting, the victim hit a defect in the wood, causing kickback, and the victim amputated the tip of his left middle finger.

060308HEP9004	060218	77-year-old male. The wood jumped while he was cutting it, and when he reached for the wood, he cut 3 of his right-hand fingers, which included the amputation of the tip of his thumb.
060302HEP9005	060219	60-year-old male. Was on his last cut when he hit a knot in the wood. His left hand got pulled toward the blade and he amputated his left thumb and index finger.
060323HEP9008	060104	67-year-old male completed a cut and reached for the wood and put his left thumb into the blade.
060517HEP9001	060501	73-year-old male. Reached for a piece of wood and put his left index finger into the blade, amputating his finger at the 1st joint.
060527HEP9003	060505	38-year-old male...and as he was cutting the stock kicked back causing the victim to amputate his left thumb and cut his index finger.
060526HEP9001	060519	68-year-old male. Using table saw to cut a 2x4. Victim was just about through the cut when he reached to pull the wood through and amputated his left index finger.
060526HEP9004	060509	29-year-old male. Using table saw when the wood kicked back and his left hand slammed into the blade causing him to amputate his little finger and tip of his 4th finger.
060615HEP9003	060520	53-year-old female. Cutting with table saw and using the push stick to guide the stock. Somehow the push stick flipped causing the stock to shift and pulling her left hand fingers into the blade. Victim amputated 2 fingers and cut the other 3.
060710HEP9015	060605	66-year-old male. Ripping cedar. The wood kicked back causing the victim to amputate part of his left index finger and cut the middle finger.
060728HEP9002	060707	16-year-old male. Near the end of the cut when the wood started to fall. Victim reached for the wood and put his left hand into the blade and cut 2 of his fingers.
060720HEP9004	060707	43-year-old male. Near the end of the cut when the saw sucked the wood and victim cut his right hand and 3 fingers.
060810HEP9001	060725	58-year-old male. Near the end of a cut, victim hit a knot in the wood as he was reaching with his left hand to get the wood and amputated his left index finger.
060810HEP9002	060729	68-year-old male. Ripping wood when the wood kicked back and hit his hand, causing his left thumb to go into the blade, and amputating it and part of his index finger.

060908HEP9001	060812	21-year-old male. Hit a knot in the wood causing the wood to slide with his left hand. Partially amputated 3 fingers.
060710HEP9004	060611	58-year-old female. The stock kicked back causing the victim to amputate the tip of her left index finger.
060907HEP9003	060815	56-year-old male. While cutting hit a knot in the wood which caused him to amputate the tips of 3 of his left hand fingers.
060908HEP9006	060813	44-year-old male. Completed a cut when the wood started to fall. Victim reached with his left hand to grab the wood and amputated his 2nd finger and cut 2 others.
061023HEP9002	061012	54-year-old male. Completed the cut. He reached for the piece of wood and put his right thumb into the blade.
061005HEP9001	060827	68-year-old male. 1st cut when the stock kicked back and he amputated his 5th finger of his left hand.
061124HEP9008	061028	73-year-old male. Turned off saw and reached for the wood and put his left finger into the blade.
061122HEP9002	061027	51-year-old male. Completed his first cut. Victim reached for the wood and amputated 2 left fingers and badly lacerated 2 other fingers.
061025HEP9036	061013	60-year-male. End of 1st cut when the stock kicked back causing the victim to amputate the tip of his left thumb.
061124HEP9003	061031	62-year-male. Near end of cut when part of frame became unglued causing the wood to slip. Amputated the tip of his middle finger.
061128HEP9002	061029	40-year-old male. Cutting for 15 minutes and was in the middle of a cut when he hit a knot and reached for the wood, and put his middle finger into the blade, amputating the tip.
070125HEP5121	070117	83-year-old male. Hit a knot in the wood and the stock kicked back. The stock hit him, causing his left hand to go toward the blade and he cut the tip of his left thumb.
070125HEP9036	070118	49-year-old male. Using friend's table saw for first time. As he was cutting, the stock kicked back and he cut his thumb.
070126HEP0721	070124	64-year-old male. Stock kicked back causing the victim to cut his left-hand finger.

070201HEP9039	070116	23-year-old male. Cut hardwood floors. Victim cutting for 3-4 hours when the stock kicked back and pulled his right hand into the blade, causing him to cut his index finger and knuckle.
070210HEP6983	070124	46-year-old male. Laceration to left thumb when he accidentally reached across the back of a semi-portable contractor's saw to grasp a board being cut.
070226HEP8942	070217	34-year-old male. Laceration to right index finger and middle finger. While using a table saw at home, he hit a void in a piece of Styrofoam and it sucked his hand into the saw blade.
070318HEP5601	070313	85-year-old male. Cutting small pieces of wood, a piece of wood hit a light bulb, breaking it, startling the victim. He hit his thumb on the saw blade.
070321HEP4081	070312	62-year-old male. Cut hardwood. Guiding the wood with his right-hand, got distracted and cut his right thumb when it got too close to the blade.
070416HEP9092	070411	66-year-male. Ripping wood. Cutting for 10-15 minutes and not sure what happened. He believes a piece of wood hit him in the head and then his left hand fell into the blade, cutting and or amputating all 5 fingers.
070709HEP8057	070705	44-year-male. Laceration to thumb while cutting a board. He was cutting 2x4s when a board kicked back causing the push board to slip out of his hand and he hit the blade.
070903HEP6001	070830	18-year-male. Cut hand on table saw when it tipped on an uneven surface while cutting wood flooring.
070920HEP5761	070905	90-year-male. Cut his finger on a bench saw when a push stick slipped and his finger went into the blade.
080208HEP9007	080205	41-year-male. Ripping a 2x4. Push stick got caught in the blade and pulled his 2 fingers into the blade and cut them.