Industry Usage, Stakeholder Perceptions, and Usability Characteristics of Hazard Controls Leading to the Development of a Design Process and Taxonomy for Large Handheld Powered Equipment

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ABSTRACT

Three studies were conducted to better understand the current status of the industry and create a design process and taxonomy. Study 1 assessed current industry usage of dust control technologies and stakeholder perceptions in the concrete and masonry trades. Study 2 was similar but assessed emission control technologies in the asphalt roofing trade. Study 3 used the information from studies 1 and 2 to select a tool for further evaluation. The handheld cutoff concrete saw was chosen. An iterative design process was utilized to evaluate the saw. The design process and subsequent usability inspection engendered a taxonomy, or set of design recommendations can be applied to large handheld powered tools.

A telephone survey was conducted with a sample of 5,241 decision makers in the concrete and masonry trades. The survey measured perceptions of risk caused by concrete and/or masonry dust. It also assessed the familiarity, frequency of use, perceived benefits, trust in technology, relative advantage, perceived usefulness, and adoption readiness of four dust control technologies. Finally, it assessed business factors affecting adoption and projects specifying the use of dust control technologies.

A telephone survey was conducted with a sample of 4,000 decision makers in asphalt roofing. The survey measured perceptions of risk caused by heated asphalt vapors and

fumes. It also assessed the familiarity, frequency of use, perceived benefits, trust in technology, relative advantage, perceived usefulness, and adoption readiness of five fume control technologies. Finally, it assessed business factors affecting adoption and projects specifying the use of fume control technologies.

In this study a design process and taxonomy were created for large handheld powered equipment. The researcher used an iterative design process whose goal was to better equip industry with a dust control device, specifically a vacuum based control for the gasoline powered handheld cut-off concrete saw. Results from Studies 1 and 2 influenced the direction of the design process. The design did not yield a prototype fit for dust concentration and usability testing, so the researcher conducted a usability inspection on a commercially available system. The results were transformed into a design taxonomy for anyone interested in creating better hazard controls for similar power tools.

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GENERAL AUDIENCE ABSTRACT

Three studies were conducted to better understand the current perceptions of risks associated with the construction industry and create a process for designing tools that mange the associated risks. Study 1 and Study 2 assessed current industry use of technologies for managing health hazards present when working in the concrete, masonry, and asphalt roofing industries; and the interested party's perceptions of the industries. Study 3 used the information from Studies 1 and 2 to select a tool for further evaluation. The handheld cut-off concrete saw was chosen. An iterative design process was utilized to evaluate the saw. The design process and subsequent usability test created a set of design recommendations which can be applied to large handheld powered tools.

A telephone survey was conducted to assess the concrete, masonry, and asphalt roofing industries. The survey measured decision makers' perceptions of health hazard control technologies. Finally, it assessed business factors affecting adoption of the control technologies and projects specifying the use of health hazard control technologies. The results show the concrete and masonry industries understand the risks associated with working in the industry and are more likely to adopt health hazard management technologies. The asphalt roofing industry is unsure if they view heated asphalt to be a

health hazard and are more resistant to adopting current technologies. There are more projects specifying the use of control technologies in concrete and masonry and a decreasing number of projects are specifying the use of control technologies in asphalt roofing. The business factors for adopting technologies are the same across industries, specifically worker safety and government regulation. Those looking to have an impact on the construction industry should focus on the concrete and masonry industries over asphalt roofing.

In the final study, a design process and guidelines were created for large handheld powered equipment. The researcher used an iterative design process whose goal was to better equip industry with a dust control device, specifically a vacuum based system for the gasoline powered handheld cut-off concrete saw. Results from Studies 1 and 2 influenced the direction of the design process. The design did not yield a prototype fit for testing, so the researcher assessed the usability of a commercially available system. The results were transformed into design guidelines for anyone interested in creating better hazard controls for similar power tools. The guidelines created are: have clear symbols, efficiently provide feedback, provide feedback when attaching parts, make attaching parts easy, have efficient design to reduce dangers inherent with the tool, increase visibility, reduce overexposure to dangers, ensure it is easy to move, and enable a wide variety of users to be able to use the saw. The process used to design the prototype can be used to design similar large handheld powered tools. The design process starts with looking at how the tool is currently used, then brings stakeholders together to discuss the problem, then create prototypes, and finally test the prototypes for performance and/or usability which will create the design guidelines.

Dedication

This is dedicated to all those who are pursuing their personal legend.

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Chapter 1

Introduction

Statement of Problem

Health hazards in construction are prevalent, especially in the concrete, masonry and, asphalt roofing trades. Some of the most pressing are inhalation hazards which can lead to respiratory issues, chronic illness, and even death. Despite multiple controls available, they are not always used in construction practice. To better understand this phenomenon, we need a better understanding of current use of the controls, stakeholder perceptions, and the adoption readiness of owners in these industries. Those who do use controls are still overexposed but there are few guidelines for creating better hazard tool designs which hinder occupational safety and health issues. The current state and barrier to adoption of engineering controls of the concrete, masonry, and asphalt roofing industries is not known and a design taxonomy for large handheld tools does not exist.

Summary of Research

Three studies were conducted to better understand the current status of the industry and create a design process and taxonomy. **Study 1** assessed current industry usage of dust control technologies and stakeholder perceptions in the concrete and masonry trades. **Study 2** was similar but assessed emission control technologies in the asphalt roofing trade. **Study 3** used the information from studies 1 and 2 to select a tool for further evaluation. The handheld cutoff concrete saw was chosen. An iterative design process was utilized to evaluate the saw. The design process and subsequent usability inspection engendered a taxonomy, or set of design recommendations can be applied to large handheld powered tools.

Study 1

A telephone survey was conducted with a sample of 5,241 decision makers in the concrete and masonry trades. The survey measured perceptions of risk caused by concrete and/or masonry dust. It also assessed the familiarity, frequency of use, perceived benefits, trust in technology, relative advantage, perceived usefulness, and adoption readiness of four dust control technologies. Finally, it assessed business factors affecting adoption and projects specifying the use of dust control technologies.

Study 2

A telephone survey was conducted with a sample of 4,000 decision makers in asphalt roofing. The survey measured perceptions of risk caused by heated asphalt vapors and fumes. It also assessed the familiarity, frequency of use, perceived benefits, trust in technology, relative advantage, perceived usefulness, and adoption readiness of five fume control technologies. Finally, it assessed business factors affecting adoption and projects specifying the use of fume control technologies.

Study 3

In this study a design process and taxonomy were created for large handheld powered equipment. The researcher used an iterative design process whose goal was to better equip industry with a dust control device, specifically a vacuum based control for the gasoline powered handheld cut-off concrete saw. Results from Studies 1 and 2 influenced the direction of the design process. The design did not yield a prototype fit for dust concentration and usability testing, so the researcher conducted a usability inspection on a commercially available system. The results were transformed into a design taxonomy for anyone interested in creating better hazard controls for similar power tools.

Literature Overview

Asphalt Vapors and Fumes

Workers in the asphalt roofing trade are exposed to multiple hazards, the primary health hazard being heated asphalt vapors and vapors and fumes. The industry estimates 50,000 on-roof workers are exposed to asphalt vapors and fumes during 40% of the time they are working (National Institue for Occupational Safety and Health (NIOSH), 2003). The mopping of hot asphalt is when workers are most exposed and it generally takes three to seven phases to complete one roof. When asphalt is mopped onto rooftops, it is generally melted onsite in a roofing kettle, rather than arriving in a liquid form. (NIOSH, 2003). The asphalt is then delivered from the kettle into a rooftop container called a “hot lugger.” Of concern is when workers must manually mop the hot asphalt onto the roof using open containers. The heated asphalt may overexpose workers to volatilized asphalt in the form of vapors and fumes (NIOSH, 2003; Plog & Quinlan, 2002). The heated asphalt emissions can irritate the upper airways and some workers have also reported skin irritations such as rashes (Norseth et al, 1991). A more pressing concern is lung cancer which has been shown to be elevated for asphalt roofers compared to other hot asphalt trades such as highway pavers. Additionally, lung cancer mortality increases with time on the job (Engholm et al, 1991). In October of 2011, the IARC listed exposure to "oxidized bitumens and their emissions during roofing" as a Group 2A carcinogen, probably carcinogenic to humans (IARC, 2011). Thus, asphalt vapors and fumes are a hazard in asphalt roofing which should be controlled.

<u>Silica</u>

Crystalline silica is a leading occupational health hazard. Crystalline Silica is a compound commonly found in the form of quartz. The main concern derives from inhalation of thoracic and respirable sized particles. Thoracic size class has an aerodynamic diameter of <10 μm and can enter the lung airways (Lees & Breysse, 2006). Thoracic dust particles can cause multiple health problems including irritating the eyes and upper airways which causes coughing (National Institute for Occupational Safety and Health [NIOSH], 2010). Respirable size class has an aerodynamic diameter <4 μm and can enter the gas exchange region of the lungs (Lees & Breysse, 2006). Respirable crystalline silica is thought to act like asbestos by killing cells in the gas-exchange region (Plog & Quinlan, 2002). Respirable crystalline silica can cause numerous problems including cancer. The International Agency for Research on Cancer (IARC) classifies crystalline silica as a group 1 carcinogen, defined as carcinogenic to humans (IARC, 1997). Lung cancer is the leading cause of cancer deaths in the United States (Jemal et al., 2008). Additionally, those who smoke have a greater risk of silica-induced lung cancer. Hnizdo (1990) found in South African miners, where overexposure to silica is common, those who smoked were at a higher risk of dying from lung disease. This is problematic because construction workers have the highest prevalence of smoking, by industry (Bang & Kim, 2001). Thus, overexposure to silica and the prevalence of smoking in construction leads to large incidences of lung cancer. Besides a heightened cancer risk, those inhaling silica are at risk for developing silicosis. Formation of scar tissue leads to silicosis, which reduces the person's ability to breathe and absorb oxygen (Meeker, Cooper, Lefkowitz, & Susi, 2009; OSHA, 2002). Acute silicosis may develop in weeks while chronic silicosis occurs after ten years of exposure to low concentrations (Yassin, Yebesi, & Tingle, 2005). Silicosis is debilitating because the person cannot breathe well which affects their quality of life. Additionally, it is irreversible and incurable which increases the risk of fatality (Meeker et al., 2009; Simcox, Lofgren, Leons, & Camp, 1999). For those with advanced silicosis, the only option for survival is a lung transplant (Beckett & Lyons, 2007). Silicosis increases the risk of other diseases as well. Pulmonary tuberculosis was shown to be elevated in construction workers suffering from silicosis. Pulmonary tuberculosis, once the leading cause of death in the United States, is an infectious disease caused by a bacteria. Though treatable, it usually requires drug dosing for six to nine months (Center for Disease Control and Prevention, 2012; Flanagan, Seixas, Majar, Camp, & Morgan, 2003; Rees & Murray, 2007). Additionally, those with silicosis are at a heightened risk for developing cancer (Kurihara & Wada, 2004). In other words, silica can cause cancer, silicosis, and increase the risk of other pulmonary diseases.

Silica in Concrete and Masonry

Crystalline silica is used extensively in construction, especially concrete and masonry. Silica composes the sand and rock used to make concrete, blocks, mortar, brick, and stone (Beaudry et al., 2013; Linch, 2002; Tharr & Lofgren, 1993). In other words, silica is a main ingredient for all the building materials used in concrete and masonry. Concrete operations use concrete poured into molds to form shapes and structures. Masonry operations use blocks, bricks, and stone secured with mortar to form structures. Multiple operations used in concrete and masonry can emit silica-laden dust including crushing, drilling, grinding, or sawing (Beaudry et al., 2013; Occupational Safety and Health Administration [OSHA], 2009). Thus there is a large potential for worker overexposure to silica dust.

Overexposure to silica dust is common in concrete and masonry. Rappaport et. al (2003) estimate the probabilities of overexposure are between 64.5% and 100% (Rappaport, Goldberg, Susi, & Herrick, 2003). Additionally, the number of people potentially overexposed is likely higher because workers doing ancillary activities not involving silica are also at risk (Verma, Kurtz, Sahai, & Finkelstein, 2003). From 1968-1990, silicosis was the underlying cause of death for 6,322 cases and was implicated as a cause in 13,744 cases (Bang, Althouse, Kim, Game, & Castellan, 1995), but silicosis is underreported so these numbers may be higher (Goodwin, Stanbury, Wang, Silbergeld, & Parker, 2003). This is not surprising because occupational illnesses, injuries, and fatalities are severely underreported (Azaroff, Levenstein, & Wegman, 2002; Pransky, Snyder, Dembe, & Himmelstein, 1999). Of 14 trades commonly exposed to silica, only one, plumbing and steamfitters, was below the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) of 0.025 mg/m^3 (Beaudry et al., 2013). The TLV is used as a guideline for making decisions regarding safe levels of exposure (ACGIH, 2008). Flanagan et al. (2003) found the usual protection method for concrete workers, respirators, was not always adequate. Also, engineering controls are infrequently used and are often ineffective (Flanagan et al., 2003). There is a large number of workers who are at risk of being overexposed. In 2012, the U.S. Bureau of Labor Statistics (BLS) estimated there were 135,200 people employed as cement masons or concrete finishers (BLS, 2015d). In other words, there are approximately 135,000 concrete workers nationally who are potentially overexposed to silica. The number of exposed may be higher since many times unskilled labor can be used in concrete operations which is not common for trades such as masonry and carpentry. Additionally, Beaudry et al. (2013) found the top three worker classes overexposed to silica were tunnel construction workers which primarily deals with concrete, cement masons/concrete finishers, and bricklayers/stone masons. Thus, concrete workers and masons may be at a heightened risk for overexposure regardless of tool.

<u>Prevention through Design (PtD)</u>

Prevention through Design (PtD) is the ideal way of mitigating the risk from safety and health hazards by addressing them early in the design process (Schulte, Rinehart, Okun, Geraci, & Heidel, 2008). PtD methods include material substitution, isolation, and process re-design. Material substation constitutes using less-toxic materials. Isolation involves isolating the hazardous process or isolating workers from the hazard. Finally, process re-design involves tool/equipment changes or work process changes (Ertas, 2010). Although PtD methods are available, better diffusion in the workplace is needed. Increased diffusion can increase the quality of life of workers and improve business profitability through less absenteeism and decreased worker compensation payments. The total direct and indirect cost of workers' compensation in the United States is estimated to range between $128 and $155 billion (Schulte, 2005). NIOSH recently identified PtD to be a priority, especially in construction (National Occupational Research Agenda [NORA], 2008). The United States is said to lag other countries in adopting PtD controls (Toole & Gambatese, 2008). For instance, the fatality rate in construction per 100,000 workers for the United States and Australia is 9.7 and 4.4, respectively (The Center for Construction Research and Training [CPWR], 2013). Driscoll et al. (2008) showed that 37% of workplace fatalities in Australia were caused by design-related issues (Driscoll, Harrison, Bradley, & Newson, 2008). Thus, even in countries that have safer work practices than America, design is still an issue and needs to be addressed. PtD controls can be useful in concrete, masonry, and asphalt roofing.

One of the most widely used PtD control for concrete and masonry is wet method systems. Wet-methods involve wetting the dust at the point of contact to suppress it from becoming airborne (OSHA, 2013). Water cannot be used on electric tools because of electrocution concerns. Wet-methods have been shown to reduce dust concentrations produced by handheld saws (Shepherd & Woskie, 2013; Thorpe, Ritchie, Gibson, & Brown, 1999). Wet-methods used on stationary masonry saws demonstrated as high as 99% reductions in dust concentrations levels (Carlo, Sheehy, Feng, & Sieber, 2010). It has shown promise in abrasive blasting operations, although more studies are needed

(Old & Heitbrink, 2007). Wet-methods are an effective control for dust in concrete and masonry.

Another common PtD control is local exhaust ventilation (LEV). LEV systems use a vacuum to pull dust from the cutting point into a collection device (OSHA, 2009). Multiple studies demonstrated the effectiveness of LEV systems on angle grinders in reducing dust concentration levels (Akbar-Khanzadeh & Brillhart, 2002; Akbar-Khanzadeh et al., 2007; Akbar-Khanzadeh et al., 2010; Collingwood & Heitbrink, 2007). In addition to angle grinders, LEV can be effective for tuck-point grinders, stationary masonry saws, hammer drills, and handheld electric saws (Carlo et al., 2010; G. A. Croteau, Guffey, Flanagan, & Seixas, 2002; Meeker et al., 2009; S. Shepherd, Woskie, Holcroft, & Ellenbecker, 2008). Thus, LEV may be a good solution for controlling concrete and masonry dust on a variety of tools.

Handheld Cut-off Saw

Figure 1. Handheld cut-off saw producing dust containing silica

The handheld cut-off saw is a common tool in concrete and masonry. They are essential to modern construction because of their high power, portability, and ability to cut through numerous materials (G. A. Croteau et al., 2002). Both gasoline and electric models exist for the saw. Electric models are available but are not as common on the jobsite because they are not as powerful, and they require an electrical outlet (cord) making them less maneuverable and thus less desirable. When cutting masonry products, it is possible to use a stationary saw. The nature of the table saw makes it impossible to use on poured concrete structures. Thus, the cut-off saw may be more desirable to concrete industry but is still used in masonry.

The cut-off saw is one of the leading dust producing tools in concrete and masonry operations. From a 2013 literature-based exposure database, masonry cutting was the task with the highest respirable crystalline silica exposure, second only to abrasive blasting (Beaudry et al., 2013). Abrasive blasting, spraying silica-laden sand to prepare a surface, is by its nature hard to control (Rappaport et al., 2003). Masonry or concrete cutting is akin to grinding because the material being cut away is not actually severed, but ground into dust to make the cut. The masonry cutting described includes both stationary saws and handheld cut-off saws. The geometric mean of multiple studies on respirable quartz for masonry cutting was found to be 0.70 mg/m^3 (Beaudry et al., 2013). Silica concentrations from concrete cutting can sometimes be as high as 16.4 mg/m^3 for short durations (Middaugh, Hubbard, Zimmerman, & McGlothlin, 2012). The current OSHA permissible exposure limit (PEL), the amount of silica dust an employee can be exposed to over an 8-hour work day, uses an equation that is outdated. In August of 2013, OSHA announced it will set a single standard PEL to 0.50 mg/m^3 (OSHA, 2013). The rule will go into effect in June, 2017 in the construction industry (Occupational Safety and Health Administration (OSHA)). In other words, concrete cutting with the cut-off saw exposes workers to well above the soon to be adjusted legal limit.

Controls for the cut-off saw may be inadequate. Exploratory investigations by the principal investigator (PI) determined that controls are not consistent between construction sites and methods include isolating the task, using fans, using leaf blowers, and trying to cut in the direction of the wind. The most common controls for the cut-off saw are wet-methods and LEV. Shepherd and Woskie (2013) showed wet-methods can reduce levels by up to 85%. There are many drawbacks to wet-methods though. These include water source and sludge clean up requirements, and quality concerns (Tharr & Lofgren, 1993; Wang, Wei, Du, & Fang, 2003). Croteau et al. (2002) also identified "…water damage potential, surface discoloration, material expansion,…and cold weather issues (freezing, hypothermia, and slip hazards)…" (G. A. Croteau et al., 2002). The water can cause electrocution hazards as well (OSHA, 2013). In 2011, there was a total of 738 fatalities in construction. Of this, 259 were due to falls and 69 were due to electrocutions, the first and third leading causes for fatalities, respectively (OSHA, n.d.-a). Wet-methods have multiple issues associated with them and may inadvertently increase safety hazards while trying to control health hazards. LEV may be preferable over wet-methods. Cutting without water causes high cutting temperatures, high noise levels, and reduced life of the blade (Wang et al., 2003), but LEV is more conducive for use on construction sites than wet-methods (G. Croteau, 2000). There is decreased clean-up time and LEV systems can be used in any geographic region and any time of the year. There are commercially available LEV systems for the cut-off saw but their effectiveness is limited. Croteau et al. (2002) showed LEV systems can greatly reduce the respirable dust levels for three common cutting tools used in concrete and masonry, but for the handheld saw, dust exposures for ventilated and non-ventilated treatments were not significantly different (G. A. Croteau et al., 2002). Meeker et al. (2009)

demonstrated for the electric models, the LEV systems can be effective though these are not available for the gasoline powered models. Middaugh et al. (2012) evaluated a built-in LEV system which reduced dust concentrations but not below the PEL. Further research is needed to assess the effectiveness of controls for the cut-off saw.

User Experience/Usability

User experience encompasses all aspects of the user's interaction with a company, service, or product (Nielsen, n.d.). User experience (UX) is important in the design of tools. UX incorporates usefulness, usability, and emotional impact. Usefulness is how well the system is able to be used to accomplish the goals of work (Hartson & Pyla, 2012). Usability is the ability of the user to use the system to carry out a task (Tullis & Albert, 2010). There are various standards and models which attempt to define usability. A common method uses five attributes to define usability: learnability, efficiency, memorability, errors, and satisfaction. In other words, how easy a system is to learn, how efficient the user is at using the system, how easy it is to remember how to use the system, how many errors users make while using the system, and how pleasant the system is to use. These attributes are both objective and subjective, with user satisfaction being a subjective assessment (Gould & Lewis, 1985; Nielsen, 1994b; Seffah, Donyaee, Kline, & Padda, 2006). Though usability may cover satisfaction, user experience is broader, and looks at the entire interaction with the system and the thoughts, feelings, and perceptions resultant from the interaction with the system, known as emotional impact (Tullis & Albert, 2010). Hartson and Pyla (2012) say emotional impact includes, "... pleasure, fun, joy of use, aesthetics, desirability,...novelty, originality, sensations, coolness, engagement,…and appeal and can involve deeper emotional factors such as self-expression, self-identity, a feeling of contribution to the world, and pride of ownership." Specifically though, UX incorporates the internal state of the user, the characteristics of the system, and the context in which the interaction occurs (Hassenzahl & Tractinsky, 2006). Satisfaction has traditionally been part of usability but UX involves multiple characteristics in context. Overall, good UX of tools means the tool is usable, useful, and has a positive emotional response from the user interacting with the tool.

Nielsen (1994b) says usability is a subset of system acceptability. System acceptability is, "the question of whether the system is good enough to satisfy all the needs and requirements of the users and other potential stakeholder, such as users' clients and mangers." Acceptability is a combination of social acceptability and system acceptability (Figure 2). Understanding the social acceptability would be to understand the barriers to adoption in construction. The practical acceptability pertains to the system itself.

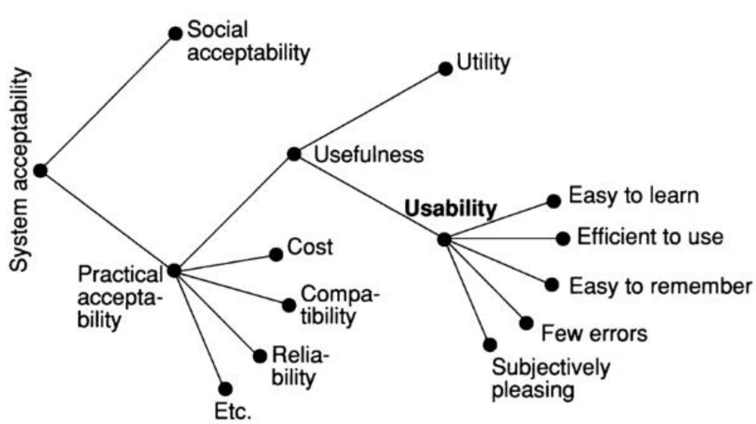


Figure 2. A model of the Attributes of System Acceptability (Adapted from (Nielsen, 1994b)).

Tools with better UX have higher adoption rates.   In electronic medical records, adoption and usability are interrelated and usability problems detrimentally affect adoption (Kushniruk, Kaipio, Nieminen, Nøhr, & Borycki, 2013). Having a product more usable is essential to having it diffused in industry. Usability is vital because if the tool is not usable, people simply will not use it (Nielsen, 2003). Thus it directly impacts technology adoption   Also, more usable products are associated with company cost savings (Bias & Mayhew, 2005; Nielsen, 1994b; Rubin & Chisnell, 2008; Tornatzky & Klein, 1982). One issue is the usability cost savings are not always visible and there is a high perceived cost by managers (Fisher & Sless, 1990; Mantei & Teorey, 1988). Regardless, usability has the added benefit of making tools safer to use. This is because a tool with unfavorable usability characteristics may cause the user to make errors which would create a safety hazard. By increasing the technology usability, there is a better chance for diffusion in the workplace.

There have been limited studies on usability of hand tools, especially powered tools. Most usability studies have only focused on comfort or discomfort. Subjective ratings of comfort for powered screwdrivers, rubber grips for tool handles, rebar tying machines, and orbital sanders, was conducted (Fellows & Freivalds, 1991; S. L. Johnson & Childress, 1988; Schneider & Vi, 2005; Spielholz, Bao, & Howard, 2001). Additionally ratings of discomfort was recorded for meat hook handles and wire twisting tasks (Dempsey, McGorry, Leamon, & O'Brien, 2002; Kong & Freivalds, 2003). Aside from only determining comfort or discomfort, screwdrivers have been assessed for predicting both comfort and discomfort (Kuijt-Evers, Twisk, Groenesteijn, De Looze, & Vink, 2005). Preferences of tools is another common assessment technique. Preferences for pistol grip handles and triggers, and ergonomic aids for in-line screwdrivers were assessed (Freund, Takala, & Toivonen, 2000; Oh & Radwin, 1993). Rok Chang, Park, and Freivalds (1999) evaluated handle types of garden tools for grip force and user satisfaction with the work performance. Finally, perceptions of vibration exposure were documented for various tools (Vergara, Sancho, Rodríguez, & Pérez-González, 2008). Although many studies were primarily evaluating forces on the body, usability characteristics were documented as well. All of these studies did not take into account the entirety of the user experience.

Adoption Barriers in Construction

An innovation is a an artifact which is perceived as new and results in change (Gambatese & Hallowell, 2011; Zaltman, Duncan, & Holbek, 1973). For the change to be realized, it must be adopted and thus the benefits of an innovation are a function of how well it is adopted (Mitropoulos & Tatum, 1999). Innovations are developed to fill a void. Innovation adoption refers to a stakeholder's decision to use or not use a system (Davis, Bagozzi, & Warshaw, 1989). Many times stakeholders may resist adopting a new system because the system requires process changes, and these changes come with risks and unforeseen costs (Häkkinen & Belloni, 2011). Thus, there are barriers to adoption. Innovation adoption barriers are characterized by anything that can prevent successful implementation of an innovation (Barrett, Sexton, & Lee, 2008). Thus, to successfully implement an innovation to enact change, the barriers must be overcome.

Even if the barriers are overcome and an innovation is adopted by a select group of stakeholders, it does not mean the innovation will be widely accepted. Thus, the rate of adoption may be slow. Economic, sociological, organizational, and psychological constraints may affect the rate of adoption (Butler & Sellbom, 2002). Thus, to realize the benefits of an adopted technology, the rate of adoption through industry known as diffusion, should be quick.

To diffuse an innovation through industry, the characteristics of the barriers to adoption should be understood. Though, Tatum (1986) says, "Examining mechanisms for innovation rather than barriers to technical progress is one means to stimulate advance." In other words, by looking at the way an innovation is adopted rather than the barriers inhibiting the adoption is a possible approach. The following describes barriers to adoption in the context of innovation adoption.

There are many barriers to innovation adoption in the construction industry. The industry is said to lag other industries in being innovative (Business Roundtable, 1982; Manley, 2008). This is especially evident compared to other industrial employers such as the services and manufacturing industries (Reichstein, Salter, & Gann, 2005). Though slow, innovation and adoption do occur (Slaughter, 1993). It behooves the industry to adopt more innovative practices because innovation may lead to enhanced performance, higher profits, and increased competitive edge over rivals (Ling, 2003; Sexton & Barrett, 2003). Thus, innovation is vital to the long term success of a company in the construction industry (Gambatese & Hallowell, 2011). Barriers to adoption can happen at different levels in the construction project. Since the individual firms are part of the overall system, they are not capable of independent operations and thus there are multiple bounding forces. In other words, there are both internal and external sources which can be conducive or obstructive to innovation adoption (Dosi, 1988; Nelson & Winter, 1982; P. L. Rogers, 2000). The main categories within these are external barriers, organizational barriers, and barriers from individuals within the organizations.

There are many barriers to adoption from external sources. Government regulations affect both residential and commercial construction (Pries & Janszen, 1995). Building codes are not always consistent. For instance, there are building codes at the federal, regional, state, and local levels. Also, zoning ordinances, permitting, and the inspection processes all hinder innovation because a potential adopter may not know when an innovation will delay a project to satisfy the regulators (Duke, 1988; D. M. Kramer et al., 2010; Toole, 1998). Thus, competition is usually cost driven rather than innovation driven (Pries & Janszen, 1995). This is confounded by the construction industry being a mature market. In mature markets, competition is usually based on price (Utterback & Abernathy, 1975). Regulations may help the adoption of innovations at times. If regulators gather enough information, standards can be made which codify existing technologies. This would create demand for innovations (Gann & Salter, 1998). This means the government can create a guaranteed market for innovations (Miozzo & Dewick, 2002). In other words, strict standards force the industry to adapt, and thus adopt new innovations to meet codes. Labor unions are another source of external barriers. Many times, labor unions can affect technology adoption. Sometimes, labor unions may be a hindrance because they may resist labor saving innovations. They do so because this may reduce the amount of work available. Even so, labor savings does not always mean the union will be a hindrance to adoption (Blackley & Shepard III, 1996). Additionally, when an innovation may improve the health and safety of workers, labor unions can be helpful in getting a technology adopted. Because unions represent the workers, anything that improves the quality of life of workers may be welcomed (Hess, Weinstein, & Welch, 2010; D. Kramer et al., 2009). Organized crime can directly affect the construction industry as well. The Organization for Economic Co-operation and Development (OECD) (2008) says organized crime, or cartels, have historically affected the industry and the problem is not subsiding. This problem is not unique to America but is a global issue. The industry has been notorious for having criminal impact, thus, there is rampant corruption in construction. This can be a barrier that needs to be overcome since organized crime can dictate policies and thus what innovations are adopted. External sources may make it difficult for the construction industry to adopt new technologies.

There are organizational sources which are barriers as well. The essence of buildings and structures innately hinders innovation because buildings are meant to last and be durable. Trialability is also low since potential adopters cannot quickly use the product to determine if it works. When trialability is low, the barrier is higher. Having durable structures means there is a preference for conservative practices (Barlow, 2000; Pries & Janszen, 1995). Additionally, many companies do not have to be innovative to succeed as long as they meet the local needs and keep up with regulations (Reichstein et al., 2005). Thus, there is a culture engrained in construction which is resistant to change.

Cost may be a major factor in deciding to adopt or reject a technology. Manley & McFallen (2003) found for the private sector, the cost of an innovation was the biggest obstacle, while in the public sector, the biggest obstacle came in the form of funding constraints. The barrier of cost needs to be understood in the context of the life cycle of a tool. Besides the initial cost, costs of repairs and replacements is reflective of the true cost. Hsu and Chen (2000) found when testing different shroud configurations on an angle grinder, a tool common in masonry, one shroud configuration easily broke and needed to be repaired until it could be replaced. This slowed research efforts which is reflective of what would happen in the field. Firm size and financial constraints are closely linked. Small firms are limited geographically, operate in competitive markets, and suffer from a lack of capital (Hess et al., 2010; Manley & Mcfallan, 2006). Many times, small firms are attempting to stay viable in the market and do not have excess resources to be devoted to innovations (Barrett & Sexton, 2006). The technologies that are adopted tend to be quick and immediately used (Sexton, And, & Aouad, 2006). Therefore, small firms may have a short-outlook and may not have the ability to adopt new technologies. Large firms on the other hand can more easily afford investing in innovations, thus they can tolerate risk better (Nam & Tatum, 1997). Additionally, large firms are able to draw on larger amounts of resources to adopt long-term, formal technology adopting strategies (Sexton et al., 2006). Even so, for developing innovations, larger firms do not develop a disproportionate amount innovations (Nam & Tatum, 1997). Thus, firm size differences play an important role in technology adoptions. Observability within the organization is important. When a specific tool is used by one organization on a construction site, other firms are more likely to adopt it. People in construction tend to be more tactile learners (Meeks, Sweaney, & Swagler, 1992). When an individual in construction can see a tool being used, even if they do not use it themselves, they have a much better understanding of the tool than if they just saw a picture of it and had to imagine how it worked. Having a tool on a site means having a higher observability, which means there is a higher chance of it being adopted by other organizations because the relative advantage is apparent (D. M. Kramer et al., 2010). Organizations may hinder technology adoption.

Individual sources of barriers to adoption are clients/project owners, business owners, and project managers. Clients, the people who own the land where the construction is occurring, can be instrumental in bringing innovations to the construction site. They do this by outlining the building specifications by demanding higher performance, and they enable better communication and collaboration among the people in the project. They also share in the risk of adopting the new innovation (Blayse & Manley, 2004; Dewick & Miozzo, 2004; Nam & Tatum, 1997). By having the client more involved, this may help with technology adoption, but this is not usually the case because clients do not want to share in the risk (Ivory, 2005). Additionally, more experienced clients are better at enabling the adoption of new innovations. The more experience the client has with construction projects, the better the client is at minimizing risks and evaluating solutions. Therefore, experience enables the client to better judge the relative advantage of the innovation (Hartmann, Dewulf, & Reymen, 2006). Business owners can also be a barrier. Owners are inherently involved in the building process, especially in small business. Owners can be conservative because in construction, things are costly and have dire consequences if something fails. Sometimes though, this conservatism comes from limited knowledge of the technology (Nam & Tatum, 1997). Project managers are another barrier. Project managers, members of the project management firm, are responsible for executing the project (Hendrickson & Au, 1989). How innovative a firm is can highly depend upon the project manager. A project manager's willingness to innovate is dependent upon their past experiences. Many learned management informally and social norms such as moving on a short time lines was ingrained. Once in an authoritative position, these individuals make policy decisions based on short-term project management (Pries & Janszen, 1995). Even though larger firms tend to be able to invest in long-term innovation solutions, their willingness to do so may depend on the individual project managers. This results in slow diffusion of information and an apprehension to using new practices (Hess et al., 2010). Therefore, individuals within an organizations can pose problems for technology adoption.

A theoretical model is available to understand adoption readiness within construction. Our research group developed a theoretical model, the Prevention through Design (PtD) Adoption Readiness Model (PtD ARM), specifically for construction (J. E. Weidman, Young-Corbett, & Koebel, 2014a). This evaluates stakeholder constructs that influence the adoption readiness for PtD controls. Additionally, the research group developed and validated a survey instrument to assess PtD adoption readiness for the drywall finishing trade through the associated model constructs (J. E. Weidman, Young-Corbett, & Koebel, 2014b). For workers, there was a low perceived risk to health from drywall dust, low organizational trust and self-efficacy, as well as a lack of cues-to-action, something that provides a stimulus which alters behavior. Firm owner barriers to adopting dust-related PtD controls include technology usability, productivity, cost, and a misperception of the risk associated with the dust (Young & Nussbaum, 2009).

The differences between small and large firms can be seen through the lens of entrepreneurship. Entrepreneurship is a processes where individuals recognized, prepare, and exploit opportunities to create value (Van der Veen & Wakkee, 2004). Entrepreneurship is associated with innovative and behavioral change. There are three kinds of entrepreneurial innovation: incremental or continuous, discontinuous or radical, and architectural. Incremental or continuous refers to step by step slow improvements. Discontinuous or radical refers to abrupt changes and can have transformative impressions on the industry. Architectural can be seen as an in-between of the continuous and discontinuous (Habets, Voordijk, & Sijde, 2006; Schumpeter, 1961). Habets et al. (2006) showed that larger companies prefer incremental innovations while smaller companies prefer architectural innovations. This implies that regardless of firm size, radical innovations are not generally adopted. Therefore, the tool developed in the proposed research should be architectural and smaller firms are more likely to adopt the technology.

Firm size is directly related to financial constraints. Small firms are limited geographically, operate in competitive markets, and suffer from a lack of capital (Hess et al., 2010; Manley & Mcfallan, 2006). Many times, small firms are attempting to stay viable in the market and do not have excess resources to be devoted to innovations (Barrett & Sexton, 2006). The technologies that are adopted tend to be quick and immediately used (Sexton et al., 2006). Therefore, small firms may have a short-outlook and may not have the ability to adopt new technologies. Large firms on the other hand can more easily afford investing in innovations, thus they can tolerate risk better (Nam & Tatum, 1997). Additionally, large firms are able to draw on larger amounts of resources to adopt long-term, formal technology adopting strategies (Sexton et al., 2006). Even so, for developing innovations, larger firms do not develop a disproportionate amount innovations (Nam & Tatum, 1997). Thus, firm size differences play an important role in technology adoptions.

Key factors for implementing an LEV system in the concrete industry have been expressed (Shepherd & Woskie, 2010). These factors include a cooperative relationship between the general contractor and subcontractor, effect of dust on schedule other work, public relations, and subcontractor perceived benefits.

Add-on System

Add-on systems, rather than built-in systems, can have a greater likelihood of adoption (Hsu & Chen, 2000; Shepherd & Woskie, 2010). One reason for better adoption rates with add-on systems is they can be used on many makes and models of saws. When investigating different dust capturing systems for a hammer drill, Hsu and Chen (2000) noted having the system capable of fitting all makes and model was a priority to have it accepted by industry. Shepherd and Woskie (2010) echo this sentiment when discussing fitting off-the-shelf dust capturing systems on grinders. Construction firms tend to have multiple brands across all tools used on site so add-on systems are important. Additionally, the cost of the add-on system is significantly cheaper than built-in LEV systems for the saw. The iQ PC912, an LEV system for the cut-off saw, is $2,005.00 including shipping while the Saw Muzzle GP, another LEV system for the cut-off saw, is $171.16 including shipping. Cost can be a barrier when getting innovations adopted in construction. Hess et al. (2012) demonstrated that a new masonry material with the same performance as the traditional material reduced ergonomic stressors. The authors estimated the difference in cost is only 2%. Ling (2003) says that construction projects operate on slim margins. Therefore, even if the technology is slightly more expensive, this may be a large barrier to adoption. Kramer et al.(2009) attempted to have a ladder lift accepted by industry but it was not widely adopted by small companies because of financial constraints. Add-on systems can be substantially cheaper, therefore, the research focused on developing add-on systems to enable better adoption rates

Design Taxonomy

A design taxonomy help guide the design process (Wondrack, 2015). Taxonomy originally derives from natural sciences. Rich (1992) says in the tradition of natural sciences, a taxonomy is, "a specific classification scheme that expresses the overall similarity between organisms in a hierarchical fashion." Thus a design taxonomy is a way of expressing similarity between design guidelines. A taxonomy in design is helpful because it eliminates the highly subjective world of good user experience (Wondrack, 2015). Though design taxonomies do exist for hand tools, the researcher cannot find any for large handheld powered tools. Meagher (1987) created categories for hand tools including size, shape, purpose, ease of operation, shock absorption, and weight. This specifically addresses issues to prevent hand and wrist injuries. Additional tool indices of importance are static loading of arm and shoulder muscles, awkward hand position especially wrist deviation, excessive or continuous pressure on the palm and fingers, exposure to vibrations and cold from power tools, pinch points with double handle tools, and handles that require stretching of the hand to grip or high force to hold (Putz-Anderson, 1988). Product weight, product size, product shape, surface color and texture, sharp edges and corners, protrusions, openings in products, frequency of exertion, electrical energy, and fluid energy are categories of importance in hand tool design (L. Greenberg & Chaffin, 1977). For powered ventilated drywall sanders, ease of use and perceived comfort are the two overarching categories one should consider when doing a redesign (Young-Corbett, Nussbaum, & Winchester, 2010). Additionally, overarching aspects that are important to cover in the evaluation of hand tools when it relates to cumulative trauma disorders are the characteristics of the tool itself and the effects on the operator (Kadefors et al., 1993). Some of these guidelines such as those by L. Greenberg and Chaffin (1977) are broad and cover much, others are more tool specific.

Conclusion

Asphalt emissions and silica are a leading health hazards in construction. Multiple concrete and masonry operations produce dust concentrations which may overexpose workers. PtD is the ideal way of combating these issues. One of the biggest dust producers is the handheld cut-off saw. Though controls exist for this saw, they may be inadequate. Barriers to innovation adoption exist in construction and there tends to be low adoption rates. One reason may be because of the inadequacy of controls. One way of designing better controls would be through a specialized design taxonomy.

Chapter 2

Study 1 and Study 2-Current Industry Perceptions, PtD Control Usage, and Adoption Readiness in the Concrete, Masonry, and Asphalt Roofing Trades

Objective 1: Explore decision maker perceptions of risks from dust overexposure, perceptions and usage rates of control technologies, and adoption readiness of the concrete and masonry trades

Objective 2: Explore decision maker perceptions of risks from fume overexposure, perceptions and usage rates of control technologies, and adoption readiness of the asphalt roofing trade

Introduction

Concrete, masonry, and asphalt roofing operations have some of the most pressing health hazards in construction and current usage of PtD controls are not known. Though there are known health hazards, decision makers' thoughts on the extent of their harmfulness has not been documented. Additionally, controls exist to manage fume and dust overexposure but the extent of their use is not known. This study details these two factors and determines the adoption readiness of these industries using a questionnaire. This may lead to the development of better adoption rates of current controls and the development of new controls.

Methods

Site Visits

The decision-makers in concrete, masonry, asphalt roofing had to be determined. The PI visited three construction sites on the Virginia Tech Blacksburg campus. The first site visited was Davidson Hall, managed by Barton Malow Company. The project manager granted an interview with the research team, and the visit consisted of touring the site while asking predetermined questions (Appendix A) and any relevant site-specific questions. The first question asked regarded how they made purchasing decisions. Purchasing agents exist for large construction management firms to negotiate prices on materials. Although Barton Malow is a large construction management firm, their project managers on individual sites make the purchasing decisions. The research team posed the same question on the following two site visits, Human and Agricultural Biosciences Building 1 managed by SKANSKA, and the Center for Performing Arts (Moss Arts Center) managed by Holder Construction Company. Interviews were granted with the project manager for each site. The project managers were informed of the purpose of the research and verified purchasing agents would not be the best option. Additionally, because many of the firms surveyed would not be large construction management firms, understanding who the decision maker is in small firms is important. Based on the three site visits, it was determined the decision maker if small firms are the owners themselves as they are subcontracted to do the work on these larger sites.

Participants

When the surveyor contacted the firms, they asked to speak with the decision maker. No specific job title was asked for as the decision maker may differ between each firm, especially across firm sizes. Firms were contacted by obtaining membership directories of the Mason Contractors Association of America (MCAA)(n=700), the Concrete Sawing and Drilling Association (CSDA)(n=541), the American Concrete Pavement Association (ACPA)(n=4000), and the National Roofing Contractors Association (NRCA)(n=4000).

The researcher hypothesized the age of the decision maker, his or her gender, and the size of his or her firms may all have an effect on the dependent variables. The surveyor asked the participants' age and gender. Gender was classified as Male or Female. Age was categorized according to the Bureau of Labor Statistics reporting age brackets seen in Table 1 below as there were no participants under 20 years old (Bureau of Labor Statistics (BLS), 2015b).

Table 1

Categorization of Participant Ages

Age Range (years)	**Category**
20-24	1
25-34	2
35-44	3
45-54	4
55-64	5
65+	6

Participants were asked their number of full time employees. Firm size was categorized according to the European Union standards for small and medium-sized enterprises (The Commission of the European Communities, 2003). The classification for Large was inferred considering Medium enterprises are <250 full time employees.

Table 2

Categorization of Firm Size

Number of Full Time Employees	**Firm Size Classification**
1-9	Micro
10-49	Small
50-249	Medium
250>	Large

<u>Procedures</u>

The researcher chose surveys for these studies. Rubin and Chisnell (2008) says surveys are used to understand a broad base of users and its large samples can be used to generalize to an entire population. The surveys (Appendix C and Appendix D) developed were based on previous work by our lab, a dry wall employer questionnaire to evaluate sanders in drywall finishing operations, project DUSTI (J. Weidman, 2012). The drywall sanding questions were based on the PtD ARM. This model was developed by our lab and is based on three well established models, the Health Belief Model (HBM), the Technology Acceptance Model (TAM), and the Diffusion of Innovation Model (DOI). The previous questionnaire was developed to measure and model constructs. The same principals were applied for the adapted survey instrument.

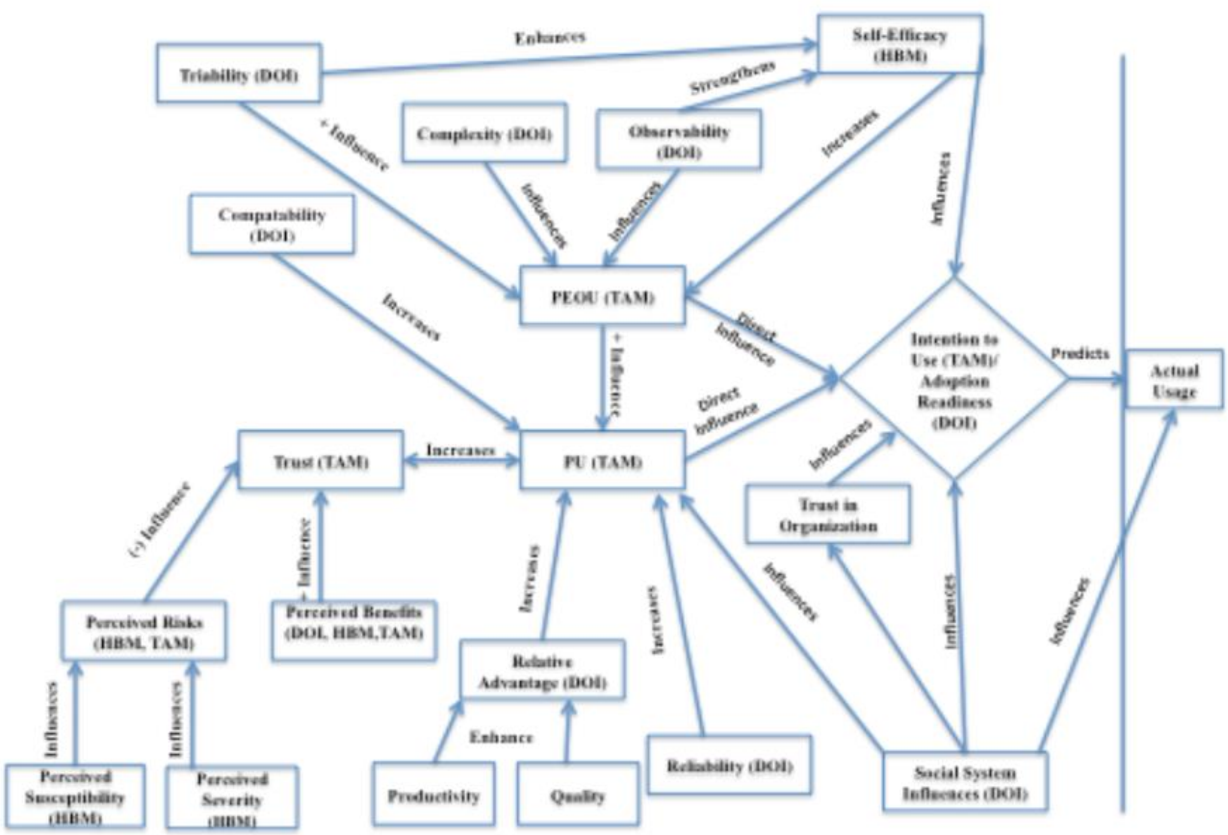


Figure 3. Prevention through Design Adoption Readiness Model

A phone survey was chosen because of the speed of data collection and the economic benefits. Electronic means were not used because many of the decision makers may not have internet access or do not spend their day at a desk. All questions were phrased so that they are positively correlated with the construct they are intended to measure. Controls of interest were identified through a literature review. Final controls identified are presented in Table 3. Wet-method systems use water at the point of contact to suppress dust. Dust collection equipment use vacuums to collect dust. Isolation systems entail either isolating the workers from dust producing activities, isolating dust producing activities from the workers, or enclosure systems for certain tools. Sweeping compound binds to dust as it is poured onto it, causing it to stick together making it easier to sweep. Liquid asphalt tanker delivery systems deliver heated asphalt to the job site, ready to be used. Hot luggers, mechanical spreaders, and felt laying machines are mechanical tools which aid in the laying and spreading of asphalt. Insulated kettles/hot luggers have an insulation system built into the kettle where the asphalt is heated and the hot luggers which are used to move asphalt from the kettle to where it will be applied. Low-fuming asphalt, also known as odor-reducing asphalt, is a material which when heated in a kettle forms a skim on top to suppress fume dispersion. Kettle fume guards reduce fume transition from the kettle to the surrounding air.

Table 3

Dust and Fume Control Technology Analyzed

Controls	Industry
Wet-method Systems (WET)	Concrete/Masonry
Dust collection Equipment (DCE)	Concrete/Masonry
Isolation Systems (ISO)	Concrete/Masonry
Sweeping Compound (SWP)	Concrete/Masonry
Liquid Asphalt Tanker (TDS)	Asphalt Roofing
Hot Luggers, Mechanical Spreaders, Felt Laying Machine (MEC)	Asphalt Roofing
Insulated Kettle/Hot Lugger (INS)	Asphalt Roofing
Low Fuming Asphalt (LFA)	Asphalt Roofing
Kettle Fume Guards (KFG)	Asphalt Roofing

The researcher used the card sort technique to initially validate the questions (Appendix B). Card sort is a way to understand how items are grouped into categories (Martin & Hanington, 2012). Specifically, close card sort was used where the categories are already determined and the participants are only doing the grouping (U.S. Department of Health and Human Services, 2016). Each question was written on an index card and each construct and construct definition from the PtD ARM was written on an index card. Some constructs are nested in other constructs so the cards were placed in the appropriate hierarchical order on a table per the PtD ARM. Ten human factors and ergonomics graduate students from Virginia Tech were recruited as participants. The order of questions was randomized between participants. Participants were instructed

to read a question and place in in the appropriate category. For each question, the PI recorded how many times each question was categorized under each construct.
The U.S. Department of Health and Human Services (2016) say one way of analyzing card sort results is to see how often cards appear in a specific category. From the results, questions that were below 0.80 agreement were eliminated.

The final constructs and their definitions are in Table 4. Most definitions were directly from DUSTI, except for perceived usefulness. Participants noted perceived usefulness' definition of "perception of the benefits associated with use of technology" was confusingly similar to perceived benefit and thus an alternative definition directly from the TAM was used.

Table 4

Theoretical Constructs and Their Definitions

Construct	Definition	Source of Definition
Trust in Technology	Belief in the value of and willingness to depend upon the technology	(J. Weidman & Young-Corbett, 2012) adapted from Technology Acceptance Model (TAM)
Perceived Usefulness	degree to which a person believes that using a particular system would enhance job performance	Davis 1989 (TAM)
Perceived Benefit	Perception of benefits to be attained through adoption	(J. Weidman & Young-Corbett, 2012) adapted from Diffusion of Innovation (DOI), Health Belief Model (HBM) and Technology Acceptance Model (TAM)
Relative Advantage	Perception of how innovation will impact profitability of company	(J. Weidman, 2012) adapted from Diffusion of Innovation (DOI)
Perceived Risk	Worker and owner perception of barriers to or associated with adoption	(J. Weidman, 2012) adapted from Health Belief Model (HBM)
Adoption Readiness	State-of-mind about the need for an innovation and the capacity to undertake technology transfer	(Armenakis, Harris, & Mossholder, 1993)

The survey was validated using subject matter experts (SME). The first round of SME validation used industry representatives. To validate the control names, the PI spoke with an industrial hygienist from Fluor Corporation who suggested reviewing leading material/equipment suppliers' websites. Suggestions for alternate control names were recorded. Next, decision makers in each industry were contacted by reviewing membership directory information. A total of one decision maker for asphalt roofing, one for concrete, and two for masonry were recruited. The researcher told the decision maker the purpose of the research and gave him the questionnaire. The researcher asked the decision maker if the question appropriately represented the concept it was trying to measure, if the terminology used in the questions were correct, and if the terminology of the control of interest was correct. The majority of the questions are repeated for each control of interest so only one set needed to be validated. Though, depending on the control of interest, sometimes a question's phrasing had to change. For these specific instances, these questions were also validated through the same process. After this round of validation, questions were removed and updated. Additionally, one control for concrete and masonry, material substation, was eliminated because there did not seem to be any material that could take the place of silica-based products.

The researcher change or defined control names based on the information from the SMEs and reviewing the internet. For asphalt roofing, tanker delivery systems became liquid tanker delivery systems, fume-suppressing asphalt became low-fuming asphalt, and local-exhaust ventilation became kettle fume guards. For concrete and masonry, ventilated tools/local exhaust ventilation (LEV) became dust collection equipment. For some controls, a definition was added to the questionnaire to ensure clarity.

The final round of validation involved survey SMEs. The researcher contacted a professor from Virginia Tech who instructs a graduate level course entitled, "Questionnaire Design and Survey Research." She conducted two rounds of validation on the instruments. Next, another survey expert who operates the Virginia Tech Center for Survey Research validated the survey. The survey originally had a 7-point Likert scale but because a phone survey was chosen, users may have found it difficult to remember the choices. The expert suggested using a 4-point Likert scale, eliminating a middle choice because participants will most often choose an indifferent choice if given the opportunity. Although those surveyed were not given a choice other than the four options, the surveyor was able to record if a respondent didn't know the answer or refused to answer. Changes from the two survey SMEs were integrated into a final version, and the Center for Survey Research conducted data collection. The Center was used to reduce experimental bias.

The final concrete/masonry survey (Appendix C) and the asphalt roofing survey (Appendix D) had to be altered after calling the first 200 respondents. With the last question for Adoption Readiness (which was Adoption Readiness 2) and the second Trust in Technology (what was Trust in Technology 2) eliminated during the actual testing per the Center for Survey Research's advice; they were getting negative feedback from respondents. Specifically, "My company looks forward to using or continuing to use [technology name.]" was eliminated because decision makers who were already using the technology found the first part confusing. Secondly, "I feel [technology name] works well" was eliminated because decision makers found it too vague.

Table 5

Final Survey Questions with Card Sort Frequencies

Question	Construct	Card Sort Score
Exposure to (concrete or masonry dust OR asphalt vapors and fumes) poses a potential health risk to workers.	Perceived Risk 1	10/10
(Concrete or masonry dust OR asphalt vapors and fumes) can cause severe health effects.	Perceived Risk 2	10/10
How familiar are you with [technology name].	Familiarity	N/A
How often do your employees use [technology name]?	Frequency of Use	N/A
I trust [technology name] will get the job done well.	Trust in Technology	9/10
[Technology name] is beneficial to the health of my workers.	Perceived Benefit 1	9/10
[Technology name] reduces (concrete or masonry dust OR asphalt fume) overexposure.	Perceived Benefit 2	9/10
[Technology name] is a useful tool for working with (concrete or masonry products OR asphalt.	Perceived Usefulness 1	8/10
[Technology name] improves job performance.	Perceived Usefulness 2	8/10
More work gets done when using [technology name].	Relative Advantage 1	9/10
[Technology name] allows my workers to accomplish more work than would otherwise be possible.	Relative Advantage 2	8/10
I anticipate my company will use, or continue to use, [technology name] in our work.	Adoption Readiness	8/10

Data Analysis

Closed-ended and Multiple Choice Questions

The researcher analyzed the data to determine current usage and stakeholders' perceptions. The procedures were used to understand closed ended questions regarding decision makers' thoughts on the perceived risk from the hazard. Some constructs used more than one question to assess it, so results were averaged. For instance, results from Perceived Risk 1 and Perceived Risk 2 were averaged to create Perceived Risk Combined which represents the construct "perceived risk." A MANOVA was used to determine if firm size, age, or gender had an effect on perceived risk 1, perceived risk 2, and perceived risk combined. Decision makers were also asked about business factors affecting control adoption, if the number of projects specifying fume or dust control technologies are increasing, and how many projects are specifying fume or dust controls per year. A MANOVA was used to determine if firm size, age, or gender had an effect on these dependent variables. Finally, the decision makers were asked about their familiarity, frequency of use, perceived benefit, perceived usefulness, trust in technology, relative advantage, and adoption readiness of specific controls. A MANOVA was used with one within-subjects factor (tool type) on all dependent variables related to specific controls. Tukey's HSD were used to perform all post-hoc comparisons of means. Subsequent repeated-measures univariate ANOVA was used to test for differences in constructs across tool types. Finally, one-way ANOVA was used to analyze significance for perceived risk, business factors, projects increasingly specifying dust or fume control, and the percent of projects specifying controls a year. All analyses were performed using JMP Pro 12.0.1 (SAS Institute Inc., Cary, NC) with significance determined when $p<0.05$.

Open-ended Questions

Open ended questions were analyzed using content analysis which is a qualitative procedure for coding information from text data (Berelson, 1952; Hsieh & Shannon, 2005). A categorical coding scheme was implemented with the categories being exhaustive and mutually exclusive (Neuendorf, 2002). Categories that both asphalt roofing and concrete/masonry share are: cost, not applicable to company, job size/size of work, site/climate/environment issue or dependent, and not necessary/don't need. The actual coding of the protocols was conducted by two independent coders to mitigate bias from the research team imprinting their hypotheses into the data (Van Someren, Barnard, & Sandberg, 1994). Thus, inter-rater reliability was calculated. Inter-rater reliability is important because without reliability, the measure is not valid (Neuendorf, 2002). Intercoder agreement refers to the extent independent judges make the same coding decisions (Lombard, Snyder-Duch, & Bracken, 2002). Intercoder reliability/intercoder agreement on this nominal data was calculated using Krippendorff's alpha in Equation 1.

$$\boldsymbol{\alpha_{nominal} = 1 - \frac{D_o}{D_e} = \frac{(n-1)\sum_c o_{cc} - \sum_c n_c\,(n_c-1)}{n(n-1) - \sum_c n_c\,(n_c-1)}} \qquad \textbf{(1)}$$

(K. Krippendorff, 2011)

Where:

D_o "is the observed disagreement among values assigned to units of analysis."

D_e "is the disagreement one would expect when the coding of units is attributable to chance rather than to the properties of these units."

Tentative conclusions were drawn when relatabilities were between 0.667 and 0.79, and conclusions were made when reliability was ≥0.80 (Klaus Krippendorff, 2004). Items that did not have agreement between both coders were not included in the frequency tables.

Results

Study 1

Study 1 assessed perceptions of stakeholders in the concrete and masonry trades. They were first asked about perceived risk, then about specific tool, and finally open ended responses were recorded.

Perceived Risk

Table 6

Perception of Risk in Concrete/Masonry Trades

	Perceived Risk 1-Perceived Health Risk (%)	Perceived Risk 2-Perceived Severity of Health Risk (%)
Strongly Agree	35.3	35.9
Somewhat Agree	43.7	37.7
Somewhat Disagree	15.0	15.0
Strongly Disagree	5.4	6.0
Don’t Know/Refuse to Answer	0.6	5.4

Percent of firm owner responses to questions regarding perceived risks. Perceived Risk 1 Question: “Exposure to concrete or masonry dust poses a potential health risk to workers. Perceived Risk 2 Question: “Concrete or masonry dust can cause severe health effects.” (scale anchors: 1=strongly agree, 5=don’t know/refuse to answer)

Mean (SD) scores for the scaled items were 1.92(0.88) for Perceived Risk 1, 2.07(1.11) for Perceived Risk 2, and 2.00(0.91) for Perceived Risk Combined. While 79% of respondents (combining strongly agree and somewhat agree) feel concrete/masonry dust poses a health risk to workers, more than 73% feel it poses a severe health effect. A MANOVA assessing the effect of age, firm size, and gender on the three perceived risk factors showed no significant effects.

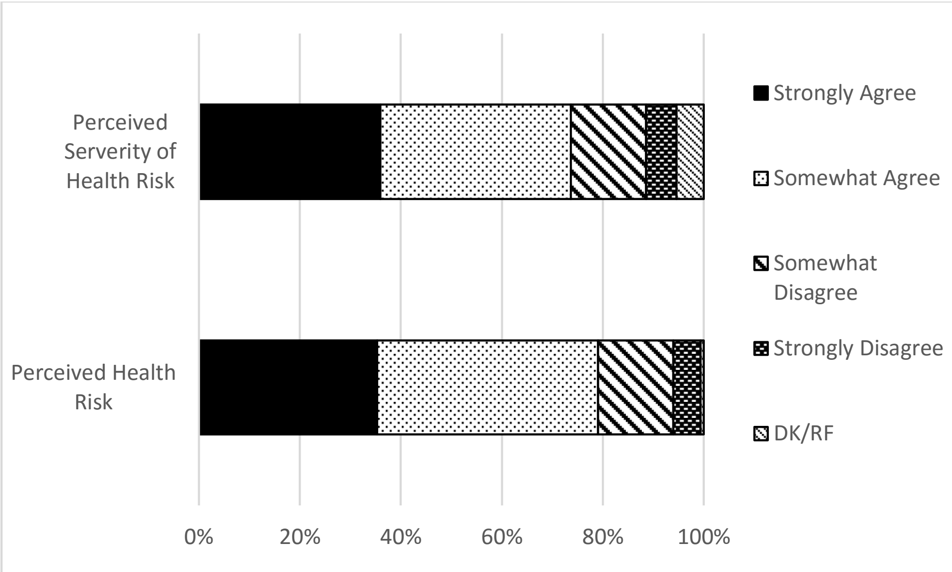


Figure 4. Perception of Risk Associated with Concrete/Masonry Dust

Tools and Constructs Overview

A MANOVA with all constructs that assess tools as dependent variables revealed a significant multivariate effect for type of tool (Wilk's lambda=0.59, $F(39,1081.6)=5.3$, $p<0.0001$). Subsequent univariate ANOVA showed significant difference between dust control technologies for familiarity ($F(3,664)=68.0$, $p<0.0001$), frequency of use ($F(3,428)=65.9$, $p<0.0001$), trust in technology ($F(3,377)=18.2$, $p<0.0001$), perceived benefit 1 ($F(3,377)=11.2$, $p<0.0001$), perceived benefit 2 ($F(3,377)=17.5$, $p<0.0001$), perceived benefit combined ($F(3,377)=16.5$, $p<0.0001$), perceived usefulness 1 ($F(3,377)=19.0$, $p<0.0001$), perceived usefulness 2 ($F(3, 377)=15.5$, $p<0.0001$), perceived usefulness combined ($F(3,377)=21.8$, $p<0.0001$), relative advantage 1 ($F(3,377)=19.7$, $p<0.0001$), relative advantage 2 ($F(3,377)=14.2$, $p<0.0001$), relative advantage combined ($F(3,377)=18.6$, $p<0.0001$), and adoption readiness ($F(3,377)=24.3$, $p<0.0001$).

Familiarity

Of the four dust control technologies evaluated, decision makers were most familiar with wet-method systems 1.77 (1.11), followed closely by dust collection equipment 1.98(0.93). When decision makers were referring to sweeping compound and isolation systems, they reported they were only slightly familiar with 3.05(1.23) and 3.11(1.11), respectively.

Table 7

Percent of Decision Makers' Responses to Questions Regarding Familiarity with Dust Control Technologies

	Wet-method Systems	Dust Collection Equipment	Isolation Systems	Sweeping Compound
Very Familiar	39.3	34.1	9.6	18.6
Somewhat Familiar	18.0	43.1	27.5	16.8
Slightly Familiar	5.7	13.2	5.4	6.0
Not at all Familiar	36.9	9.6	57.5	58.7

Decision makers are most familiar with dust collection equipment, with over 90% familiar in some capacity. Decision makers are second most familiar with wet-method systems with 63% familiar in some capacity. Decision makers are most unfamiliar with isolation systems and sweeping compound with 57.5% and 58.7% not at all familiar with the technologies, respectively. Tukey's HSD shows decision makers are significantly more familiar with wet-method systems and dust collection equipment than solation systems or sweeping compound.

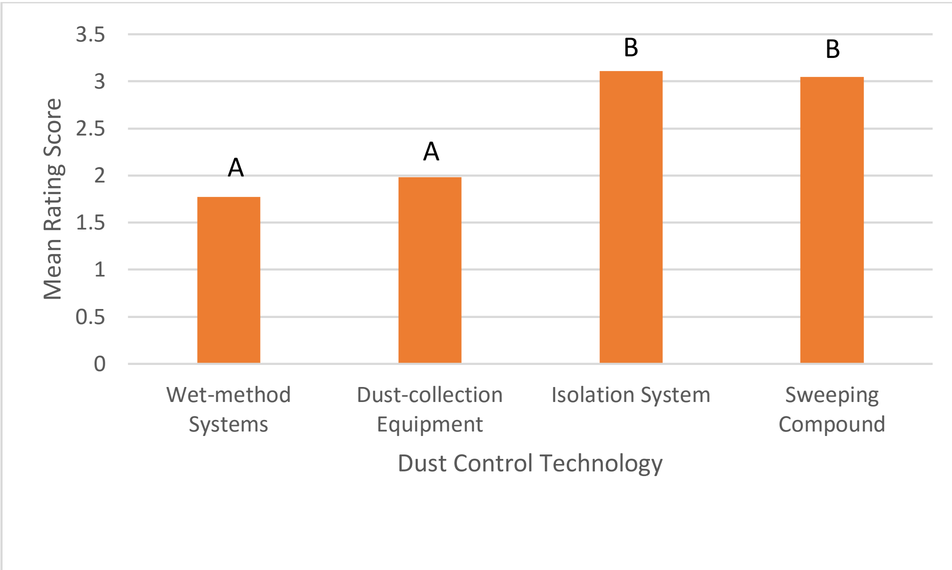


Figure 5: Concrete/Masonry Technology Familiarity. Mean score for questions #3,15,27, 39 "How familiar are you with [Technology name]."
Likert scale anchors: 1=very familiar, 4= not at all familiar.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

Frequency of Use

Table 8

Percent of Decision Makers' Responses to Questions Regarding Frequency of Use of Dust Control Technologies

	Wet-method Systems	Dust Collection Equipment	Isolation Systems	Sweeping Compound
Always	31.4	28.5	1.4	8.7
Regularly	33.3	29.8	11.3	21.7
Sometimes	12.4	17.9	28.2	15.9
Rarely	11.4	15.2	39.4	27.5
Never	10.0	8.6	19.7	24.6
Don't Know/Refuse to Answer	1.4	0.0	0.0	1.4

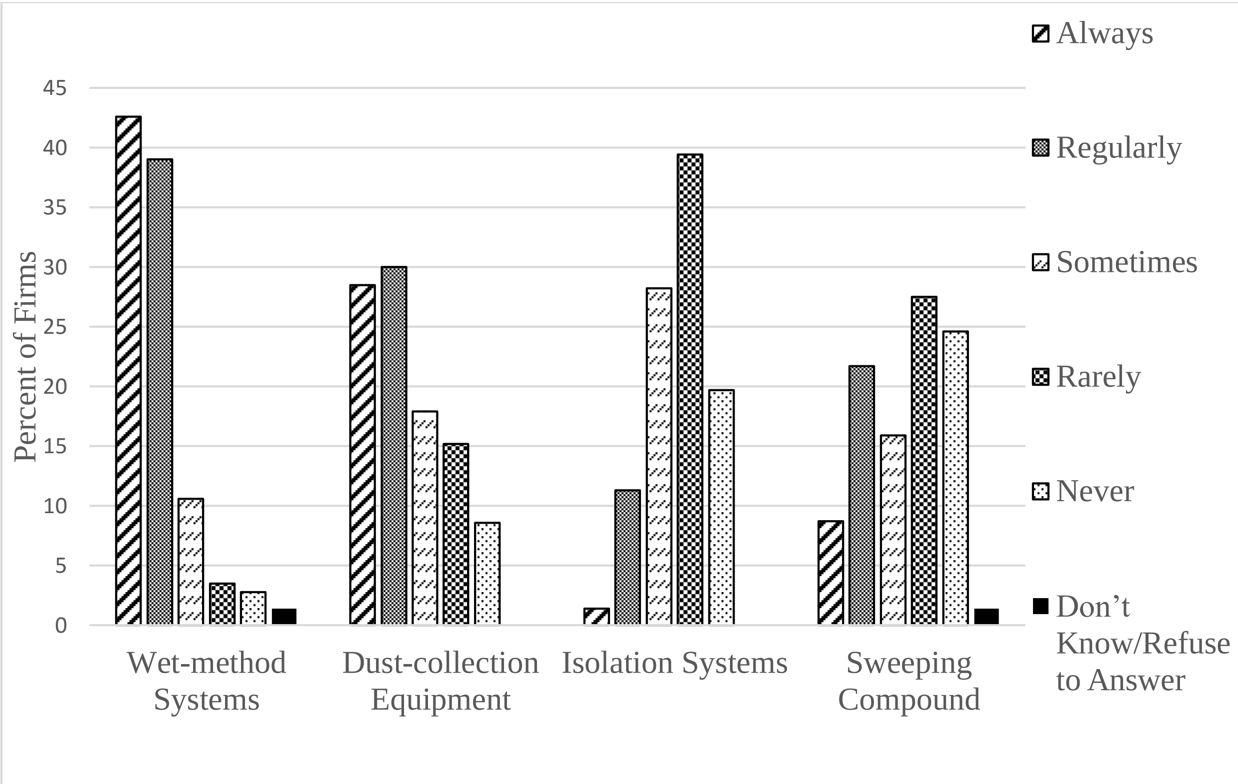


Figure 6. Frequency of Use of Dust Control Technologies

Wet-method systems and dust collection equipment are the most frequently used dust control technologies. Decision makers responded they either always or regularly use wet-method systems and dust control technology 64.7% and 58.3% of the time, respectively. Isolation systems are rarely or never used, totaling 59.1%. Totaling 24.6% of decision makers never use sweeping compound. Wet-method systems are significantly different from all other technologies and the most frequently used. Likewise, dust collection equipment is also significantly different from all other technologies assessed with the second highest frequency of use. Isolation systems and sweeping compound are not significantly different from each other.

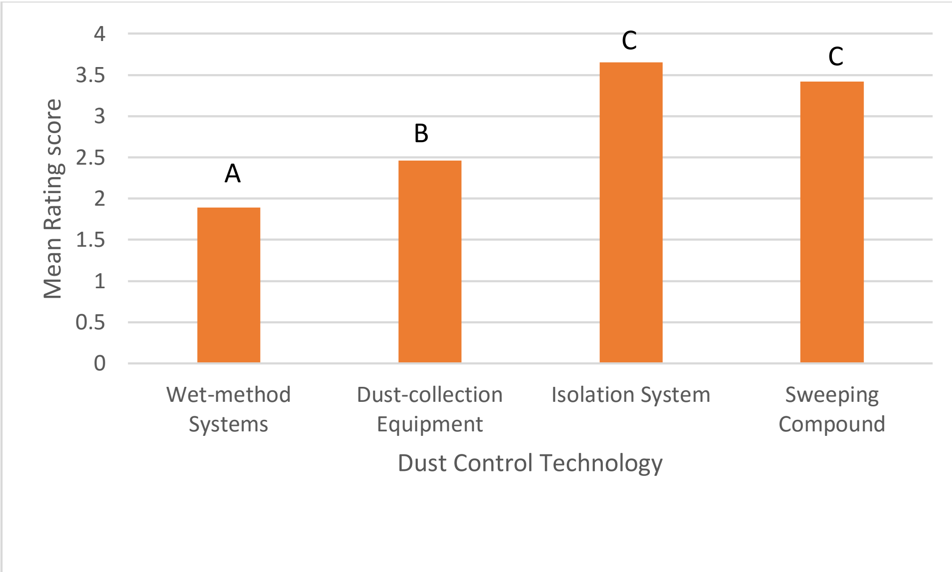


Figure 7: Concrete/Masonry Technology Frequency of Use. Mean score for questions #4,16,28, 40 "How often do your employees use [Technology name]."
Likert scale anchors: 1=always, 5= never.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

All Other Tool Constructs

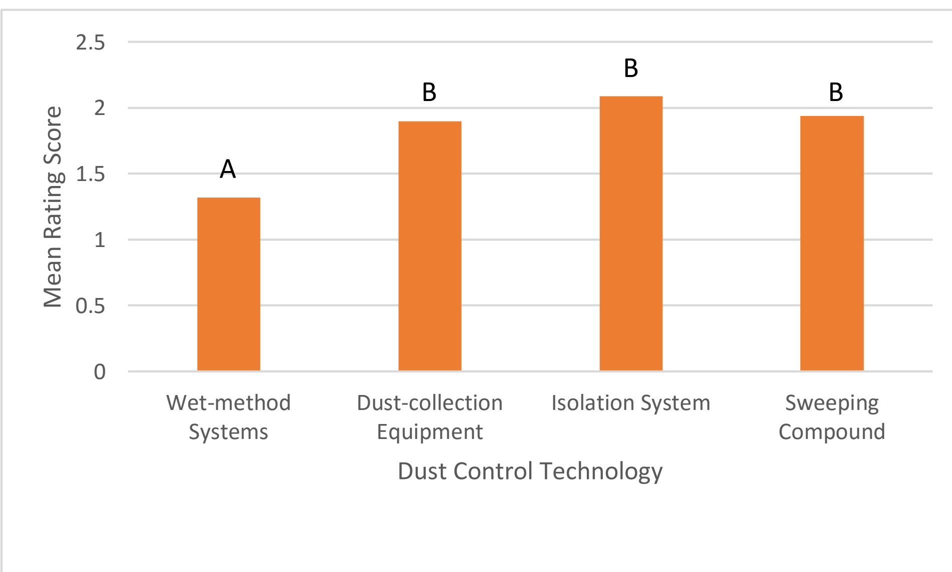


Figure 8. Concrete/Masonry Trust in Technology. Mean score for questions #5,17,29, 41 "I trust [Technology name] will get the job done well."
Likert scale anchors: 1=strongly agree, 4= strongly disagree.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

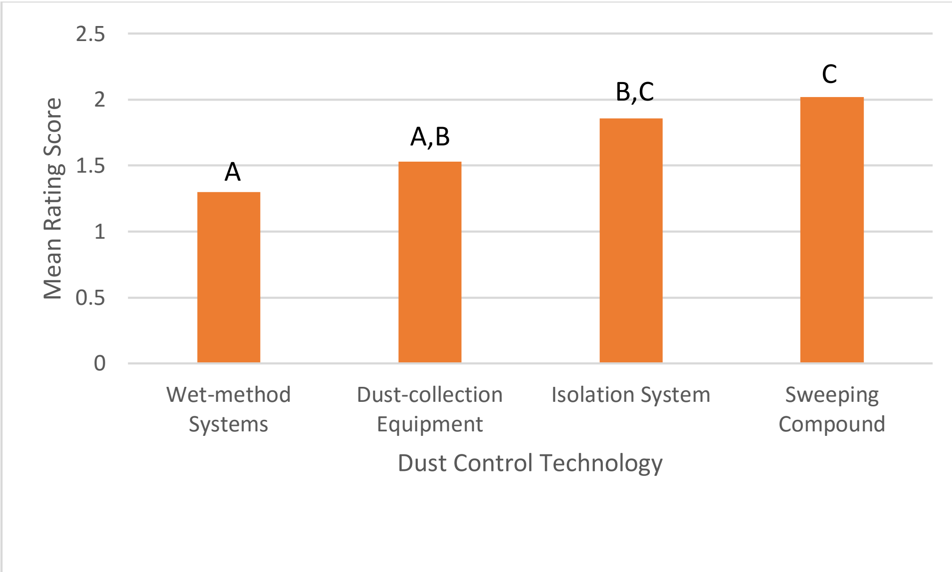


Figure 9. Concrete/Masonry Technology Perceived Benefit 1. Mean score for questions #7,19,31, 43 "I feel [Technology name] work well."
Likert scale anchors: 1=strongly agree, 4= strongly disagree.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

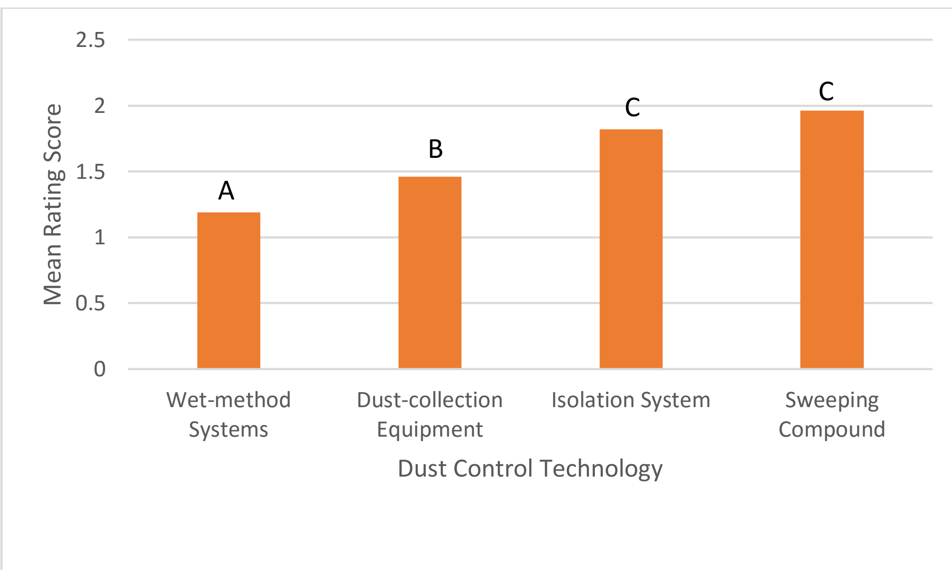


Figure 10: Concrete/Masonry Technology Perceived Benefit 2. Mean score for questions #8,20,32, 44 "[Technology name] is beneficial to the health of my workers."
Likert scale anchors: 1=strongly agree, 4= strongly disagree.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

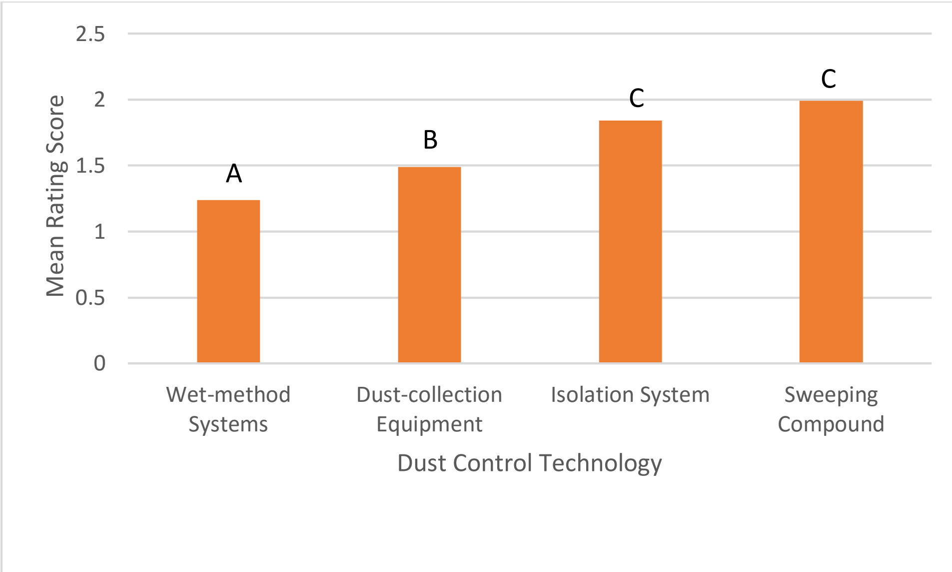


Figure 11: Concrete/Masonry Technology Perceived Benefit Combined. Mean score for questions #7,8,19,20,31,32,43,44. The scores from Perceived Benefit 1 and Perceived Benefit 2 were averaged. Likert scale anchors: 1=strongly agree, 4= strongly disagree.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

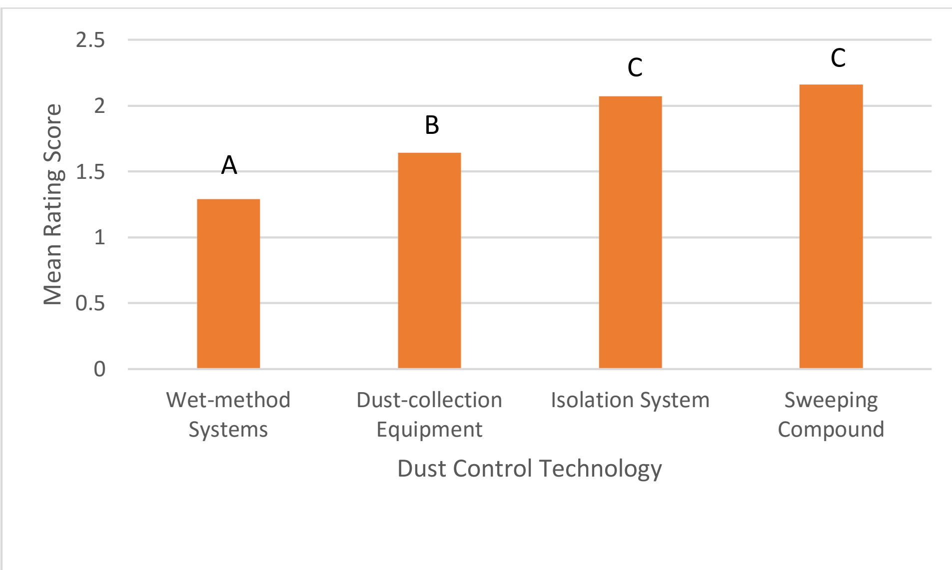


Figure 12. Concrete/Masonry Technology Perceived Usefulness 1. Mean score for questions #9,21,33, 45 "[Technology name] reduces concrete or masonry dust exposure."
Likert scale anchors: 1=strongly agree, 4= strongly disagree.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

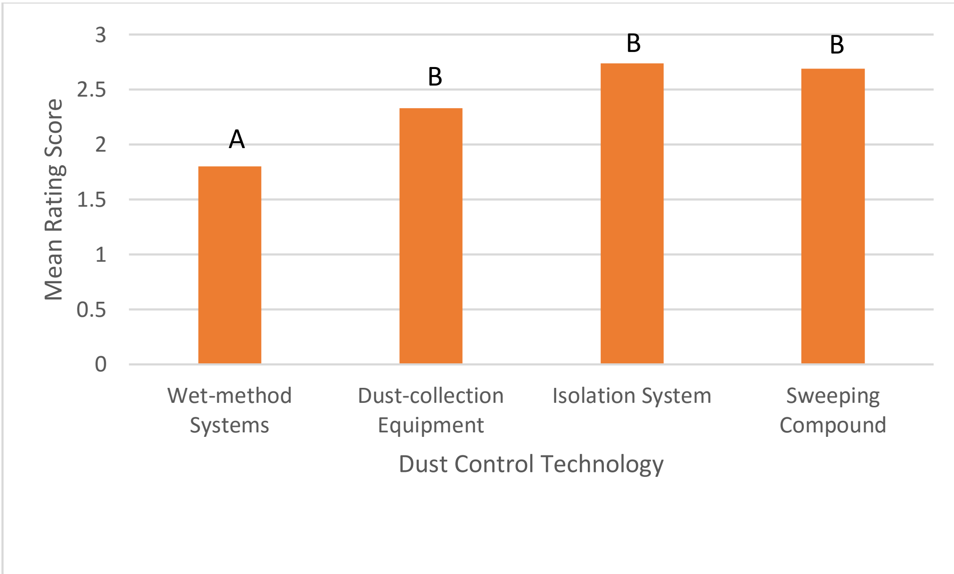


Figure 13. Concrete/Masonry Technology Perceived Usefulness 2. Mean score for questions #10,22,34,46 "[Technology name] is a useful tool for working with concrete or masonry products."
Likert scale anchors: 1=strongly agree, 4= strongly disagree.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

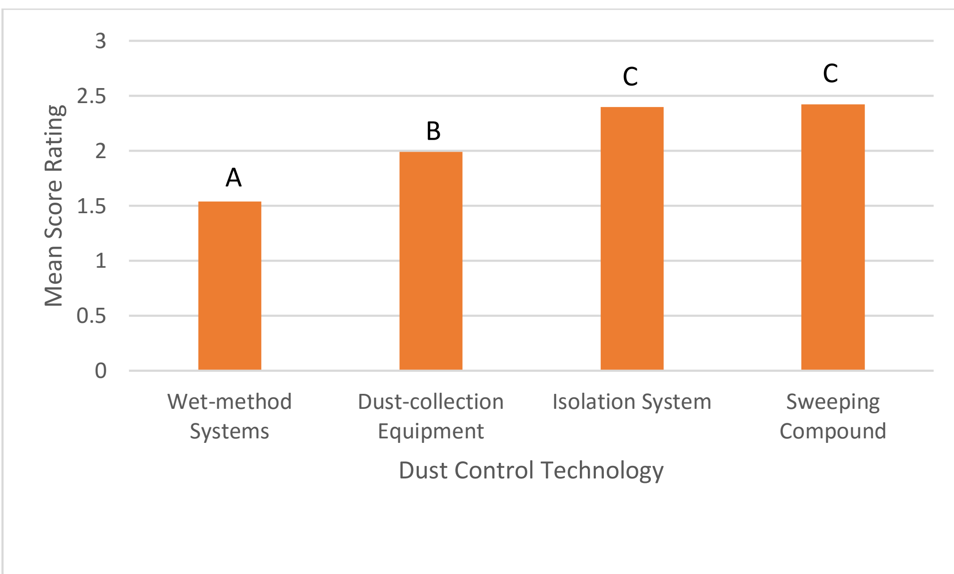


Figure 14. Concrete/Masonry Technology Perceived Usefulness Combined. Mean score for questions #9,10,21,22,33,34,45,46. The scores from usefulness 1 and usefulness 2 were averaged for each user.
Likert scale anchors: 1=strongly agree, 4= strongly disagree.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

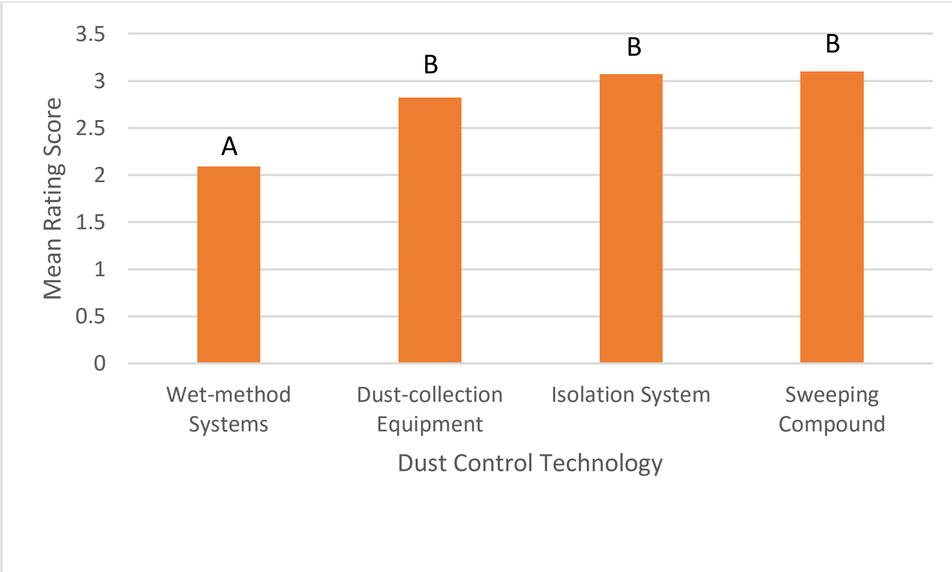


Figure 15. Concrete/Masonry Technology Relative Advantage 1. Mean score for questions #11,23,35,47.
"[Technology name] improves job performance."
Likert scale anchors: 1=strongly agree, 4= strongly disagree.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

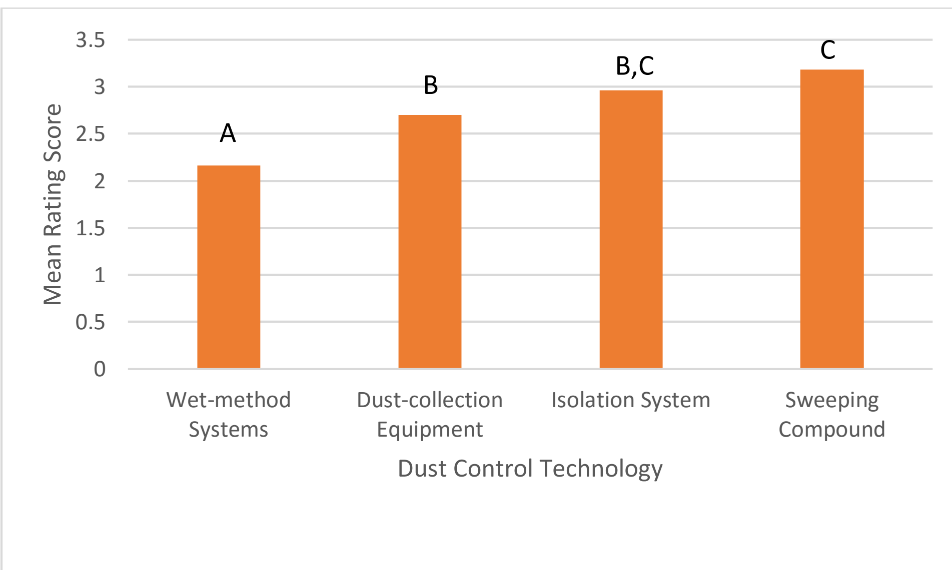


Figure 16. Concrete/Masonry Technology Relative Advantage 2. Mean score for questions #12,24,36,48
"More work gets done when using [Technology name]."
Likert scale anchors: 1=strongly agree, 4= strongly disagree.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

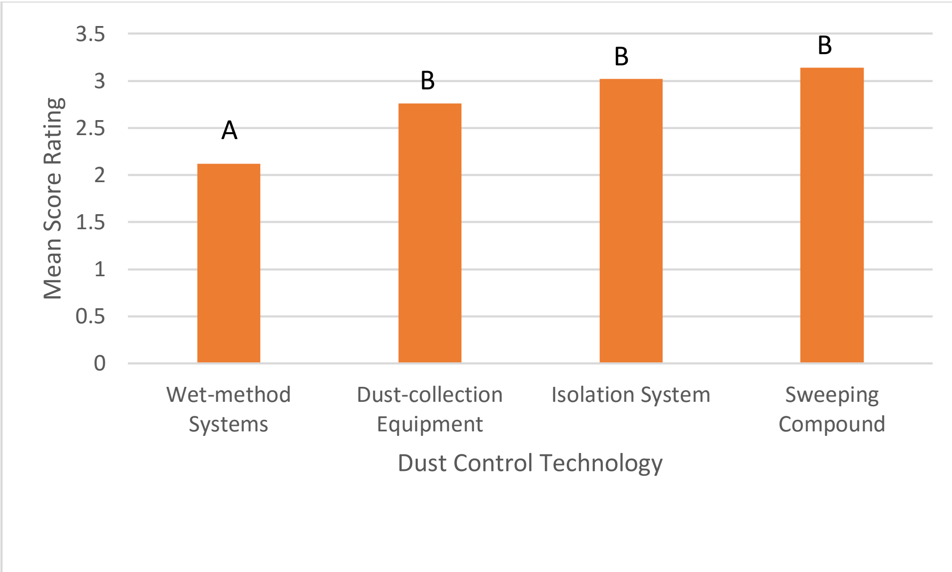


Figure 17. Concrete/Masonry Technology Relative Advantage Combined. Mean score for questions #11,12,23,24,35,36,47,48. The scores from Relative Advantage 1 and Relative Advantage 2 were averaged. Likert scale anchors: 1=strongly agree, 4= strongly disagree.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

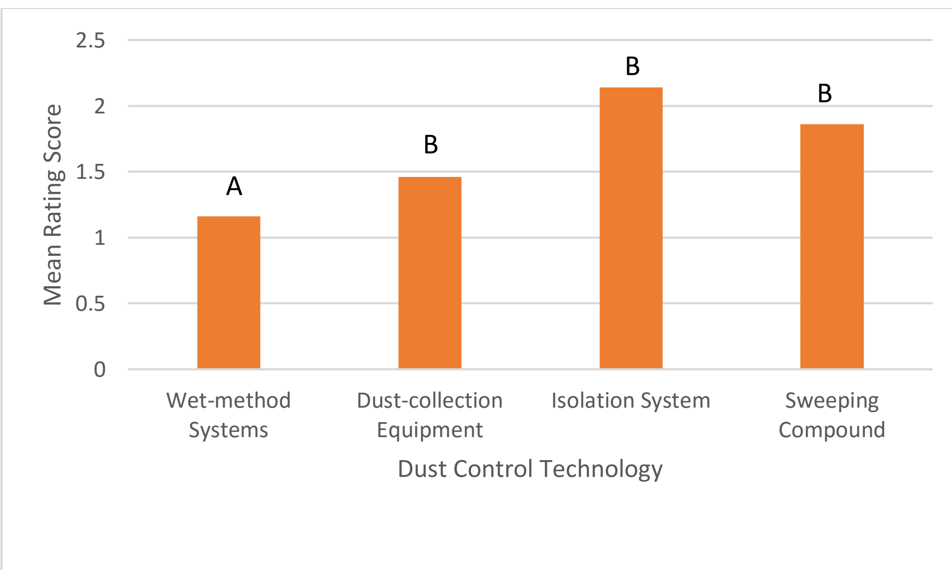


Figure 18. Concrete/Masonry Technology Adoption Readiness. Mean score for questions #13,25,37,49 "More work gets done when using [Technology name]."
Likert scale anchors: 1=strongly agree, 4= strongly disagree.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

Multiple Choice Questions

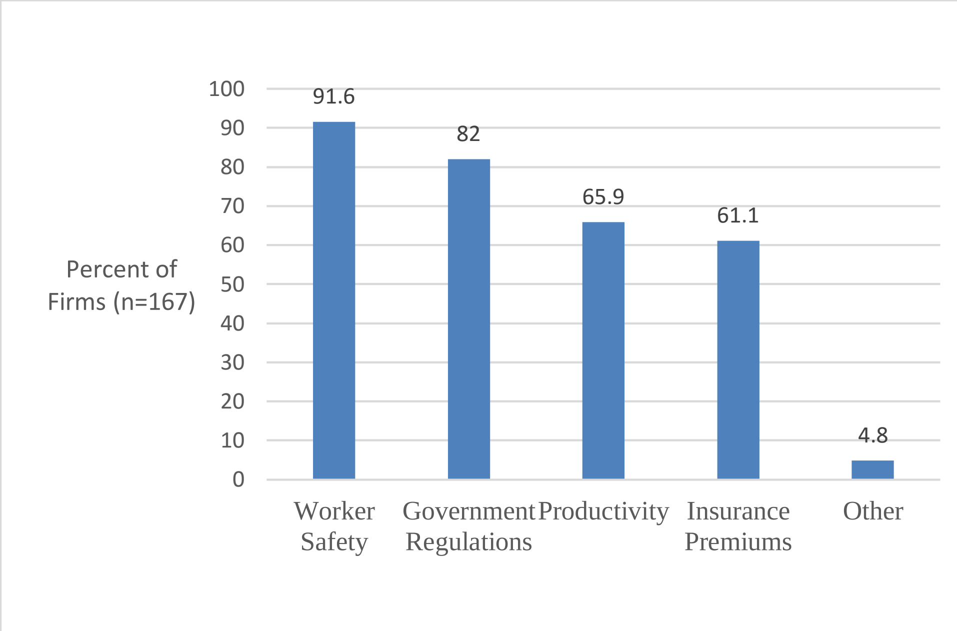


Figure 19. Business Factors Affecting Dust Control Technology Use. Results for question I "What business factors would affect the way you address dust control on your projects?"

Decision makers were asked which business factors would affect adoption of dust control technology. They were given four options and were able to check all that apply. Worker safety was the most commonly stated reason for adopting dust control technology with 91.6% of stakeholders agreeing.

Table 9

Question I. Summary Open-ended Responses for question "What other business factors would affect the way you address dust-control on your projects?"

Response Code/Category	**Frequency**
Dust Control	2
Cost	2
Weather	1
Company Appearance	1
Construction Site Requirements	1

α= 1.0

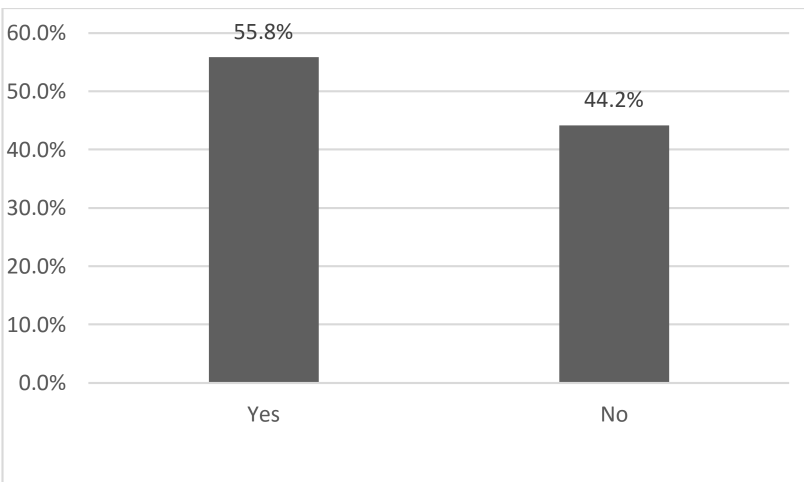


Figure 20. Projects Specifying Dust Control. Results from question II "Have you seen an increase in projects specifying dust control methods?"

Over half of decision makers responded they are seeing an increase in the number of projects specifying dust control technologies must be used on site. This may give insight into the current trend evolving within the industry.

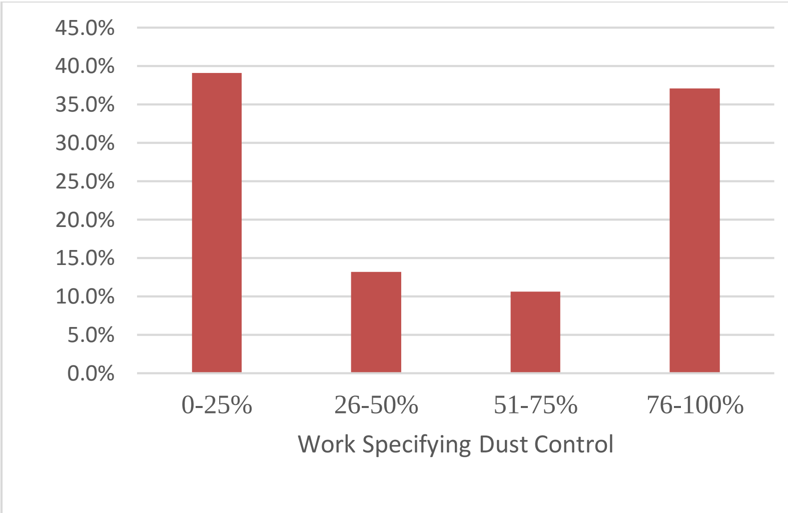


Figure 21. Concrete/Masonry Percent of Work. Results from question III "In the past year what percent of your work specifies using dust control methods?"

It appears jobsites are either almost entirely or almost never requiring dust controls be used. Over 35% of decision makers respond jobs are specifying the use of dust control 0-25% of the time. Likewise, another 35% of decision makers respond jobs are specifying the use of dust control technologies 76-100% of the time. A three-way full factorial determined that neither age, firm size, or gender had a significant effect on the percentage of work specifying using dust control technology.

Open ended responses

Open ended responses were analyzed using content analysis. All responses had $\alpha \geq 0.667$ so all results are shown below. Only Question 40 had $\alpha \leq 0.80$.

Table 10

Concrete/Masonry Question 4 Responses "Please tell me why your employees do not use dust collection equipment?"

Respondent#	***Response***
10	Don't have it for our application.
15	Availability expense.
37	Just don't use it.
38	Don't deal directly with concrete and concrete dust; service provider for the industry.
51	No reason for me to use them because I build buildings. We use water when we cut.
85	Most of work is small.
97	Using wet blade/saw.
99	Use wet method.
124	Dust mask, respirator.
131	We don't cut concrete. O'Brien international is the management company that manages certain concrete companies.
136	Outside most of the time, use it inside.
140	Use wet methods systems mostly.
194	Use wet methods.

Table 11

Concrete/Masonry Question 4 Frequencies "Please tell me why your employees do not use dust collection equipment?"

Response Code/Category	**Frequency**
Other dust control method used	5
Not applicable to company	2
Cost	1
Just don't want to	1
Job size/work size concerns	1
Site/climate/environment dependent	1

α = 0.902

Table 12

Concrete/Masonry Question 16 Responses "Please tell me why your employees do not use wet-method systems?"

Respondent#	***Response***
36	Works mostly with steel.
38	Don't use it because they are service provider.
73	Because they are at a concrete plant, it is messy.
78	Don't know.
186	Don't think it's necessary.

Table 13

Concrete/Masonry Question 16 Frequencies "Please tell me why your employees do not use wet-method systems?"

Response Code/Category	**Frequency**
Not Applicable to Company	3
Just Don't Know	1
Not Necessary/Don't Need	1

α = 1.0

Table 14

Concrete/Masonry Question 28 Responses "Please tell me why your employees do not use isolation systems?"

Respondent#	***Response***
12	We use wet systems, and dry when outside.
38	Service provider; don't use.
49	Most of the work is out in the open so that's not an issue.
70	Don't have a need for it.
87	Not always an option.
92	Usually work outside.
97	Not necessary.
109	We normally use wet method systems.
110	Not familiar.
148	They are out in the open.
185	Because of the work they do, cannot isolate.

Table 15

Concrete/Masonry Question 28 Frequencies "Please tell me why your employees do not use isolation systems?"

Response Code/Category	Frequency
Site/climate/environment dependent	3
Not necessary/don't know	2
Not always possible	2
Other dust control method used	1
Not applicable to company	1
Not familiar	1

$\alpha = 0.891$

Table 16

Concrete/Masonry Question 40 Responses "Please tell me why your employees do not use sweeping compound?"

Respondent#	Response
3	Not sure why they use it...certain jobs necessitate using it because of the sweeping compound, especially if they are doing work on a building that is occupied.
8	Being a brick lane contractor, we are well before clean up stages.
12	Big guys lay brick, not sweep floors.
13	Don't sweep that much; pick up debris with shovels instead.
48	We work with industrial jobsites so the clean up happens after we leave the site.
70	Don't have a need for it.
79	It is not necessary. It's for indoor and they mostly work outdoor.
81	They don't do their own clean up.
83	Wet method is primarily used.
89	Don't do any sweeping.
90	Just don't do much sweeping.
104	80% of the time working in the dirt so it wouldn't make sense. When working on concrete surfaces we use sand in order prevent adhesion of the mortar to the concrete.
108	We don't sweep.
129	We are outside, outside construction.
178	They don't need to use it for the purpose of their work.
194	Wet methods.

Table 17

Concrete/Masonry Question 40 Frequencies "Please tell me why your employees do not use sweeping compound?"

Response Code/Category	**Frequency**
Don't' sweep when doing clean up	4
Don't do clean up	3
Not necessary/don't know	2
Other dust control method used	2
Just don't know	1

α = 0.699

Table 18

Concrete/Masonry Question I Responses "What business factors would affect the way you address dust-control on your projects?"

Respondent#	***Response***
10	Weather.
16	Keeping dust down.
74	Overall cost.
101	Company profile, what looks nicest, neatest.
103	A lot of it has to do with job site requirements.
136	Willingness of client to pay for it.
174	Working with other trades on the same job site - dust.

Table 19

Concrete/Masonry Question I Frequencies "What business factors would affect the way you address dust-control on your projects?"

Response Code/Category	**Frequency**
Dust Control	2
Cost	2
Weather	1
Company Appearance	1
Site Requirements	1

α = 1.0

Table 20

Concrete/Masonry Question IV Responses "What are some other dust control methods that you know about or have used?"

Respondent#	***Response***
9	Mostly just use water on the blade when doing saw cuts to keep dust down.
13	Orientation on the job site; where locating equipment on the job site in relation to where people are located, which way the wind blows etc.
24	Breathing apparatuses.
26	Only use wet-method systems.
27	Water truck.
34	Fans.
40	Use sand.
41	Vacuum, wet concrete cutting.
46	Vacuum systems.
51	Respirator.
53	I don't know of any. We just wet cut if we can.
54	Vacuum systems.
61	Vacuum.
66	None, other than the ones that exist-like Ecogel and a vacuum to get the slurry. He has previously used sweeping compound, considers it 1980s technology but that style is difficult with the slurry or anything wet.
72	Respiratory protection.
104	Dust masks and respirators.
116	Hepa vacuum.
118	Engineering controls such as fresh air supply and crew substitution.
124	Respirator.
129	Hanging plastic.
132	Shop-vac.
133	Respirators, PPE.
148	Watering, respirators.
150	Dust collectors on batch plants.
154	Personal protective gear.
162	Water trucks and such.
174	Respiratory masks. (Only other one he could name.).
175	Vacuum systems on small tools/saws, which they use those. Also respiratory equipment like masks and inhaling protection for when dust is not controlled at the source.
185	Air filtration.
186	Masks and goggle.
191	Too many to list.
192	Saw with a vacuum.
194	Tents.

Table 21

Concrete/Masonry Question IV Frequencies "What are some other dust control methods that you know about or have used?"

Response Code/Category	**Frequency**
Personal protective equipment	10
Vacuum	7
Water used on blade	3
Water truck	2
Just don't know	2
Hanging plastic/tarps	2
Air filtration	2
Vacuum specifically attached to tool	2
Wind/orientation of work	1
Fans	1
Sand	1
Ecogel	1
Crew substitution	1
Fresh air supply	1

α = 0.938

Table 22

Concrete/Masonry Question V Responses "If you could imagine an ideal way of controlling dust that does not currently exist, what would it be?"

Respondent#	***Response***
31	Create products that don't generate any type of dust.
34	Huge vacuum filter.
35	Dustless concrete.
40	Doesn't think it's possible.
44	Create product without using silica or just reduce it significantly.
48	Leave a helicopter hovering over the job site all the time, blow all the dust away.
50	Water.
57	Masks, not working in confined or closed areas.
58	A material that doesn't produce dust at all.
66	I don't know-likes the wet method a lot and feels that it is easy to control. If there was another way to do it, it would already be implemented.
74	Ease of use.
89	Cut with no water...lasers something with no dust.
91	Something that is not affected by weather. Something that is better in price and does not hinder performance.
93	Something that collects all the dust.
101	Cutting with water.
104	Go back to hammer cutting because it doesn't create much dust.
108	Wet method is the best.
113	Product that you're cutting that doesn't contain silica.
114	Manufacturing/material side.
133	Advanced technology with tools.
136	Create a dustless product.
137	Eliminate the harmful products in masonry.
147	Dry vacuum system.
151	Combination of using wet system and a removal system.
153	There needs to be a method that requires less maintenance to keep it functioning properly, because the ones now will clog after so many uses.
154	Something that is relatively full proof and relatively simple to use.
155	A product that does not create dust.
159	A machine that can vacuum the dust as you are cutting concrete.
174	Ideal would be some sort of dry cut system - a more effective way to dry-cut than the dust producing systems they have now. Current dust collection/vacuum systems aren't as effective as they should be - it's hard to contain all the dust as much as is required. The wet method is an issue with electricity dangers or when working in an existing building, you don't want to get water everywhere and can't wet cut, so a happy medium would be a wish.
182	Using water methods.
191	He's very tired of government getting involved. 90% of this is common sense. OSHA tells him he has to cut his material wet, when he goes to a government job they tell him it has to be cut dry because cutting wet damages it. They need to have a consistent approach. It's just common sense.

Table 23

Concrete/Masonry Question V Frequencies "If you could imagine an ideal way of controlling dust that does not currently exist, what would it be?"

Response Code/Category	**Frequency**
Different material	9
Water	4
Better vacuum/dust collector	3
High/future technology	2
Old/past technology	2
Low maintenance tools	2
Nothing	1
Personal protective equipment	1
Combinatory system	1
Joke	1

α = 0.916

Table 24

Summary of Findings for Concrete and Masonry

1. **Perceived Risk**
   - Most decision makers understand the risk posed by concrete and/or masonry dust and perceive the severity of risk to be high
2. **Wet-Method Systems**
   - Wet-method systems were the most highly ranked tool across all constructs.
   - It is significantly different than all other controls in every construct except for familiarity and perceived benefit 1.
3. **Dust Collection Equipment**
   - Dust collection equipment is the second highest frequently used control technology and is the second highest rated for all other constructs.

- Though, it is not significantly different than sweeping compound or isolation systems for adoption readiness

4. **Sweeping Compound and Isolation Systems**
    - Sweeping compound and isolation systems were the least known and used technologies
    - They were not significantly different from each other on almost all constructs
5. **Reasons for Adopting Dust Control Technologies**
    - Decision makers choose to adopt dust control technologies based on worker safety, government regulations, productivity, and insurance premiums, in that order. Other reasons include dust control and cost.
6. **Industry Trend**
    - More projects are specifying use of dust control technologies
    - The data suggests the industry has a binomial distribution, either projects are specifying use of dust control technology (75%-100%) or they are not (0%-25%)
7. **Other Control Technologies**
    - The most used control technology which was not investigated is personal protective equipment
8. **Inventions**
    - The most proposed new technology from the decision makers was material substitution.

Discussion

The data suggest decision makers in concrete and masonry understand the health risk posed by concrete and/or masonry dust and are receptive to using dust control technologies. Decision makers in concrete and masonry feel dust overexposure poses potential health risks to workers. Only 20.4% of decision makers do not agree.

Decisions makers remarked that worker safety is the biggest reason why they would adopt dust control technology.

Frequency of use of dust control technologies was high, with 64.7% of decision makers either always or regularly using wet-method systems and 58.3% either always or regularly using dust collection equipment. Adoption readiness was high across all technologies, though there were differences between tool types. Additionally, there is an increasing number of projects specifying the use of dust controls. Shepherd and Woskie (2010) found general contractors may have qualifications for jobs which include more sophisticated health and safety plans. This may suggest job site requirements are a forcing function for dust control technology adoption.

Wet-method systems were associated with the highest rating across all constructs of interest. There were very few open-ended responses for why decision makers do not use wet-method systems. Most responses were because it was not applicable, but of the five responses, one decision maker mentioned they do not use them because of the mess it creates. This is consistent with findings from G. A. Croteau et al. (2002) which found clean up and disposal to be problematic with water based controls in the concrete and masonry trades.

Isolation systems may be a viable option when possible, but not as a standalone control. Open ended responses indicate isolation systems are not always possible either because the work is done out in the open or because the work simply cannot be isolated. Flanagan et al. (2003) found work enclosure area and cross draft to mediate dust levels.

Using tarps to block off an area was noted in the open ended responses as a type of control. This would be a way that isolation systems are implemented which is consistent with this researcher's site visit to Davidson Hall. Isolation systems have the potential to be used in conjunction with other controls such as wet-methods or dust collection equipment. This researcher hypothesizes there may be a beneficial combinatory effect of isolation systems with other dust control technologies which should be investigated in future research.

This researcher believes sweeping compound has the least potential for impact in concrete and masonry dust reduction. Other studies have shown that cleanup is among the lowest dust producing tasks on a jobsite (Flanagan et al., 2003). Open ended responses from sweeping compound indicates many times there is no need for it, especially on new construction as they may be outside or in the dirt already. Sweeping compound, therefore is not as versatile as the other types of controls. Sweeping compound was consistently among the lowest ranked along all constructs. That said, it may be a good control for specific situations, namely completed buildings.

Respirators are already used in conjunction with other tools onsite (Flanagan et al., 2003; Middaugh et al., 2012). Decision makers report respirators to be the other technology most used outside of the four technologies investigated. Flanagan et al. (2003) found respiratory protection was worn 70% of the time in 42 on-site samples. Using personal protective equipment should be a last resort (Department of Health and Human Services, 2014). Anyone looking to increase engineering controls and foster PtD technology adoption need to understand that respirators will most likely be used in conjunction with another control.

The purpose of this study was to determine which sectors in construction have high health hazards and to determine current use of tools, barriers to adoption, and perceptions of those tools to see if there are any areas that could be targeted for improvement. Decision makers were just as familiar with dust collection equipment as they were with wet-method systems though dust collection equipment was not as frequently used. Dust collection equipment was ranked second for perceived benefit and perceived usefulness. Though, dust collection equipment was not significantly different in trust in technology, relative advantage, or adoption readiness compared to sweeping compound or isolation systems. For almost all decision makers, when asked why they don't use dust collection equipment, it is because they use wet-method systems instead. Other studies have investigated using LEV systems and they have shown significant reductions in dust concentration levels for various tools in concrete and masonry (Akbar-Khanzadeh et al., 2010; G. A. Croteau et al., 2002). Based on the current findings, this researcher chose to investigate tools with dust collection equipment.

Decision makers also posed possible dust control technologies which do not exist yet. They not using silica based products as their preferred technology which does not exist yet. As technology progresses, using different materials not containing silica or containing less silica may be beneficial. Elimination of the hazard is the best control there is (Department of Health and Human Services, 2014; Young-Corbett, 2013) and therefore this researcher believes new kinds of building materials may be the best way to reduce silica overexposure for the long term.

Conclusion

The concrete and masonry trades understand the risks involved in their work and there are increasing numbers of jobs specifying dust control. Therefore, it appears the industry is ready to adopt dust control technologies. Worksites are increasingly specifying that dust controls must be used which may be a forcing function for technology adoption.

This researcher recommends wet-method systems as the best control for silica dust overexposure in the concrete and masonry trades of the four technologies investigated. Wet-methods ranks the highest in all constructs investigated. Other controls, specifically dust collection equipment, shows promise for being adopted by industry.

Study 2

Study 2 assessed perceptions of stakeholders in the asphalt roofing trade. They were first asked about perceived risk, then about specific tool, and finally open ended responses were recorded.

Perceived Risk

Table 25

Perception of Risk in Asphalt Roofing

	Perceived Risk 1- Perceived Health Risk	Perceived Risk 2- Perceived Severity of Health Risk
Strongly Agree	13.0%	15.0%
Somewhat Agree	38.0%	31.0%
Somewhat Disagree	25.0%	20.5%
Strongly Disagree	21.5%	24.0%
Don't Know/Refuse to Answer	2.5%	9.5%

Percent of firm owner responses to questions regarding perceived risks. Perceived Risk 1 Question: "Exposure to asphalt vapors and fumes poses a potential health risk to workers. Perceived Risk 2 Question: "Asphalt vapors and fumes can cause severe health effects." (scale anchors: 1=strongly agree, 5=don't know/refuse to answer)

Mean (SD) scores for the scaled items were 2.63(1.04) for perceived risk 1, 2.82(1.23) for perceived risk 2, and 2.72(1.03) for perceived risk combined. Results show that only 51% of decision makers (combining strongly agree and somewhat agree) feel asphalt vapors and fumes poses a health risk to workers. Additionally, only 46% feel it poses a severe health risk. A MANOVA assessing the effect of firm size, age of respondent, and gender of respondent on the three perceived risk factors showed no significant effects.

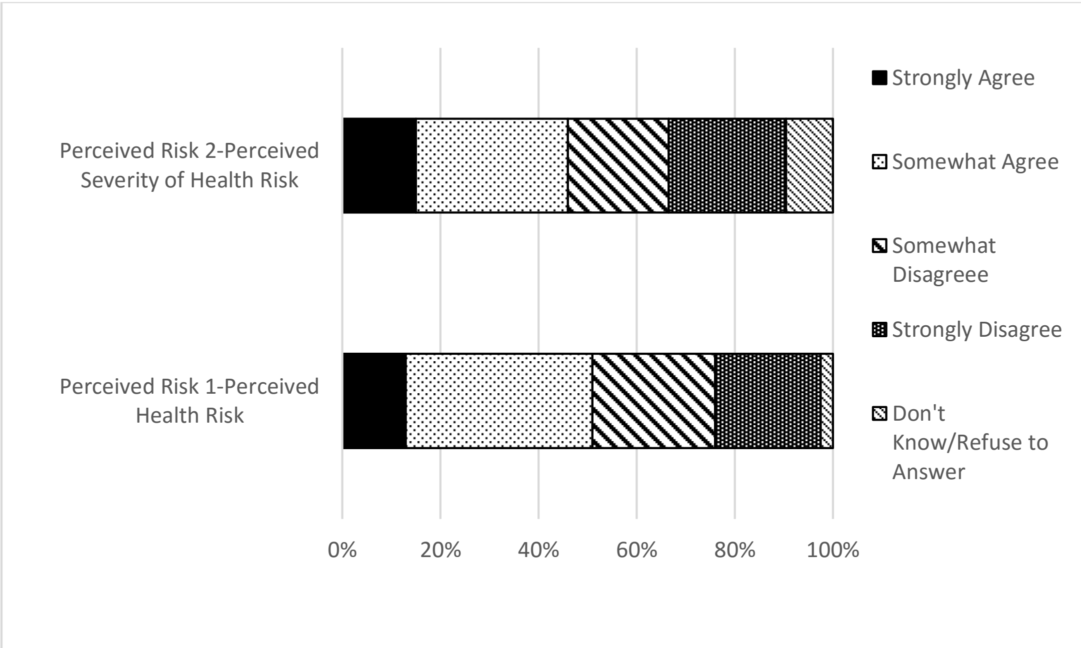


Figure 22. Perception of Risk Associated with Asphalt Vapors and fumes

Tools and Constructs

A MANOVA with all constructs as dependent variables revealed a significant multivariate effect for type of tool (Wilk's lambda=0.43, $F(52,625.66)=2.92$, $p<0.0001$). Subsequent univariate ANOVA showed significant difference between fume control technologies for familiarity ($F(4,995)=17.5$, $p<0.0001$), frequency of use ($F(4,647)=9.6$, $p<0.0001$), perceived benefit 2 ($F(4,416)=10.2$, $p<0.0001$), perceived benefit combined ($F(4,416)=6.4$, $p<0.0001$), perceived usefulness 1 ($F(4,416)=3.7$, $p=0.0052$), perceived usefulness 2 ($F(4, 416)=21.2$, $p<0.0001$), perceived usefulness combined ($F(4,416)=17.0$, $p<0.0001$), relative advantage 1 ($F(4,416)=36.2$, $p<0.0001$), relative advantage 2 ($F(4,416)=37.3$, $p<0.0001$), relative advantage combined ($F(4,416)=41.2$, p<0.0001), and adoption readiness ($F(4,416)=7.7$, $p<0.0001$). Two constructs did not show significant differences, trust in technology ($F(4,416)=1.92$, $p=0.1059$) and perceived benefit 1 ($F(4,416)=1.8$, $p=0.1269$),

Familiarity

Of the five fume control technologies, decision makers were most familiar with hot luggers, mechanical spreaders, felt laying machines 1.9 (1.2), followed by insulated kettle/hot luggers 2.2 (1.3), low fuming asphalt 2.4 (1.2), kettle fume guards 2.8 (1.3), and tanker delivery systems 2.8 (1.3).

Table 26

Percent of Decision Makers' Responses to Questions Regarding Familiarity with Vapor and Fume Control Technologies

	Tanker Delivery System	Hot Luggers, Mechanical Spreaders, Felt Laying Machine	Insulated Kettle/Hot Lugger	Low Fuming Asphalt	Kettle Fume Guards
Very Familiar	26.0	53.5	41.5	29.0	21.5
Somewhat Familiar	18.0	20.5	24.5	32.0	23.5
Slightly Familiar	11.0	5.0	6.0	7.0	7
Not at all Familiar	44.5	20.0	27.0	31.5	46.5
Don't Know/Refuse to Answer	0.5	1	1	0.5	1.5

Decision makers were most familiar with hot luggers, mechanical spreaders, felt laying machines, with 74% either very familiar or somewhat familiar. Decision makers are second most familiar with insulated kettle/hot luggers, and low fuming asphalt with 66% and 61% of firm owners being very familiar or somewhat familiar, respectively. Kettle fume guards are the technology decision makers are least familiar with, 46.5% of decision makers are not at all familiar with them which is also significantly different from all other technologies.

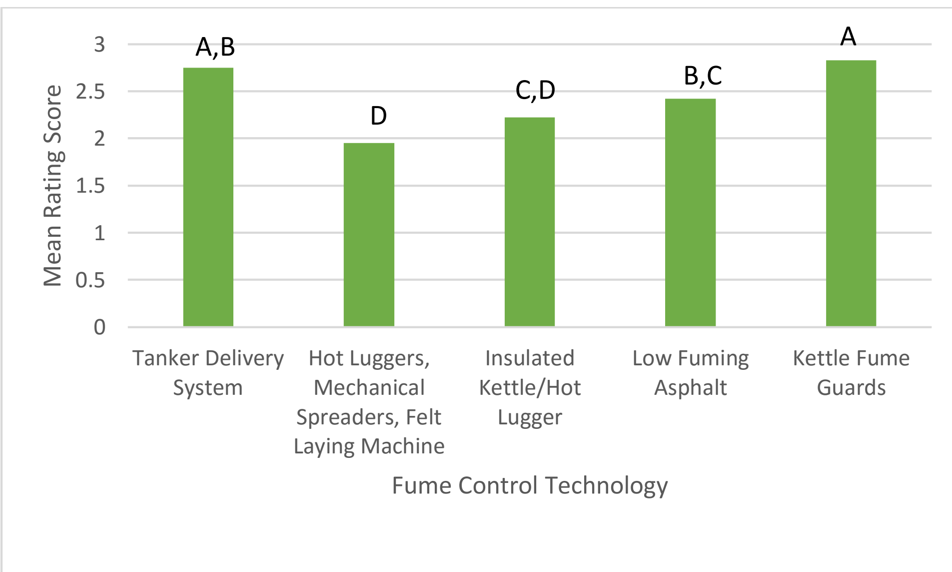


Figure 23. Asphalt Roofing Technology Familiarity. Mean score for questions #3,15,27, 39,51 "How familiar are you with [Technology name]."
Likert scale anchors: 1=very familiar, 4= not at all familiar.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

Frequency of Use

Of the five fume control technologies, decision makers most frequently used insulated kettle/hot luggers 3.1 (1.5), followed by hot luggers, mechanical spreaders, felt laying machines 3.2 (1.4), low fuming asphalt 3.4 (1.5), kettle fume guards 3.6 (1.6), and tanker delivery systems 4.1 (1.2).

Table 27

Percent of Decision Makers' Responses to Questions Regarding Frequency of Use of Fume Control Technologies

	Tanker Delivery System	Hot Luggers, Mechanical Spreaders, Felt Laying Machine	Insulated Kettle/Hot Lugger	Low Fuming Asphalt	Kettle Fume Guards
Always	4.5	14.6	18.8	16.2	19.2
Regularly	8.2	19.6	20.8	14.0	9.6
Sometimes	10.9	18.4	18.1	15.4	12.5
Rarely	20.9	24.7	13.2	22.8	11.5
Never	55.5	22.8	29.2	31.6	47.1

None of the fume control technologies were prominently used, the most being insulated kettle/hot luggers with 39.6% of decision makers either always or regularly using them. The technology which is least used is tanker delivery systems with 55.5% of decision makers reporting that they never use them. We can see that tanker delivery systems are the only technology which are significantly different than the others, being the one which is least frequently used.

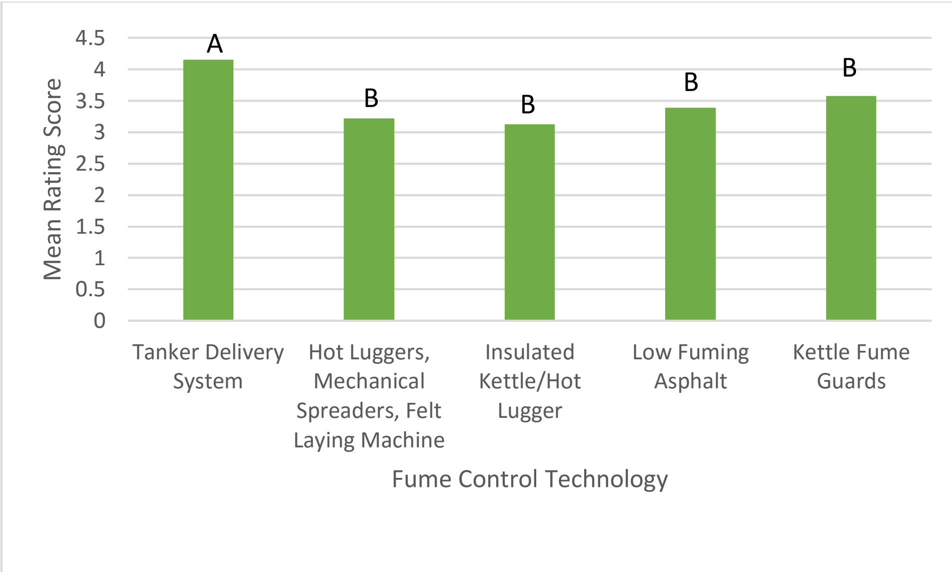


Figure 24. Asphalt Roofing Technology Frequency of Use. Mean score for questions #4,16,28, 40,52 "How often do your employees use [Technology name]."
Likert scale anchors: 1=always, 5= never.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

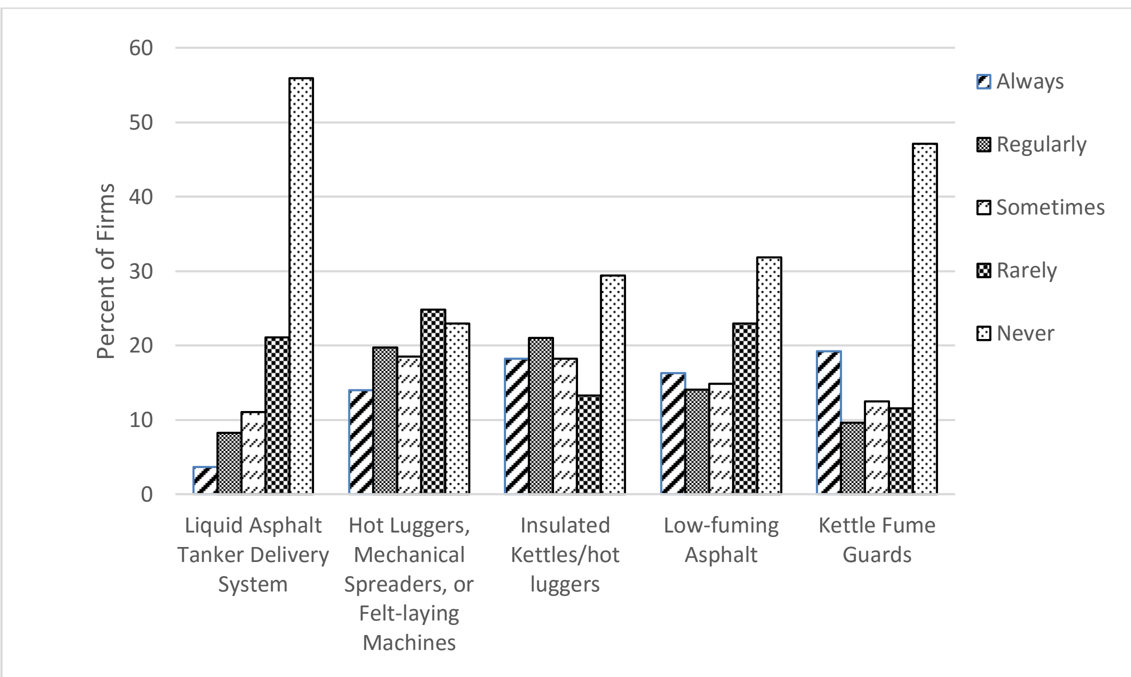


Figure 25. Frequency of Use of Fume Control Technologies

All Other Tool Constructs

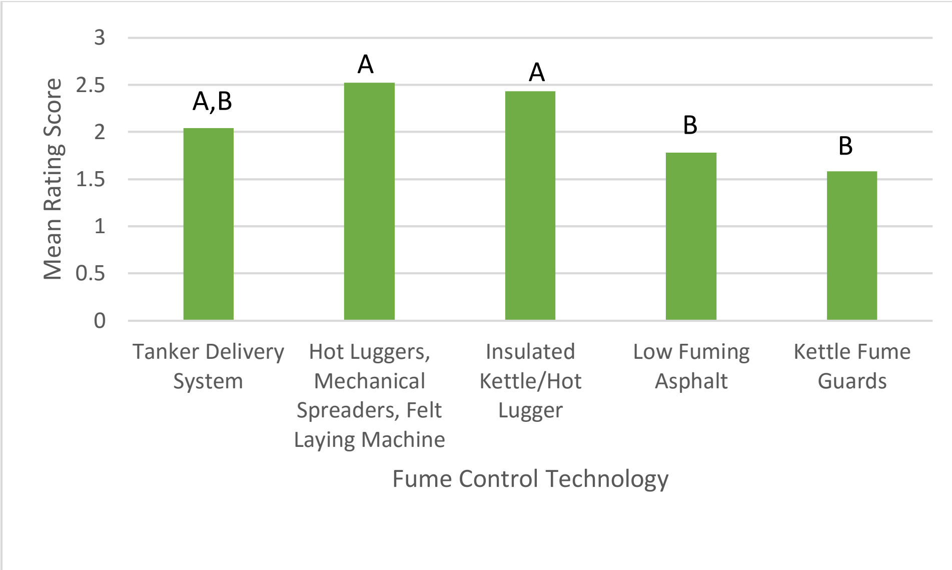


Figure 26. Asphalt Roofing Technology Perceived Benefit 2 Mean score for questions #8,20,32, 44, 55 "[Technology name] is beneficial to the health of my workers."
Likert scale anchors: 1=strongly agree, 4= strongly disagree.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

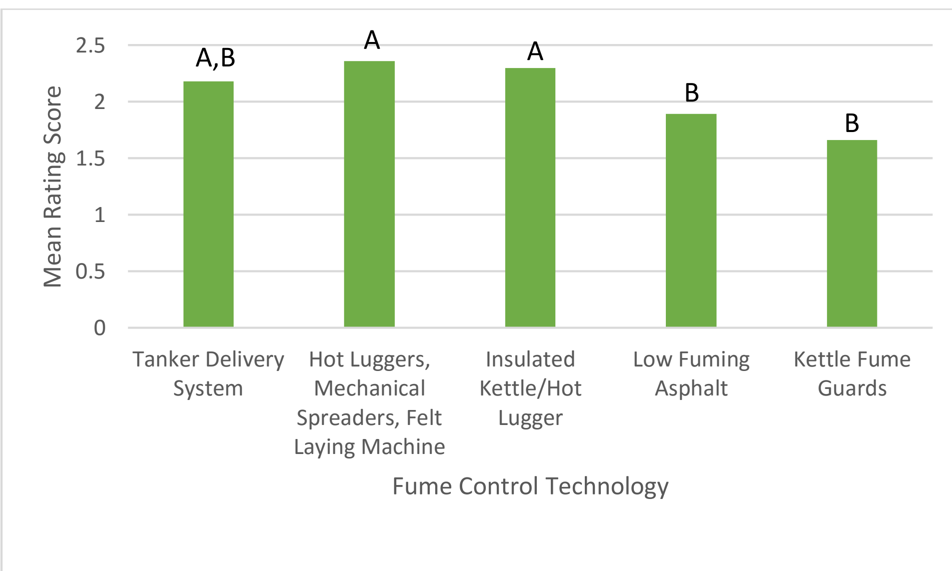


Figure 27. Asphalt Roofing Technology Perceived Benefit Combined. Mean score for questions #7,8,19,20,31,32,43,44, 54,55. The scores from Perceived Benefit 1 and Perceived Benefit 2 were averaged. Likert scale anchors: 1=strongly agree, 4= strongly disagree.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

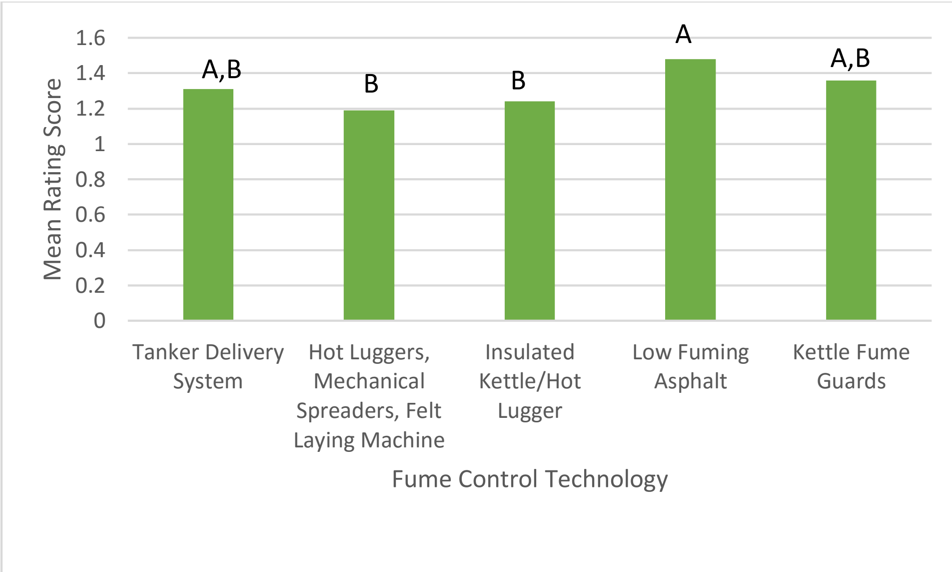


Figure 28. Asphalt Roofing Technology Perceived Usefulness 1. Mean score for questions #9,21,33, 45,57 "[Technology name] reduces asphalt fume exposure."
Likert scale anchors: 1=strongly agree, 4= strongly disagree.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

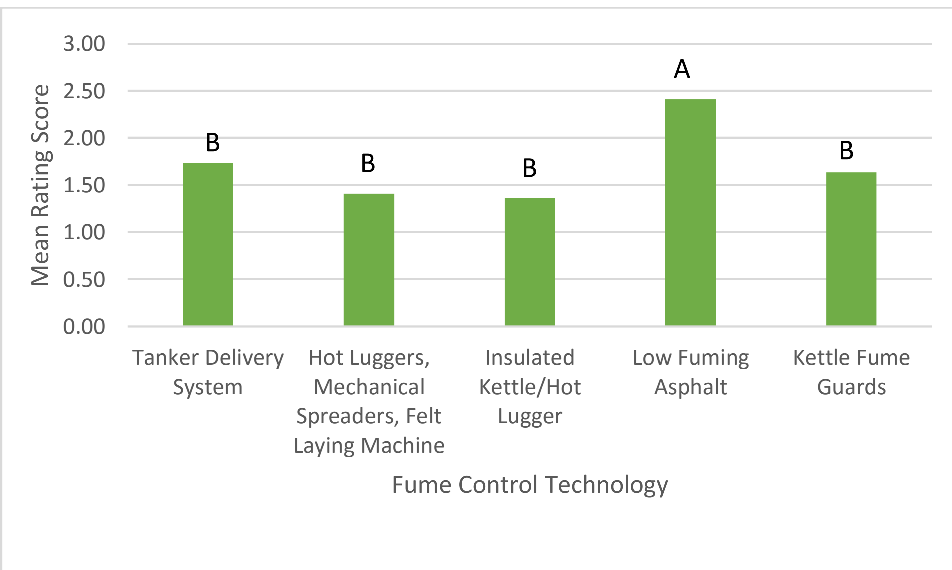


Figure 29. Asphalt Roofing Technology Perceived Usefulness 2. Mean score for questions #10,22,34,46,58 "[Technology name] is a useful tool for working with asphalt."
Likert scale anchors: 1=strongly agree, 4= strongly disagree.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

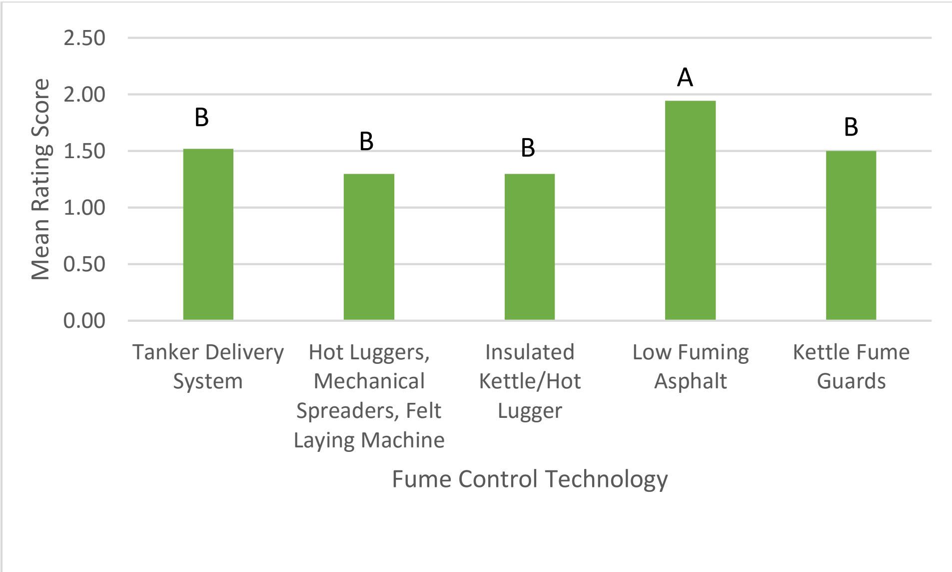


Figure 30. Asphalt Roofing Technology Perceived Usefulness Combined. Mean score for questions #9,10,21,22,33,34,45,46,57,58. The scores from Usefulness 1 and usefulness 2 were averaged.
Likert scale anchors: 1=strongly agree, 4= strongly disagree.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

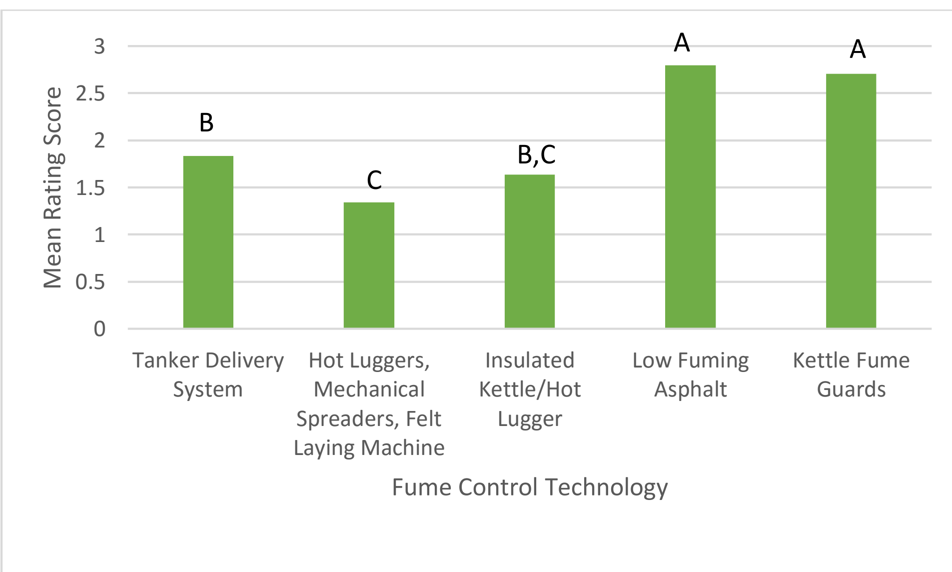


Figure 31. Asphalt Roofing Technology Relative Advantage 1. Mean score for questions #11,23,35,47,58. "[Technology name] improves job performance."
Likert scale anchors: 1=strongly agree, 4= strongly disagree.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

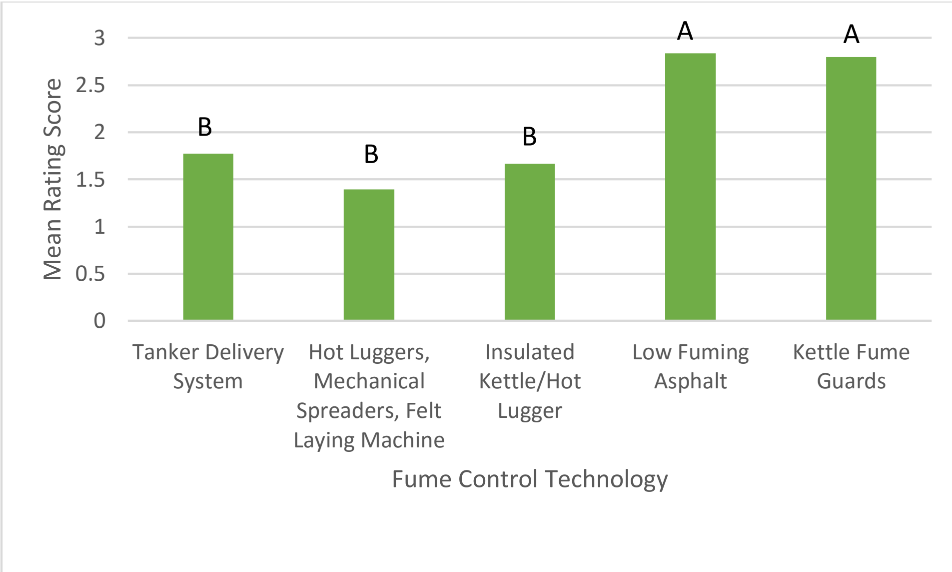


Figure 32. Asphalt Roofing Technology Relative Advantage 2. Mean score for questions #12,24,36,4,598 "More work gets done when using [Technology name]."
Likert scale anchors: 1=strongly agree, 4= strongly disagree.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

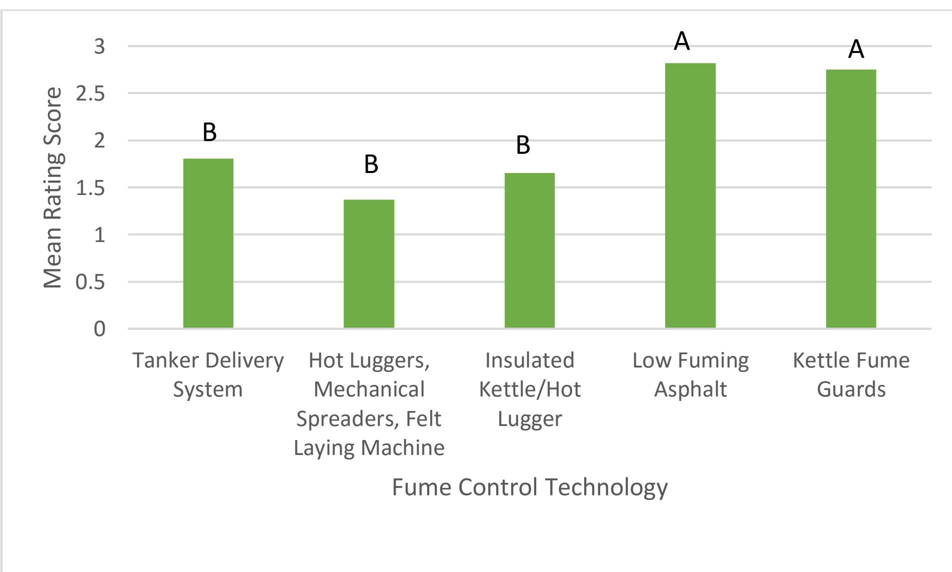


Figure 33. Asphalt Roofing Technology Relative Advantage Combined. Mean score for questions #11,12,23,24,35,36,47,48,58,59. The scores from relative advantage 1 and perceived relative advantage 2 were averaged for each user.
Likert scale anchors: 1=strongly agree, 4= strongly disagree.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

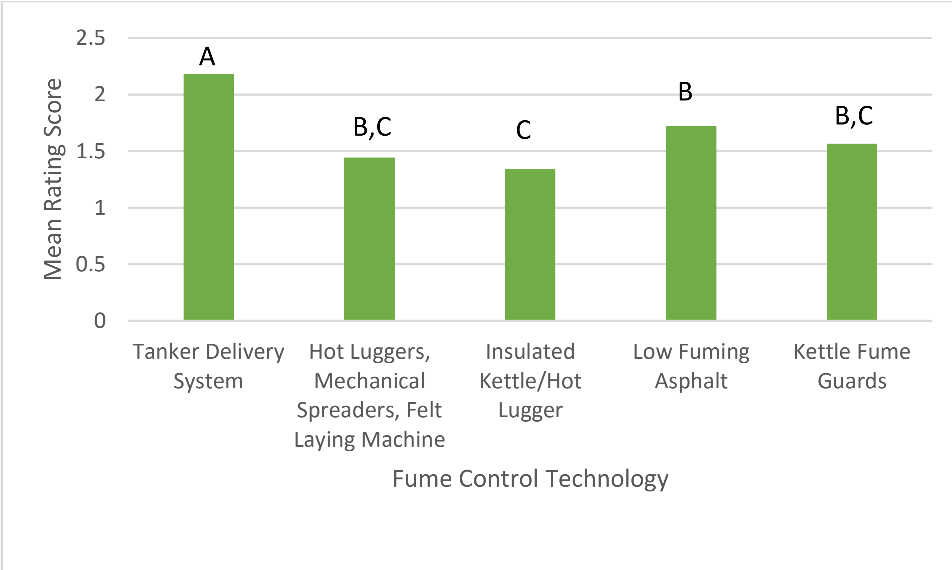


Figure 34. Asphalt Roofing Technology Adoption Readiness. Mean score for questions #13,25,37,49,61 "More work gets done when using [Technology name]."
Likert scale anchors: 1=strongly agree, 4= strongly disagree.
(Tukey's HSD all pair wise comparison means. Bars not sharing a common letter are significantly different).

Multiple Choice Questions

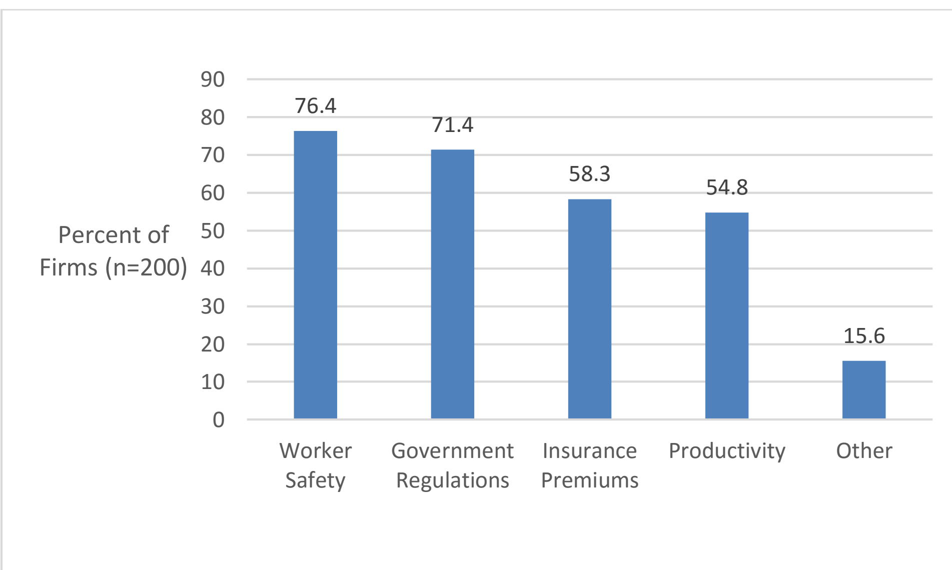


Figure 35. Business Factors Affecting Vapor and Fume Control Technology Use. Results for question I

"What business factors would affect the way you address fume control on your projects?"

Worker safety was by far the biggest determinant for adopting fume control technologies with 76.4% citing this reason. Productivity was the least cited reason with only 54.8% stating this reason. There was a large number of response for "other." Content analysis reveals Safety and/or health issues and hot asphalt not used/industry trend as the two most cited other reasons. A full factorial showed no effects due to firm size, gender, or age.

Table 28
Asphalt Roofing Question I Responses "What business factors would affect the way you address fume control on your projects"

Respondent#	***Response***
45	Job/contractor requirement.
64	Customer requirement.
70	Customer satisfaction.
77	Specific jobs require it to be used.
83	The customer concerns.
92	Customer preference.
94	Usually specified.
101	Depends on job site.
104	The environment or the inhabitant's safety.
107	The owner's requests.
108	Customer satisfaction.
117	Specifications.
118	The building and the people that are going to be working or living in them. The environment of the building.
121	Customers - if it stinks too much they'll think it's going to kill them.
125	Jobsite accessibility.
127	Owner requests.
131	Building owner requirements.
145	Architect specifications.
151	Customer demand.
159	Client discomfort, people don't want vapors and fumes.
169	Location of the hot asphalt being applied in relation to occupied buildings.
170	Specifications.
172	A higher demand for the projects.
188	As specified.
205	A mask.
211	Cost effective.
219	Job requirement.

Table 29

Asphalt Roofing Question I Frequencies "What business factors would affect the way you address fume control on your projects"

Response Code/Category	**Frequency**
Customer requirement	5
Environment where it is used/habitable concerns	3
Owner specifications	3
General specifications	3
Job/contractor requirements	2
Job site accessibility	1
Architect specifications	1
Personal protective equipment	1
Cost	1

α= 0.698

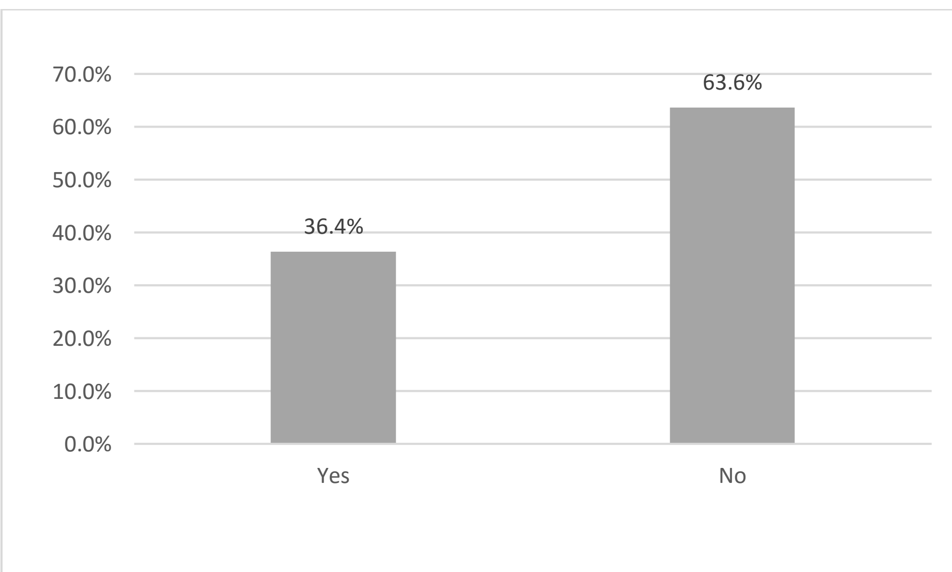


Figure 36. Projects Specifying Fume Control. Results from question II "Have you seen an increase in projects specifying fume control methods?"

Overwhelmingly, decision makers are not seeing an increase in projects specifying fume control methods. This gives insight into the trend of the asphalt roofing industry as it pertains to adopting health hazard controls. A three way full factorial determined that neither age, firm size, or gender had a significant effect on the percentage of work specifying using fume control technology.

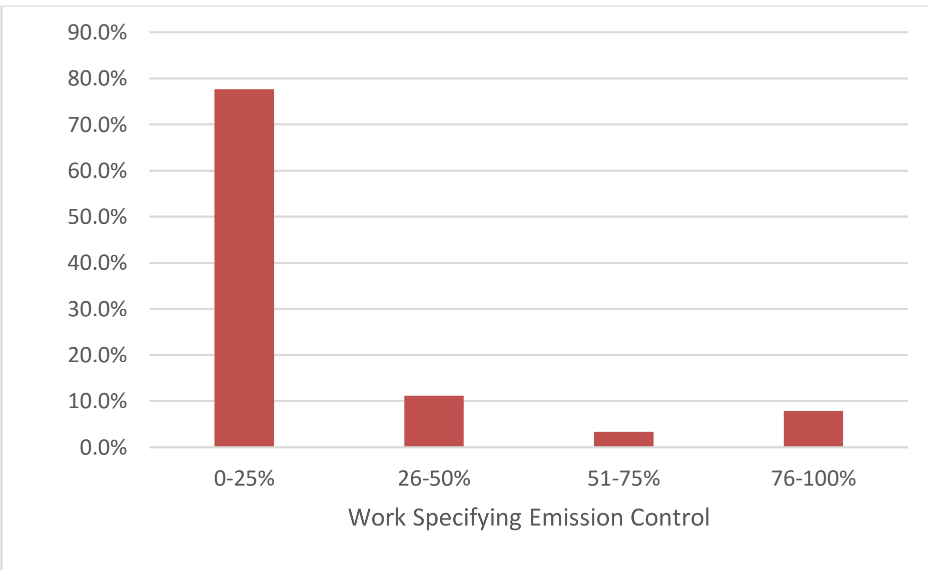


Figure 37. Asphalt Roofing Percent of Work. Results from question III "In the past year what percent of your work specifies using fume control methods?"

It is evident that that majority of firms, 77.7% are not performing work on sites that require fume control technology. A three way full factorial determined that neither age, firm size, or gender had a significant effect on the percentage of work specifying using fume control technology.

Content Analysis

Open ended questions were analyzed using content analysis. All were alpha over .667 though only tentative conclusions can be made off those under .80. All questions which were below .667 were discarded including Question 40 (α= 0.445) and Question 52 (α= 0.577)

Table 30

Asphalt Roofing Question 4 Responses "Please tell me why your employees do not use liquid asphalt tanker delivery systems?"

Respondent#	***Response***
5	We do a different type of roofing.
6	Do not have a demand for tanker asphalt delivery systems.
8	We haul it in bulk in solid form.
10	We use a different type of roofing system.
12	The vapors and fumes were too much to work with in the communities.
16	Not as prevalent; older technology.
20	Kettles are used more now.
22	Too dangerous and hot.
24	Jobs are not that big that needs a tanker.
26	The nature of roofing has changed.
31	Not anymore.
38	Too costly.
39	In Alaska, there is no service.
40	Don't do that kind of work right now.
41	We have our own kettles.
43	Decided just to go non-hot for safety reasons.
46	Not set up for it.
48	We are in a rural area.
50	Don't use entire system unless it's a commercial project offering a lot of money.
53	It's not available in the area.
57	No one sells it anymore.
71	Haven't done that much asphalt roofing.
72	Tankers for larger jobs than company is completing.
77	Tanker asphalt is usually used for large scale jobs.
80	Larger scale jobs; company does not require much jobs like these.
82	We mainly use asphalt products and customers don't want those.
84	The industry is growing in a different direction.
94	Extremely expensive.
95	Buy the asphalt in the kegs.
Q4y.	**Continued.**

Respondent#	***Response***
102	Only do smaller sized jobs and so they are not useful.
105	The type of work we do does not require that kind of volume.
110	Just don’t like the danger involved.
111	Only have kettles.
113	Do not work big enough jobs.
120	Not involved.
121	Not their preference.
122	Cost factor, transportation, etc.
130	They just don't.
133	It was too expensive.
135	Facility does not call for tankers.
139	Use more kettles.
141	Use kettles, jobs do not require tankers due to size.
142	Certain projects require them but not nearly as often as smaller jobs.
146	The vapors and fumes will kill you.
147	Asphalt is too expensive.
150	They have their own kettles.
151	We don’t have jobs that are big enough for the tankers.
155	Asphalt work is not usually specified.
159	Smaller work now than before.
164	We have better means for them.
166	They don't work with bulk tankers anymore, instead they buy in kegs.
167	Moved to drums because it was more cost effective.
169	There are not that many jobs that require these.
170	Use hundred pound kegs of asphalt.
172	Don’t have any need for those.
173	Only accounts of 1 percent of work anymore.
174	Hot asphalt is becoming more instinct.
185	Large projects.
187	Because nobody offers it in their rural area.
199	Have own asphalt kettle.
200	We had one many years ago, but there is no longer the volume of work to support it.
203	Our company does not do enough volume to warrant it.
214	Not enough exposure and don’t know enough about it.

Table 31

Asphalt Roofing Question 4 Frequencies "Please tell me why your employees do not use liquid asphalt tanker delivery systems?"

Response Code/Category	**Frequency**
Other type of delivery system (solid asphalt in kegs)	11
Job size/work size concerns	10
No need/demand	7
Cost	6
Not available in that area	5
Hot asphalt not used/industry trend	3
Not applicable to company	2
Safety and/or health issues	2
Preference	2
Fume issues	1
Don't know enough about it	1

$\alpha = 0.764$

Table 32

Asphalt Roofing Question 16 Responses "Please tell me why your employees do not use hot luggers, mechanical spreaders, or felt-laying machines?"

Respondent#	***Response***
12	Just stopped using them.
18	Other options in the industry.
22	Too dangerous and hot.
23	Chose another form of roofing.
31	Not that type of work.
32	Built up roofing systems are not specified much anymore.
38	Too costly.
54	Health risk, too much hazard.
56	Don't use asphalt anymore.
71	Have not done a lot of hot work.
72	Sold hot equipment 4 years ago.
80	Liability issues.
82	Customers dictate what we use.
88	Because it is not done anymore.
90	Codes and no specifications by designers.
91	We work with small roofs.
104	Type of work not requested; more specified work.
110	Dangerous.
113	Do not work big enough jobs.
119	Use other equipment.
120	Not in use.
127	Not used much.
135	Because a certain size job is required.
138	The industry is going towards to cheaper methods.
142	Only when jobs require them, usually bigger jobs.
146	Vapors and fumes will kill you.
153	Less than 10 percent of asphalt usage.
172	Don't have any need for them.
174	Cold adhesives are being used more than asphalt.
175	Maintenance company and do not work with hot asphalt.
176	Too expensive and dangerous.
192	Smaller scale.
208	Asphalt roofing is too expensive.
210	Marketplace, can't afford to do it.
214	Not entirely necessary.
222	Liability, cost and energy savings.

Table 33

Asphalt Roofing Question 16 Frequencies "Please tell me why your employees do not use hot luggers, mechanical spreaders, or felt-laying machines?"

Response Code/Category	**Frequency**
Job size/work size concern	5
Use other options	4
Safety and/or health issue	4
Hot asphalt not used/industry trend	3
Cost	3
Previously used	2
Not necessary/don't need	2
Liability/insurance issues	1
Customer requirements/demands	1
Not applicable to company	1
Energy required	1

α = 0.722

Table 34

Asphalt Roofing Question 28 Responses "Please tell me why your employees do not insulated kettles or insulated hot luggers?"

Respondent#	***Response***
4	That's not the equipment that they own.
12	Just stopped using these technologies.
18	Other options available.
22	Too dangerous.
24	Prefer not to work with hot asphalt.
32	Roofing systems do not specify; the single ply method has taken over.
33	Don't own one directly.
43	Decided not to use because of safety reasons.
50	Too much of insurance risk.
51	Not a lot of commercial work carried out.
52	Asphalt market has changed, don't need them anymore.
54	Too many systems that are more environmental friendly.
57	Not a new product anymore.
Q28y.	**Continued.**

Respondent#	***Response***
58	Not in a temperature sensitive environment for the insulated kettles.
62	Just not as popular anymore.
71	Have not had much hot work.
72	Sold hot equipment.
80	The industry has changed leaning more towards single-ply membranes.
88	Because the industry is changed.
103	Because that market is going away due to the demand of a new product single ply membrane.
104	Not requested; more work specified in other products.
110	Dangerous.
112	More productive and safer to use tankers and production rates are higher. Also, sometimes owners specify it.
113	Do not have equipment and do not work jobs that require them.
116	It's a dinosaur.
120	Not involved.
122	Not applicable to the climate.
140	Do not do a lot of hot jobs.
141	Primarily work with rubber roofing.
146	Vapors and fumes will kill you.
164	No business for them, we have other means.
174	Have not used them in about 8 to 10 years.
175	Job specifics do not call for them.
192	Smaller scale of business.
208	Too expensive.
210	Marketplace.
214	Not educated enough about it.
218	Stop using them due to the asphalt smell and potential cause of cancer.
222	Cost, energy, liability

Table 35

Asphalt Roofing Question 28 Frequencies "Please tell me why your employees do not insulated kettles or insulated hot luggers?"

Response Code/Category	**Frequency**
Safety and/or health issues	6
Hot asphalt not used/industry trend	6
Don't own	3
Previously used	2
Not applicable to company	2
Use other option	1
Preference	1
Liability/insurance issues	1
Environmental issues	1
Site/climate/environment dependent	1
Business size	1
Cost	1
Don't know enough about it	1
Energy required	1

$\alpha = 0.690$

Table 36

Asphalt Roofing Question 40 Responses "Please tell me why your employees do not use low fuming asphalt?"

Respondent#	***Response***
6	Limited on amount of asphalt as is and would also have to be ordered for use.
12	Still was not easy to work with due to vapors and fumes.
15	Not expect that much.
18	Other options are available.
19	Manufacturing currently do not carry low fume asphalt.
22	Too dangerous.
26	Because it wasn't a very good product compared to the standard asphalt.
32	Roofing systems do not specify any longer, the single ply method has taken over.
38	Too costly and dangerous.
50	Insurance risk.
54	Other better systems.
71	Have not had much hot work.
77	Because of the cost of it and most jobs do not call for it; no specified jobs needed the low-fuming asphalt.
78	Hasn't been required.
88	Industry has changed.
89	We don't focus on that area too much.
90	It's not specified.
91	Higher priced and not a requirement in many locations.
103	Just not in the market.
104	Not requested; only when specified.
108	Don't see the difference in the material. It comes in plastic containers and the plastic causes issues with the kettles.
112	Not required on projects and cost more. Unless specified, we do not use them.
113	Do not use.
115	Change of demand for consumers.
120	Not involved.
126	It is a rarity.
129	There is not much difference.
131	Because the job may or may not be specified in the work order.
138	Only used for specified jobs which is very seldom today.
142	Only as the job requires it such as with a school; which is rare.
146	No longer works with it because of the vapors and fumes and job specs.
172	Don't have a need for the product.
174	Familiar with but have not used the product only used in specified jobs.
175	Only use cold applications for any work needed.
176	Too expensive.
189	Used to use bulk, just have never tried it.
200	The skin that forms has a tendency to gum up machinery.
204	Shingle manufactured.
214	Manufacturer doesn't offer it.
219	Don't have the need.

Table 37

Asphalt Roofing Question 52 Responses "Please tell me why your employees do not use kettle fume guards?"

Respondent#	***Response***
4	We don't own any and they are not required.
6	The amount of asphalt needed is very low compared to other services provided by the company.
16	The option of the low-fuming asphalt is a better option.
18	Other options are available.
22	Too dangerous.
26	They are not all the same and work at very different degrees.
32	Due to the single ply method of applying roofing now.
43	Decided not to use them because of safety.
44	Don't run kettles.
46	Employees do not dictate, but they are not used based on customer wants.
48	Military base, it is required.
50	Insurance risk.
71	Have not used them due to low hot work.
72	Sold hot equipment.
77	Mostly cost of equipment.
84	We don't have one.
88	Industry is changing.
90	Hasn't been the requirement on jobs.
91	Expense is too high.
101	Not installed on kettle equipment.
104	Only when specified for a job.
105	Own them and then they don't work well so they are removed... Unreliable.
108	Use a different system in that situation in order to avoid using fume guards.
110	Dangerous.
115	Change in demand.
123	Antiquated - doesn't think they work.
125	Not useful.
126	Only used when required by a customer.
129	Not used unless required for project.
138	Only if required which is not that often.
139	Only when requested.
140	Only used them when specified in jobs which is hardly ever.
146	Vapors and fumes will kill you.
149	Just don't.
152	We don't do a lot of kettle work so we don't have them.
159	Don't have a kettle anymore.
165	Don't work very well, inhibit production process.
166	Only some of the new kettles have the fume guards, they don't see that in their market place.
172	Don't have a need for them.
173	The nature of the work generated now does not require this equipment.
Q52y.	**Continued.**

Respondent#	Response
175	Has not needed to use them.
182	We don’t do much hot asphalt.
188	Because they are a pain in the ass.
191	Don't own one.
202	Use tankers.
205	The job does not require for them.
208	Too expensive.

Table 38

Asphalt Roofing Question IV Responses “What are some other fume control methods that you know about or have used?”

Respondent#	Response
8	We attempt to the kettles on the east side of the building to direct the vapors and fumes away from employees and surrounding communities.
10	Blowers are used to help with directing the vapors and fumes.
16	Odor control - additives to product to make the smell of asphalt less repugnant. Using alternative materials that don't utilize hot asphalt.
23	Sniffing tailpipes on vehicles.
26	Giant filter system on a trailer but very expensive and a lot of maintenance.
34	Proper ventilation.
35	Only other things we've used are personal respirators. Not so much fume control, more for personal safety.
38	Uses a rubber system that also has some vapors and fumes but no tar products are used.
39	No smell asphalt.
41	Afterburners.
48	Reburners on the kettles.
50	Respirators.
53	Filtering.
54	Fume emission, low VOC.
58	Air intake units, strategically located kettles.
69	Carbon filters.
70	Lower fume asphalt, fume recovery machine.
71	Proper ventilation and fume suppressers.
74	Fume recovery system.
78	HVAC system.
79	Filtering system.
80	Location equipment with regards to the building.
82	Low fuming type materials.
86	Fume recovery systems.

IV.Continued.

Respondent#	***Response***
88	Just different job engineering on where you place the kettle.
97	Using masks and working with proper ventilation and avoid time of day when businesses are open.
98	Putting materials in the asphalts that change the odor.
100	Low odor asphalt.
102	After burners.
103	Low VOC.
108	Go down wind to avoid the vapors and fumes.
115	Cover exhaust intakes, company center schedule to avoid contact with individuals and MSDS sheets are available for all materials.
118	Fume recovery systems.
120	Filtration and afterburners.
122	Fans, afterburners.
123	Charcoal filters.
125	Fans.
129	After burners.
131	Charcoal filters.
132	Masks.
133	These are all of them.
135	Afterburners on kettles.
136	These are all of them.
139	Afterburners.
141	Employees can use masks, the frequency of opening the kettles and luggers.
142	Low VOC technology in them.
144	Respirators.
146	Single ply and modified applications.
150	Off-hour operations.
155	Asphalt perfume.
170	Cover up the air intakes, so it prevents the vapors and fumes from entering the building.
174	Single ply has bonding adhesives that produces a smelling odor.
175	Avoid working around intakes and switching the product to use less odor producing products.
177	Fume recovery system.
179	Fume recovery systems.
182	Common sense.
185	Air handling units, wind safety.
188	FRS machine which is an afterburner.
203	Charcoal filtration.
222	Engineering control set ups with prevailing winds.

Table 39

Asphalt Roofing Question IV Frequencies "What are some other fume control methods that you know about or have used?"

Response Code/Category	Frequency
Filter on trailer	8
Afterburners/reburners	8
Positioning of kettles	7
No smell asphalt	7
Personal protective equipment	6
Fume recovery machine	5
Blower/fans	3
Additive for smell	3
Ventilation	2
HVAC system	2
Cover exhaust intakes	2
No others	2
Rubber system	1
Scheduling system around vapors and fumes/off hours	1

$\alpha = 0.945$

Table 40

Asphalt Roofing Question V Responses "If you could imagine an ideal way of controlling asphalt vapors and fumes that does not currently exist, what would it be?"

Respondent#	***Response***
8	We attempt to the kettles on the east side of the building to direct the vapors and fumes away from employees and surrounding communities.
10	Blowers are used to help with directing the vapors and fumes.
16	Odor control - additives to product to make the smell of asphalt less repugnant. Using alternative materials that don't utilize hot asphalt.
23	Sniffing tailpipes on vehicles.
26	Giant filter system on a trailer but very expensive and a lot of maintenance.
34	Proper ventilation.
35	Only other things we've used are personal respirators. Not so much fume control, more for personal safety.
38	Uses a rubber system that also has some vapors and fumes but no tar products are used.
39	No smell asphalt.
41	Afterburners.
48	Reburners on the kettles.
50	Respirators.
53	Filtering.
54	Fume emission, low VOC.
58	Air intake units, strategically located kettles.
69	Carbon filters.
70	Lower fume asphalt, fume recovery machine.
71	Proper ventilation and fume suppressers.
74	Fume recovery system.
78	HVAC system.
79	Filtering system.
80	Location equipment with regards to the building.
82	Low fuming type materials.
86	Fume recovery systems.
88	Just different job engineering on where you place the kettle.
97	Using masks and working with proper ventilation and avoid time of day when businesses are open.
98	Putting materials in the asphalts that change the odor.
100	Low odor asphalt.
102	After burners.
103	Low VOC.
108	Go down wind to avoid the vapors and fumes.
115	Cover exhaust intakes, company center schedule to avoid contact with individuals and MSDS sheets are available for all materials.
118	Fume recovery systems.
120	Filtration and afterburners.
122	Fans, afterburners.
123	Charcoal filters.
IV.	**Continued.**

Respondent#	***Response***
125	Fans.
129	After burners.
131	Charcoal filters.
132	Masks.
133	These are all of them.
135	Afterburners on kettles.
136	These are all of them.
139	Afterburners.
141	Employees can use masks, the frequency of opening the kettles and luggers.
142	Low VOC technology in them.
144	Respirators.
146	Single ply and modified applications.
150	Off-hour operations.
155	Asphalt perfume.
170	Cover up the air intakes, so it prevents the vapors and fumes from entering the building.
174	Single ply has bonding adhesives that produces a smelling odor.
175	Avoid working around intakes and switching the product to use less odor producing products.
177	Fume recovery system.
179	Fume recovery systems.
182	Common sense.
185	Air handling units, wind safety.
188	FRS machine which is an afterburner.
203	Charcoal filtration.
222	Engineering control set ups with prevailing winds.

Table 41

Asphalt Roofing Question V Frequencies "If you could imagine an ideal way of controlling asphalt vapors and fumes that does not currently exist, what would it be?"

Response Code/Category	**Frequency**
Don't use asphalt	10
Non smelling asphalt or mask smell	9
Fan system to draw vapors and fumes upward	6
Personal protective equipment	1
Get rid of kettle fume guards	1
Filter system	1
Cold applied roofing	1
Burner	1
Joke category	1

α = 0.706

Table 42

Summary of Findings for Asphalt Roofing

1. **Perceived Risk**
    - Only just over half of asphalt roofing decision makers perceived asphalt vapors and fumes to be a health risk and even less feel it is a severe health concern
2. **Tanker Delivery Systems**
    - Tanker Delivery Systems are the least frequently used control in industry.
    - Though its relative advantage and perceived usefulness are high, its perceived benefit is not.
    - Industry is least ready to adopt tanker delivery systems.
3. **Hot Luggers, Mechanical Spreaders, Felt Laying Machines**

- These are not significantly different than any other technology for perceived usefulness except for low fuming asphalt.
- Its perceived benefit is lower than most other technologies but its relative advantage and adoption readiness have some of the higher rankings amongst other technologies

4. **Insulated Kettles/Hot lugger**
   - These are among the most frequently used, and have high perceived usefulness and relative advantage.
   - They are lowest in perceived benefit along with hot luggers/mechanical spreaders, felt laying machines as these are not significantly different than each other
   - Industry is most ready to adopt insulated kettles/hot luggers
5. **Low Fuming Asphalt**
   - Low fuming asphalt is as frequency used as all others except tanker delivery systems though decisions makers view it to have the lowest perceived usefulness and relative advantage
   - Decision makers somewhat agree they are ready to adopt low fuming asphalt
6. **Kettle Fume Guards**
   - Kettle fume guards are as frequently used as the other technologies except tanker delivery systems, and are high in perceived usefulness, perceived benefit.
   - Though, like low fuming asphalt, they are low in relative advantage and are relatively high in adoption readiness.
7. **Reasons for Adopting Fume Control Technologies**
   - Decision makers choose to adopt dust control technologies based on worker safety, government regulations, insurance premiums, and productivity, in that order. Customer requirements is the next most cited reason.
8. **Industry Trend**
   - There is an evolving trend of projects not increasingly specifying the use of fume control technologies

- The data suggests the industry almost entirely does not specify the use of fume control technology with almost 80% stating that 0%-25% of their projects specify fume control technology must be used

9. **Other Control Technologies**
    - The most used control technology which was not investigated are filters on trailers and afterburners/reburners, and position of the kettle in such a way to reduce fume exposure

10. **Inventions**
    - The most proposed new technology from the decision makers was material substitution.

Study 2 discussion

The data suggest decision makers in asphalt roofing are split in half, unsure if they perceive hot asphalt vapors and fumes to be health risk. About half of decision makers feel vapors and fumes pose a risk to worker health. Even so, 76.4% of decision makers view worker safety to be a driving factor for adopting fume control technology. One reason risk may not be understood is because of the switch from coal based to asphalt based roofing materials. Coal tar is carcinogenic (International Agency for Research on Cancer (IARC), 1987). A meta-analysis showed that 90% of roofers in the 1950s-1960s were exposed to coal tar, dropping to 10% in the 1980s (Fayerweather, 2007). For this survey, there were no age-related effects on perceptions of risk though. The researcher does not know why asphalt roofers do not perceive asphalt vapors and fumes to be a risk to worker health.

Adoption readiness was relatively high across all technologies, though there were difference between tool types. Trust in technology and benefit 1 were significant across control types. Primarily looking at trust in technology which may mean there are not sufficient tools for this industry which would induce a perceived sense of trust amongst decision makers. As productivity was the lowest for business factors, it may be because the current technologies are a hindrance to productive growth. There may also not be adequate controls to enable the decision makers to have trust in the technology itself. Adoption readiness is relatively high but trust technology is low.

There was a lot incident rate of projects specifying the use of fume control which may not encourage adoption. A total of 77.7% of decision makers report that 0-25% of projects specify the firm must use some kind of fume control technology. One reason for this may be because asphalt roofing does not interact with other work on the jobsite does as other trades. Shepherd and Woskie (2010) found the effect of dust levels effecting work of other subcontractors to be an incentive to implement engineering controls for concrete grinding dust. Thus, as asphalt roofing does not impede workflow, using projects specifying fume control as a forcing function for adoption may not be a viable option.

Decision makers were not very familiar with tanker delivery systems and they were infrequently used. The main reasons for not using tanker delivery systems were because it is for larger applications, it is not as highly demanded, and the cost involved. Investigating specific responses show that some decision makers view it as older technology and one even mentioned that they do not like the danger involved in using it.

Decision makers were most familiar with hot luggers, mechanical spreaders, and felt laying machines. They have high perceived usefulness and relative advantage, and the adoption readiness is high. Open ended responses reveal this may be because they aid the business side, as these systems are used on bigger roof applications.

Insulated kettles/hot luggers are ranked highest in adoption readiness and this may be due to work flow considerations. Based on conversations with SMEs, having the kettles insulated means a more consistent temperature and having the hot luggers insulated means the asphalt stays in liquid form longer. Content analysis reveals the reason they do not use insulated kettles/hot luggers is because of safety issues or hot asphalt not being used anymore. Specifically looking at the responses, it appears the safety issues they are responding to are about the asphalt industry in general and not specifically insulated kettles/hot luggers.

Low fuming asphalt's adoption most likely depends on the desire for odor control over vapor and fume control. Low fuming asphalt has low perceived usefulness and relative advantage scores but scores high on perceived benefit. Based on discussions with SMEs, this is most likely because of the reduction in odor. Low fuming asphalt does not have chemical properties which would make it more useful or beneficial, with at least two respondents mentioning how the skim may cause machinery issues. That said, low fuming asphalt can be good at reducing health hazard overexposure. Low fuming asphalt has been shown to reduce >70% of harmful chemicals (Kriech et al., 2004). Based on the open ended responses, it appears low fuming asphalt is used mostly by request. Therefore, the driving force behind adoption is most likely customer request. Focusing on getting more projects to specify fume or odor control would be a good place to target for better adoption rates of low fuming asphalt considering its health hazard reduction rate.

Amongst decision makers, kettle fume guards were one of the least familiar and least frequently used tools. Though, kettle fume guards had the highest perceived benefit to health of workers and were high in perceived usefulness, but relative advantage was low. They were ranked in the middle for adoption readiness. Content analysis had low inter-rater reliability. Therefore, looking at individual responses, it seems the guards may be removed because they are unreliable and there are other, more desirable emission control technologies.

The asphalt roofing industry seems to be moving toward other roofing techniques. Competition from new synthetic roofing materials is expected to keep the asphalt roofing industry demand at a minimum (Khursheed, 2001). The hot asphalt roofing industry seems to be shrinking. One respondent commented, "cold adhesives are being used more than asphalt." Another said, "asphalt roofing is expensive." With many others saying they have sold their hot asphalt equipment, one even saying "it's a dinosaur." Therefore, this researcher suggests looking at understanding other trade sector needs as the need for health hazard controls in asphalt roofing may shift. Other trades should be investigated to determine if a larger impact could be made there.

Conclusion

The asphalt roofing industry does not appear to be a construction sector where better health controls will have a large impact. The industry is divided about the health risks which may make implementing controls harder. Additionally, roofers are moving away from hot applied techniques in favor of cold applied.

The overall trust in the technology across all tool types is low. The industry may need better health hazard controls but based on the trend of the industry moving away from hot applied asphalt, and very few projects specifying that emission control is required, efforts to implement controls may be better for other industries.

Study 1 and study 2 Comparison

Discussion

The studies indicate that asphalt roofing is not as understanding of the health hazards and do not have high trust in any of the current technologies compared to the concrete and masonry trades. This may be because of the switch from coal based roofing to asphalt roofing itself and peoples' perceptions of the health hazards previously being a problem but not anymore. It would appear that the concrete and masonry trades are relatively receptive to dust controls and increased adoption rates could see a large impact. Asphalt roofing may not be as important to tackle as the results indicate the industry is moving towards cold applied techniques. With these new techniques, the problem associated with asphalt roofing may very well be eliminated or severely altered. Additionally, respirable silica is categorized as a group 1 carcinogen: carcinogenic to humans whereas asphalt vapors and fumes are a type 2a: most likely carcinogenic to humans (International Agency for Research on Cancer (IARC), 1997, 2011). Therefore, silica overexposure poses a more severe health effect, insinuating control of silica is a more pressing needed.

How many projects specifying fume or dust control technologies, and if there has been an increase in the number of projects specifying for the year give insights into the industries over time. The surveys give a snapshot of the industry at the time but this particular question gives a sense of use over time. It appears concrete and masonry dust control technologies are being specified at an increasing rate, and the asphalt industry is seeing the inverse. The percent of projects specifying dust control technology have almost all or almost none of the projects specifying. Whereas the asphalt roofing industry has over ¾ of its projects specifying fume control technologies 0-25% of the time. This indicates the concrete and masonry trades are moving toward more adoption of control technology while asphalt roofing is moving toward less adoption of control technology. Finally, the projects specifying vapor and fume or dust control technologies may be a forcing function for adoption.

Another possible forcing function for adoption is if the health hazard interferes with other work being done on the construction site. Asphalt roofing has few projects specifying that fume control must be used. One reason this may be the case is when they are on the rooftop, they are not interfering with other work on the site. When the

PI SMEs, one firm owner mentioned he will use low fuming asphalt when they are at a school and redoing the roof. The reason being is school is still in session and the teachers complain of foul odors. This is important because the PI on his site visits was told dust control is usually specified as there are many subcontractors on a site at any given time and the dust will interfere with other work. Therefore, one possible forcing function for adopting health hazard controls is based on if the hazard interferes with the productivity of other subcontractors.

Concrete/masonry and asphalt roofing differ in business factors affecting adoption, with productivity and insurance premiums switched. Comparing worker safety and government regulations the differences between concrete/masonry and asphalt roofing are 91.6% worker safety 82% government regulations, and 76.4% and 71.4%, respectively for asphalt roofing. Understanding why insurance premiums and productivity are different would be worth investigating further in a future study.

Limitations

Firm size is not consistent in studies that analyze its effects on dependent variables (Fink, 1998; Sexton & Barrett, 2004; J. Y.-C. Weidman, Deborah, 2012). This study aimed to be more consistent with nationalized standards and used European Union standards for United States data. The driving force was the EU standards use four size classes while the Bureau of Labor Statistics has nine (Bureau of Labor Statistics (BLS), n.d.; The Commission of the European Communities, 2003). It will be difficult to compare similar sized company results across studies for this reason. Additionally, not enough medium and larger companies were found. Sexton and Barrett (2004) says 99% of construction firms had between 1 and 52 staff members in the United Kingdom in 1999. There are less large firms by their nature but future research should aim to see if a larger sample size of medium and large sized firms has an impact.

These studies only investigated health hazards and did not take into consideration other hazards on the jobsite. Specifically tied with health is safety which is missing in these studies. Therefore, the trades investigated for a similar study but for safety may be different. Therefore, this study cannot claim to include all of occupational safety and health, only health hazards in particular. And, this was not exhaustive of all health hazards.

This study did not control for order effects. There were a total of 167 participants for concrete and masonry. When looking at the sample size for each tool, dust collection equipment (n=138) and wet-method systems (n=135) have larger sample sizes than isolation systems (n=57) and sweeping compound (n=51). Though, there is still significance in the tests. Though dust collection equipment and wet-method systems were listed first, the tests show they also ranked higher generally speaking across constructs so the decrease in sample size may be because of order effects or because decision makers skipped sweeping compound and isolation systems because they are not familiar with them. Asphalt roofing show similar effects. There were a total of 200 participants in the study. In order the order they were listed on the questionnaire, the sample sizes by each tool are tanker delivery systems (n=110). hot luggers, mechanical spreaders, felt laying machines (n=158), insulated kettles/hot luggers (n=144), low fuming asphalt (n=136), and kettle fume guards (n=104). Many decision makers were not familiar with liquid asphalt tanker delivery systems. After that, we do see a steady decline in the number of decision makers answering for each tool. In future studies, the order of tools should be randomized to attempt to have similar sample sizes. Even so, this was a descriptive study rather than hypothesis-testing inferential study.

Conclusion

Those looking to implement changes in health hazards in commercial construction should look to concrete and masonry trades over asphalt roofing. The trades are aware of the risks and are receptive to controls being implemented. Concrete is a larger industry than masonry and so intervention strategies should have a larger impact than one focused in masonry. The number of workers employed in the United States as cement masons or concrete finishers compared to brick masons and block masons is 163,360 and 61,360, respectively (Bureau of Labor Statistics (BLS), 2015c, 2015d). Most masons require a high school diploma or equivalent and usually have a 3- to 4-year apprenticeship while most concrete and other construction laborers positions require no formal education (Bureau of Labor Statistics (BLS), 2014, 2015e). Thus the number of people working with concrete in some fashion is much higher as there are 1,386,400 construction laborer and helpers who perform many tasks on construction sites (Bureau of Labor Statistics (BLS), 2015e). These numbers are probably even higher because exact statistics on undocumented workers is not available, yet they are still employed (Bureau of Labor Statistics (BLS), 2015a; Jimenez, 2003). Additionally, cement masons/concrete finishers have higher exposures to respirable quartz than bricklayers or stone masons (Beaudry et al., 2013).

Worker experience has been shown to have an effect of how much dust enters the breathing space of workers with more experience workers having less (Shepherd & Woskie, 2013). Based on conversations with subject matter experts and looking at tool manufacturers suggestions, Saw Muzzle GP, the LEV tend to do better with concrete than masonry products due to their size. Additionally, there are controls available for masonry products that are not available for concrete such as table top masonry saws. Historically, stationary saws are the primary tool for cutting brick and block. Some view the portable saws as a productivity gain but gasoline powered equipment is prohibited on scaffolding. Additionally, the operator is able to avoid certain ergonomic stressors with the table saw as they can stand upright, do not have to bear the weight of the saw (Meeks et al., 1992). Therefore, because there is a viable solution for brick and block already, the concrete industry does not have that advantage.

Chapter 3

Study 3 Saw Redesign Procedure, Usability Evaluation, and the Creation of a Design Taxonomy for Large Handheld Powered Equipment

Objective 3: Using the results from study 1 and 2, identify a trade and technology to create a redesign process, leading to a usability evaluation of a LEV system for the handheld cut-off saw. Use this information to create a design taxonomy for large handheld powered equipment.

Overview

This study contains the entire design process used and taxonomy created, for handheld powered tools. The design process uses a mix of contextual inquiry, subject matter experts, focus groups, and an iterative prototyping and testing phase. The prototype was not successful and a similar commercially available model was used to conduct a usability inspection. The researcher used a heuristic evaluation on a local-exhaust ventilation (LEV) system for the handheld cut-off saw to determine its usability problems and these problems were transformed to create the design taxonomy. Final recommendations are made based off Study 1, Study 3, and literature.

Introduction

Literature and the results from Study 1 and 2 informed the design direction. Studies 1 and 2 indicate stakeholders in concrete and masonry may be more receptive to health hazard controls than those in asphalt roofing. Therefore, concrete and masonry trades were targeted. At the completion of Study 1 and 2, a meta-study by Beaudry et al. (2013) was published. It analyzed 115 studies and showed that masonry cutting and concrete grinding are the second and third highest dust producing tasks on the jobsite, respectively. The first is abrasive blasting which sprays silica-laden dust on objects. Based on this meta-study, this researcher decided to concentrate on cutting tools used in concrete and masonry. From site visits and SME discussions, it appeared the gasoline powered cut-off saw is widely used on construction sites. An investigation into current controls for the tool show wet-method systems and dust collection equipment are used.

This researcher investigated the difference between wet-method systems and LEV systems on the cut-off saw. LEV systems exist for the cut-off saw but they are mostly available for electric models (Meeker et al., 2009). Multiple studies have shown wet-method systems to be more effective for dust control than LEV systems on the cut-off saw (Carlo et al., 2010; Shepherd & Woskie, 2013; Thorpe et al., 1999). Other studies have shown dust reduction technology on smaller handheld tools using vacuum based systems (Akbar-Khanzadeh & Brillhart, 2002; Akbar-Khanzadeh et al., 2007; Akbar-Khanzadeh et al., 2010). Additionally, the results from study 1 indicate dust collection equipment is second highest rated amongst the four dust control technologies investigated. This researcher hypothesized better LEV systems for the cut-off saw may be needed and created a design procedure for large handheld construction tools.

The outcome of the design procedure led to an evaluation of a LEV system. The results of the evaluation were used in the creation of a design taxonomy. The prototype from the conclusion of the design procedure was not fit for testing. Thus a commercially available product was used in its place. Due to resource constraints, only usability was tested and not dust concentration levels. Usability has been identified to be a barrier to adoption. Usability and adoption and linked, with usability problems negatively affecting adoption of tools and processes (Kushniruk et al., 2013). In healthcare, for a point-of-care reminder system, usability of the system impacted the adoption behavior of users (Zheng, Padman, Johnson, & Diamond, 2005). In construction, D. Kramer et al. (2009) found usability to be a main factor for worker's endorsing the adoption of a new type of ladder lift. The usability problems identified were then able to be used as inputs for creating a design taxonomy for large handheld powered equipment. It is this researcher's hopes these design guidelines can be used to redesign current engineering controls or create new designs for controlling hazards associated with large handheld powered equipment.

Design Process

The design process used multiple elements in arriving at a final prototype. Contextual inquiry, current design analysis, subject matter experts, focus groups, and current design laboratory testing informed the sketching and prototyping stage. The prototyping stage involved user testing of the prototypes and the researcher revisited as many of the aforementioned techniques as needed.

Contextual Inquiry

Contextual inquiry is used to gather descriptions of user work practices to better understand the user's rationale behind an action (Hartson & Pyla, 2012). Rather than only observing the user cutting with the saw, understanding work practices is important. Hartson and Pyla (2012) state work practice includes, "all activities, procedures, traditions, customs, and protocols associated with doing the work, usually as a result of the organizational goals, user skills, knowledge, and social interaction on the job." In other words, understanding the work practice incorporates the totality of the use of these saws on the site.

Contextual inquiry was accomplished by visiting construction sites for the first study, and two new sites. The new sites were the Classroom Building and the Indoor Athletic Training Facility on the Virginia Tech Campus. Work activity notes were made to identify areas of importance for the redesigns. During contextual inquiry, users using the saws were observed and this researcher took notes taken on anything interesting about the work activities. Additionally, users were interviewed in situ and notes taken. Observations elucidated knowledge in the world while interviews revealed knowledge in the head.

Onsite visits

During the site visits for Study 1 and Study 2, the research team observed multiple types of actions occurring, many of which contained cutting with the cut-off saw. At Davidson

Hall, cutting of concrete masonry unit (CMU) was observed. The building had no exterior walls yet so a plastic tarp was used as a barrier to keep dust from getting into the building. Also, the worker placed his foot on the block while cutting the CMU. At HABB1 the owner of the subcontracted masonry company mentioned they use a table saw for their cutting with water attachment but for small cuts they use a 16-ounce plastic soda or water bottle, filled up with water and poured over the cut to suppress the dust. The project manager at HABB1 mentioned that all of their projects specify dust control but they do not specify how it must be accomplished and that this is left up to the subcontractor.


Figure 38. Nellies Cave Road Repair

At a local apartment complex in Blacksburg, VA, the cut-off saw was used to cut asphalt. How the operation took place was observed and notes transcribed with a short interview afterward. The company instructed the research team that they use vacuums to clean up and that they prefer walk behind saws. At road construction at Nellies Cave Road in Blacksburg, VA a walk behind saw was observed in action. The walk behind saw has an integrated water system and two 330-gallon water tanks supplied Figure 38 with water tanks not pictured.

Figure 39. Indoor Athletic Facility: One Handed Use

Figure 40. Indoor Athletic Facility: Water Tank Hose Disconnecting Mid-Cut

The next on-site visit was at the Virginia Tech Indoor Athletic Training Facility. The first meeting with the subcontractor, a stone mason, had to be canceled as the outdoor temperature was below freezing. The subcontractor uses water to suppress the dust and he could have used heaters to ensure the water stayed above freezing but it was cost prohibitive for him to do so. The owner complained about guards being too big and slurry, a mixture of dust and water, being an issue if it let to set, especially on a pathway. A way to prevent slurry from causing issues is to be intentional on where you set up your cut so the slurry, flows in a specific pattern. His top reasons for adopting dust reducing technologies are crew health, insurance, and company safety. As someone who not only owns the company but works with the crew on the site, it seems he has a vested interest in maintaining crew health and company safety. Finally, he finds vacuums to be less maneuverable. Problems identified after the two visits, the canceled visit and the observance of the cutting, were cold weather issues and unsafe working habits from workers around the job site, especially not holding the saw as instructed. Problems identified with water is the amount of slurry it creates, freezing concerns, and the portable water tanks hoses coming out of the saw itself. The portable water tank is used for fertilizer but can be filled with water and used for concrete and masonry work. In other SME conversations, it seems to be frequently used so the hose coming out may just have been a faulty connection.

<u>Subject Matter Experts</u>

The researcher contacted STIHL which is a major manufacturer of cut-off saws. Daniel Pherson was contacted on three separate occasions (D. Pherson, personal communication, December 28, 2013, February 4, 2015, and February 9, 2015). He mentioned how the diamond wheel drove the adoption of the tool, how the saw originated by taking a different cutting head to their chainsaws, other dust reducing tools and tool companies such as Saw Muzzle GP and iQ Power tools, and the TSA 230 which is an air powered cut-off saw version with a footplate. He also mentioned new products always be revealed at trade shows and the problem with the electric powered cut-off saw is the lack of power. Finally, when questioned about add-on systems, he says STIHL does not advocate and explicitly say not to use add-on systems.

A regional manager for Hilti, Patrick Fowler was contacted. Hilti has the airboost vacuum which clear the hose and compact the collected material to ensure an adequate amount of airflow pressure. They also have, a fluted drill head which allows a vacuum to suck dust directly out of the hole which is being drilled. Finally, he mentioned that a subcontractor in a hospital had to drill a hole and used shaving cream to capture the dust.

Current Design Analysis

Cut-off Saw

Multiple saws, dust control technologies, and other outdoor powered equipment were analyzed. Multiple brands of saws enabled the cutting action to be assessed, documenting special features or design considerations. The most popular being STIHL, Makita, Husqvarna (Partner), and Hilti (STIHL Inc., Virginia Beach VA; Makita U.S.A. Inc., La Mirada, CA; Husqvarna Construction Products North America, Olathe KS; Hilti USA, Tulsa, OK). Most cut-off saws look the same but differing ways of connecting the blades were found in two Husqvarna models, allowing the blade to penetrate the material much deeper. Additionally, there are carts to hold the cut-off saw making the movement of the user more similar to a lawn mower. The dolly is used for making long cuts.

Figure 41. Husqvarna K6500 Power Cutter: Allowing Full Blade Depth Cut

Figure 42. Husqvarna K760 Cut-n-Break

Figure 43. Cut-off Saw Cart/Dolly

Local-exhaust Ventilation Systems

There are two types of commercially available LEV systems, add-on attachments and built-in systems. The Saw Muzzle GP is an add-on attachment that connects to an external wet/dry vacuum (Shave Away Europe Inc., Sand Diego, CA). Two built-in systems are of interest, the iQ PC912 and a discontinued model, the RedMax Hc510-DV (iQ Power Tools, Moreno Vally, CA; RedMax Corporation, Waco TX). Both of these have retractable shrouds on the front, with the iQ PC 912 being longer, heavier, and has an internal collection bag.

Figure 44. RedMax HC510-DV

Figure 45. iQ PC912

Figure 46. Saw Muzzle GP

Safety Features

Other systems were evaluated which have built in safety protection. For one, work that was done in the Virginia Tech Myers Lawson School of Construction with an enclosing shroud, and two, kickback features on the chainsaw. The chainsaw has similar kickback issues to the cut-off saw, where the machine violently rotates upward and back toward the operator (Dagalakis, Muehlhouse, Wakamiya, & Yang, 1987; Koehler et al., 2004).

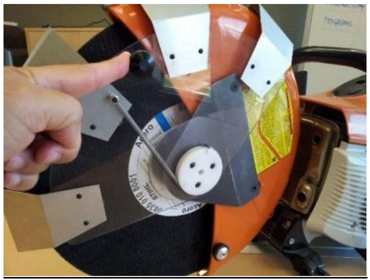


Figure 47. Shroud Prototype

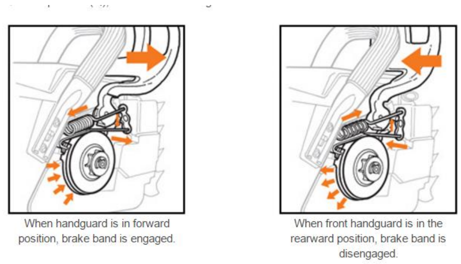


Figure 48. STIHL QuickBrake Kickback Protection

Figure 49. Chainsaw Kickback Protector

Other Power Tools Analyzed

Other residential and commercial construction and landscaping products were evaluated to see if they could inform the prototype. Modular equipment where the engine can be removed and used on other tools was found. The tools most similar to the cut-off saw is the chainsaw. The dangers are similar and the fuel and body positioning is similar (Koehler et al., 2004). Other tools of interested include the gasoline powered auger, the jack hammer, and leaf blower. A list of tools of interest were the stump grinder and lawn mower as the operator's positioning is similar and the blades are moving horizontally. Most of the tools of interest are gasoline powered as this is what the cut-off saw runs off of.

Figure 50. Modular Equipment

Figure 51. Stump Grinder

Pilot Testing with Exploratory Cutting

The PI wanted to evaluate the saw cutting concrete under controlled conditions. The purpose was to visually see the effects of dry cutting versus an LEV system, and getting participant's reactions for both systems. The Saw Muzzle GP was chosen as the LEV system. Dust levels were visually assessed and usability characteristics noted. The sessions consisted of two right handed users and one left handed user who used the saw in the right handed position. Nielsen and Mack (1994) say the more evaluators, the larger proportion of problems will be found, and they suggest a minimum of three.

Concrete was used as the testing material. Quikrete Ready-mix concrete was mixed on-site and poured into slabs 3" thick and measure 2' x 4' (The QUIKRETE Companies, Inc., Atlanta, GA). All concrete needed for this study was mixed and poured in one session to have a uniform batch for testing and cured for at least 30 days.

The STIHL brand was used for all conditions. The PI discovered through speaking with a tool rental company that STIHL is one of the most popular brands for cut-off saws.

Subsequently this researcher contacted STIHL for confirmation (D. Pherson, personal communication, December 28, 2013). The Saw Muzzle GP and the redesigns were attached to the TS 800 STIHL Cutquik (STIHL Inc., Virginia Beach, VA).

Table 43

Saw Characteristics

Attribute	**TS 800 STIHL Cutquik**
Blade size (inches)	16
Weight (lbs.)	28.7
Length (inches)	31 (W. Lemmond, personal communication, March 30, 2014)
Engine power (horse power)	6.7
Displacement (cubic centimeters)	98.5
Maximum cutting depth (inches)	5.6

(STIHL, n.d.)

A wet-dry vacuum was attached to the saw. OSHA suggests using a vacuum with a high-efficiency particulate air (HEPA) filter and a prefilter or cyclonic separator (OSHA, 2013). For the vacuum, a high ventilation rate of 76 cubic feet per minute (cfm) was found to reduce dust levels more than lower ventilation rates (G. Croteau, 2000). Though, this research was conducted fourteen years ago and ordinary wet/dry vacuums have become more powerful. Common wet/dry vacuums have high cfm but may not have HEPA filters. Though vacuums with HEPA filters may not be as common on the worksite, non-HEPA filter vacuums may be a confounding variable by emitting dust into the air after entering the vacuum. Thus, a Dustless HEPA Vacuum with micro pre-filter, model # 16006, capable of 116 cfm was used (Dustless Technologies, Price, UT).

A midgrade blade was used. The blade is the Hilti DC-D UP-S 16”x.125”x1”/20mm DC-D Segmented, model # 02025192 (Hilti USA, Tulsa, OK). The Hilit blade is $150, which is mid-level in price and is meant to be representative of what is used in industry. The blades used in the study are suited for concrete, masonry, asphalt, and cured and green (set but not hardened) concrete. Though there are blades that are specific for each of these trades/purposes, and blades specially designed for wet or dry cutting, the blade chosen for the proposed study is an all-purpose model and may be representative of what is used in industry.

Figure 52. Dry Cutting

Figure 53. Cutting with Saw Muzzle GP

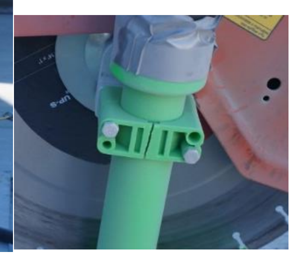


Figure 54. Cracked Saw Muzzle GP During Attachment

Each participant cut the concrete under two conditions, dry and LEV system. After all cutting commenced, the group of three and the researcher discussed what occurred and their overall thoughts on the differences between dry cutting and the LEV system. Thoughts captured include dust covering the left handed users leg, the dust occluding vision, the Saw Muzzle GP not capturing the dust, and the Saw Muzzle GP moving and knocking forward. Additionally, the Saw Muzzle GP did not use the same 18mm bolt, but a 17 mm bolt. This caused the participants to use the factory supplied wrench to remove the bolt and a separate wrench to install the Saw Muzzle GP. Finally, the research team tightened the smaller bolts and it cracked the plastic attachment mechanism. Durability has been shown to be a priority in tools in construction. Hsu and Chen (2000) found when testing different shroud configurations on an angle grinder, a tool common in masonry, that one shroud configuration easily broke and needed to be repaired until it could be replaced. This slowed research efforts which is reflective of what would happen in the field. Problems identified through consulting all participant at the end and doing a group debriefing were durability, maneuverability, and visibility, the Saw Muzzle GP moving being distracting and may be dangerous, and the redirection of dust upwards may be ineffective as the blade sends the dust backward at a high velocity.

Focus group

A focus group was used to help create design requirements and propose redesign ideas. Focus groups bring together several stakeholders to solve a common problem (Martin & Hanington, 2012). Focus groups enable multiple perspectives and insights. The focus group consisted of four members. The researcher reviewed the IRB document with the participants, instructed them on the purpose of the meeting and the desired deliverables. Additionally, they were told what an affinity diagram is and were encouraged to take notes as the team reviewed the material and to draw or take notes on possible redesigns at the same time. Affinity diagrams are used to cluster like ideas, observations, and insights (Martin & Hanington, 2012). This researcher played videos and showed pictures from residential and commercial site visits, the images from the current design analysis, and the results of the pilot test. After all material was reviewed, as a group the team put the sticky notes on the board to begin grouping them.

Table 44

Focus Group Participant Data

Participant	Education	Gender	Reason Included
PI	VT Human Factors and Ergonomics Ph.D. candidate	Male	Human factors specialist
Participant 1	Building Construction Senior	Male	Extensive experience with cut-off saw
Participant 2	VT Human Factors and Ergonomics Master's Student	Female	Human factors specialist
Participant 3	VT Industrial Design Junior	Female	Physical design expertise and design thinking methodology

The totality of the work activities notes were organized into a work activity affinity diagram (WAAD). WAAD is an affinity diagram which uses work activity notes to understand work patterns. Work activity notes documents a single point about a concept, topic, or issue from the raw contextual data (Hartson & Pyla, 2012). Notes were placed on a wall in a bottom up fashion going from single observations to overarching themes (Martin & Hanington, 2012). Affinity diagramming helped to determine areas to focus on during prototyping.

Figure 55. Focus Group Work Activity Affinity Diagram

Based on the WAAD, design requirements were made. Hartson and Pyla (2012) says, “there is an increasing recognition that detailed formal requirements cannot ever be complete…cannot ever be 100% correct…[and] cannot be prevented from changing through the lifestyle.” They suggest there are abridged versions for requirements extraction. Rather than rewriting a work activity note as a formal requirement, the person reading the note will interpret it directly as it is read. Hartson and Pyla (2012) says, “this may immediately generate ideas about how to solve the problem in the design.” Therefore, the requirements generated from the WAAD are abridged versions of formal requirements to help in the design process. In addition to requirements being created, possible designs and areas to focus on proved valuable starts when starting the design process. Design ideas that came out of the design process were oil reservoir to capture dust, electrified field for capturing dust, and a complete redesign of the saw to make the movement more intuitive to the person using it.

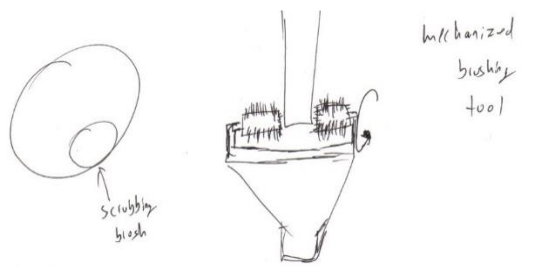


Figure 56. Brush Idea

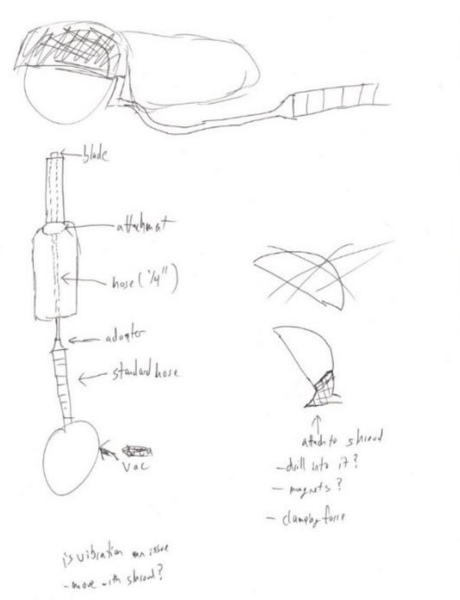
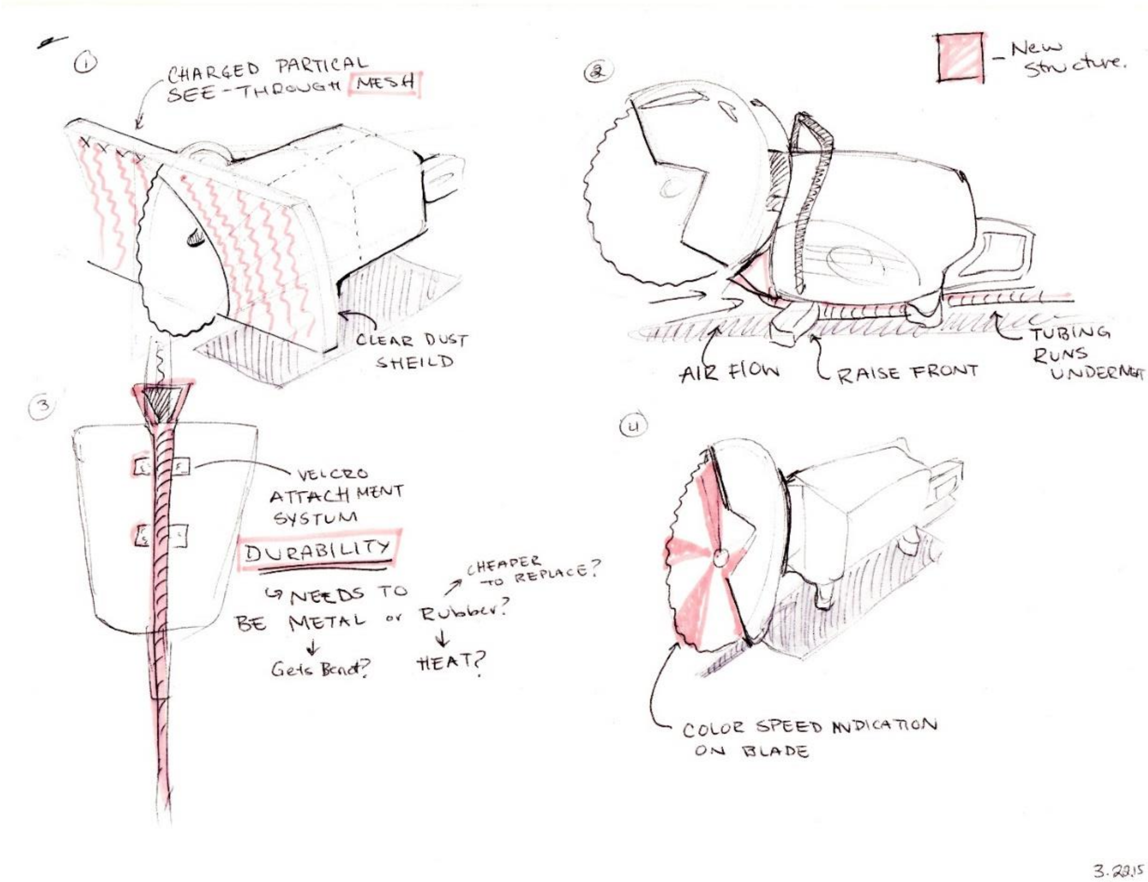
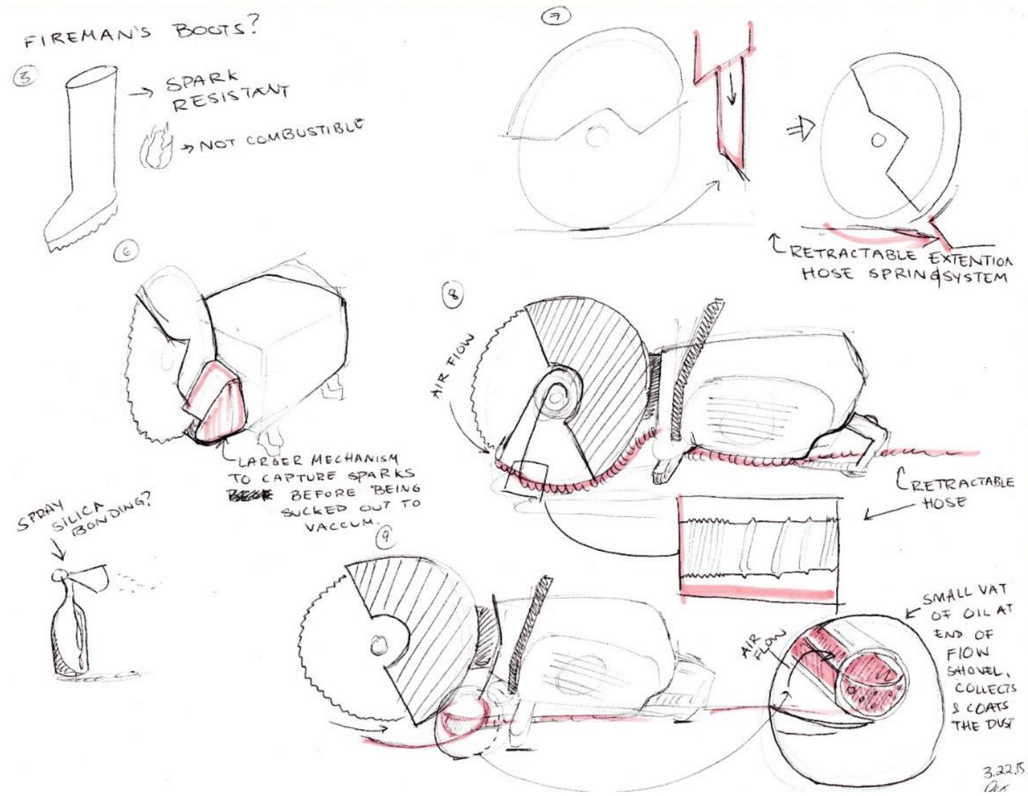


Figure 57. External
Vacuum Idea



1
CHARGED PARTICAL SEE-THROUGH MESH
CLEAR DUST SHEILD
2
New Structure.
AIR FLOW
RAISE FRONT
TUBING RUNS UNDERNEAT
3
VELCRO ATTACHMENT SYSTUM
DURABILITY
NEEDS TO BE METAL or Rubber?
CHEAPER TO REPLACE?
Gets Bent?
HEAT?
4
COLOR SPEED INDICATION ON BLADE
3.22.15



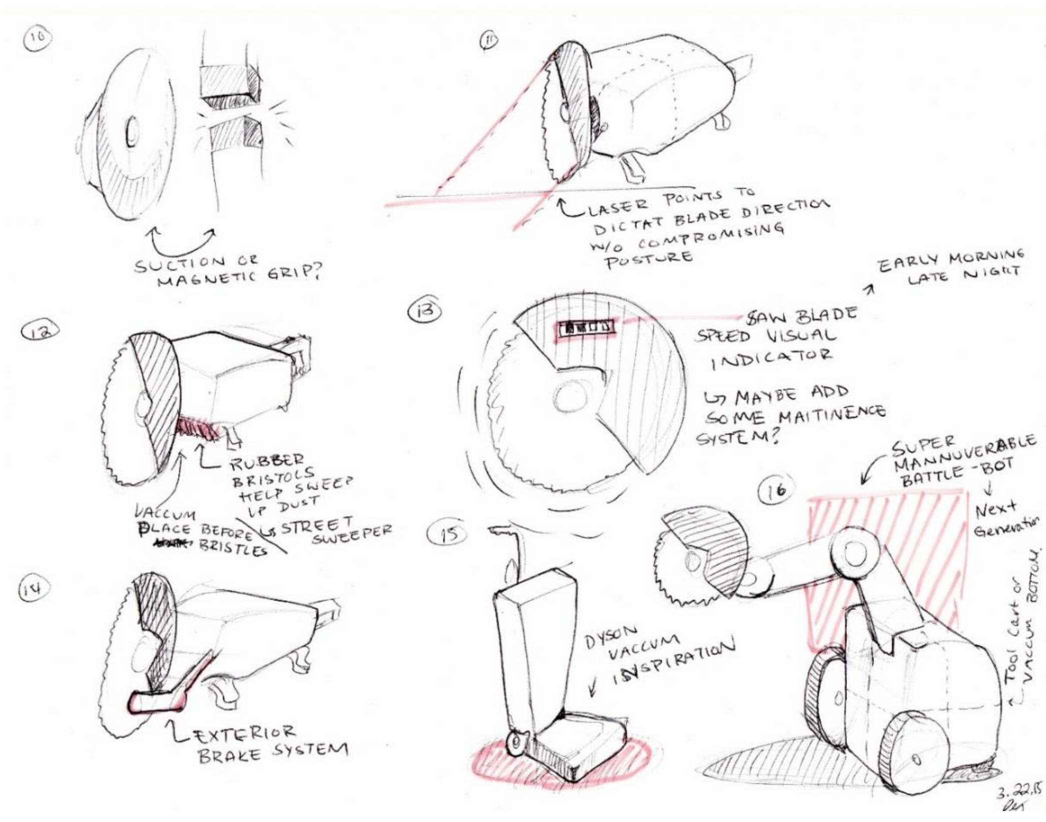


Figure 58. Focus Group Ideas

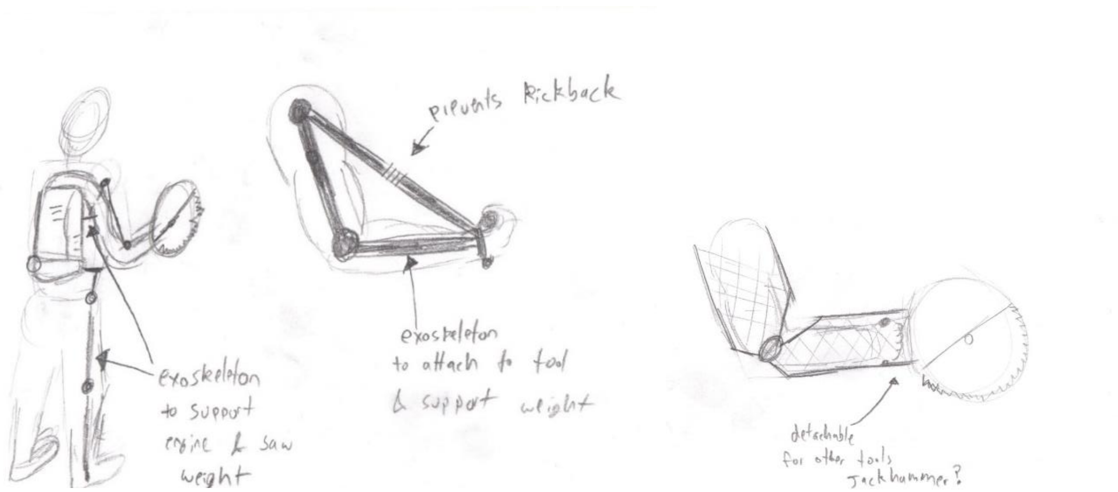


Figure 59. Kickback Protection
Idea

Prototyping

Overview

Ideation, sketching, and prototyping began based on the information collected from the first two studies, in addition to the contextual inquiry and focus group. A design thinking methodology was employed during the process. Design thinking "is human centered, requiring a thorough understanding of the needs, especially the emotional needs, of human users…[and] requiring a thorough understanding of the market, trends in usage, and technology…" (Hartson & Pyla, 2012). The three perspectives taken were ecological, interaction, and emotional. Ecological being the work in context, the interaction is the human-machine interface and how the user and system come together, and the emotional aspect ties in social and cultural implications aesthetics, and joy (Hartson & Pyla, 2012). Ideation was the core of the design process which is applied design thinking. Multiple sketching and small scale wood prototypes were used. To help with the process, subject matter experts were used, group ideation session, and constraints identified. A mixture of low-fidelity to high-fidelity ready for actual user testing were completed.

Dust Capturing Procedure

From the initial research, it seemed that many manufacturers attempt to capture the dust at the blade. When cutting, the dust flies backwards at a high velocity. Full design iterations show the progression of events. The initial design had a simple hood to capture dust right behind the blade which was ineffective. The next steps were to try and capture dust out of the groove. As the blade makes contact in the substrate, it will mark a groove in its path. The initial prototype had a slit in the bottom cut out which would sit directly on the cut. This design was attached to the saw with duct tape and when the dust collector was flush with the concrete, no visible dust was seen. This initial design was then chosen and the attachment mechanism ideation occurred.

Figure 60. Initial Dust Collector Design to Sit on Top of Groove

Figure 61. Initial Design Testing with No Visible Dust

Attachment Mechanism Initial

After the initial design was identified as the path forward, the attachment mechanism ideation occurred. First there were straps attached to the saw. During user testing, the dust collector was dragging too far behind the saw. The benefit of this system was it allowed full freedom of movement for the user. Next, to try to constrain the system, a sliding bolt and scissor lift designs were fashioned. These were meant to attach to the shroud of the saw at the top and have the bottom of the scissor lift anchored to the top of the dust collector. The researcher decided a scissor lift would be more stable and a metal prototype was created. After its creation, just looking at the mechanics of how it would attach, it seemed this would not be a worthwhile design to test. After looking at the scissor lift, this researcher decided it was important to understand the constraints of the system.

Figure 62. Strap Design

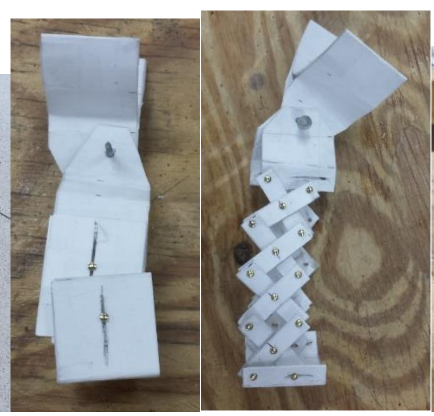


Figure 63. Sliding Bolt Design

Figure 64. Scissor Lift Design

Identifying Constraints

The researcher decided to constrain the system to better help the ideation process with the attachment mechanism. Some of these constraints were identified with the focus group such as making it detachable. The researcher had already decided not to use a dolly for the full use of the system as this limits maneuverability. From testing with the concrete, it is clear that concrete sticks to, and ultimately dry along any and all parts of the saw. Therefore, no moving parts were identified as a requirement to prevent concrete from forming. Finally, as the use of the dolly was already identified to not be used, the enabling of complex movements was identified to be important. The user's like the saw for its portability (G. A. Croteau et al., 2002). Therefore, allow user full range of motion they would have if there were no LEV attached, became a requirement. To better visually understand how the saw is used, the research developed Figure 65 below. Over the course of the rest of the design work, sketching and prototyping took place with help from subject matter experts and group ideations sessions mixed in.

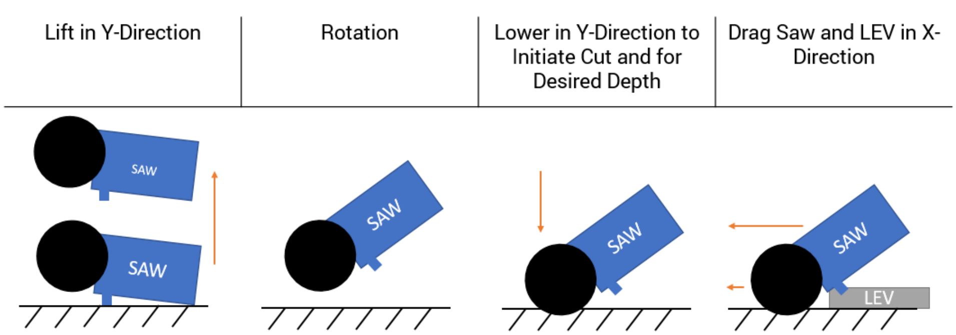


Figure 65: Motion of Saw and LEV

Sequential Order of Events: Subject Matter Experts, Group Ideation

After failed initial attempts with the attachment mechanism, the researcher scheduled a meeting with Brook Kennedy, an industrial design professor at Virginia Tech. During this ideation session, possible designs were a spring and slide, a telescoping feature, and weighing down the system. After this meeting, this researcher investigated different ways a spring could be used. Initial tests with the push springs indicated that they may be a viable option.

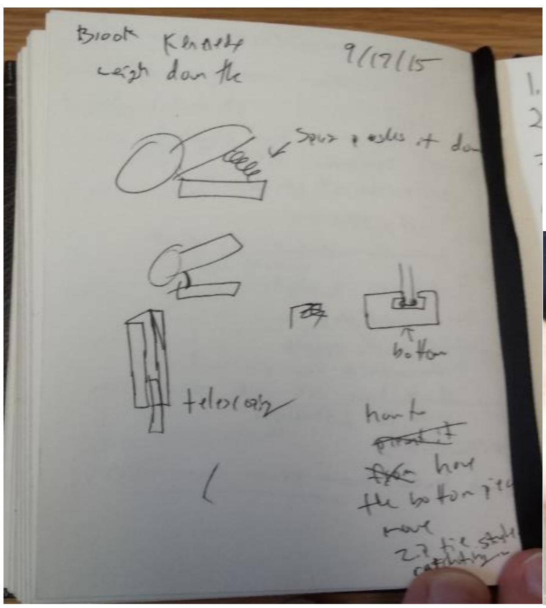


Figure 66. Industrial Design Professor Design Ideas 1

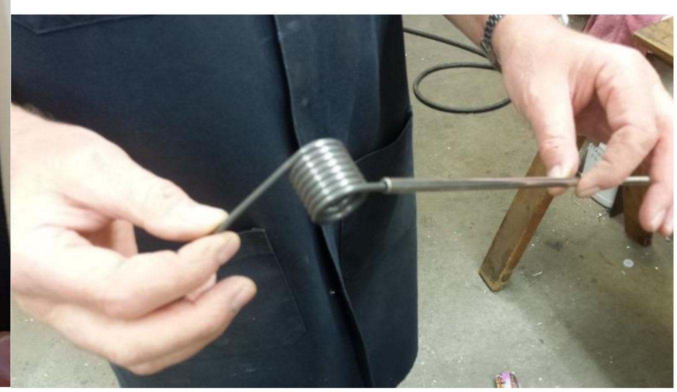


Figure 67. Push Spring with Sheath

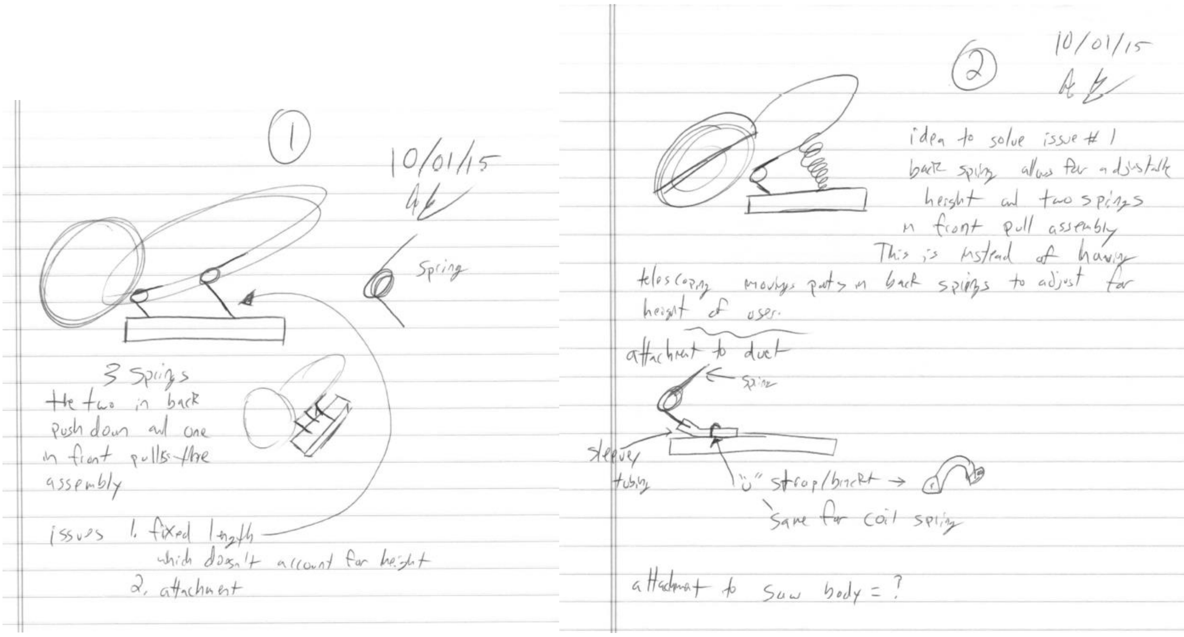


Figure 68. Spring Sketching

Figure 69. Triple Push Spring Design

Figure 70. Elastic Band Design

Figure 71. Gym Bench Design

A round of spring testing ensued to keep the back down. Aside from various push springs, ratcheting system like a gym bench and elastic bands were designed. None of these systems proved to enable user control.

Afterward, a group ideation session took place with members of Virginia Tech CEE 4064/5064 Design from Hazard control. Unique ideas verbalized were the use local positioning system to keep the LEV directly under the saw at all times, clamping machine and a ten wheels, and having the saw plunge directly into the LEV itself.

The design professor participated in a second round of ideation. A bellow-like system for starting a fire was offered. After prototyping the bellow, it would not stay in line. The researcher started to add guide arms to the bellow to keep moving smoothly with the saw. If guide arms are used, the bellow doesn't need to be used. One other possibility that came about during the same time was using a spring that was trapped so the system could move forward but also put downward pressure on the back of the saw.

This was not fruitful as there is very little downward pressure when the saw is lifted vertically.

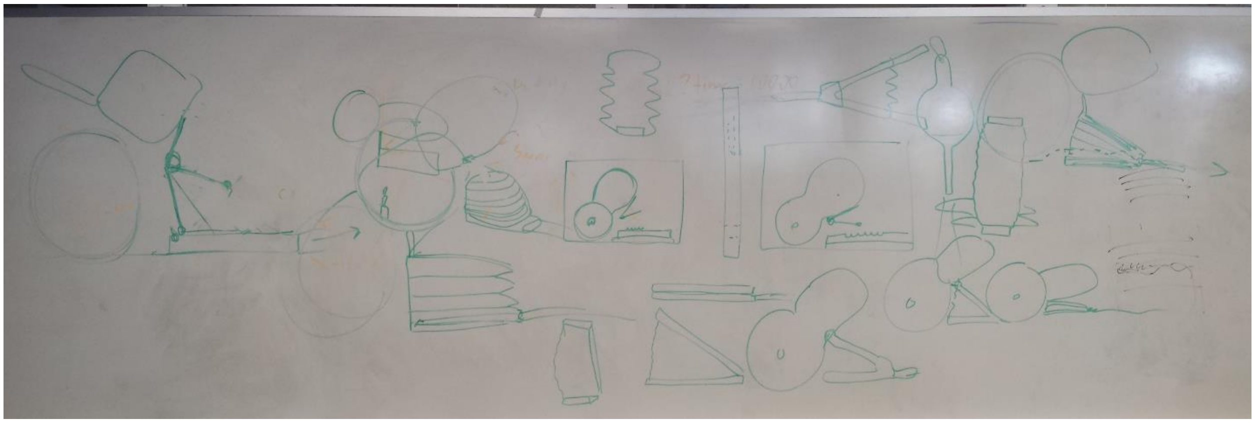


Figure 72. Industrial Design Professor Design Ideas 2

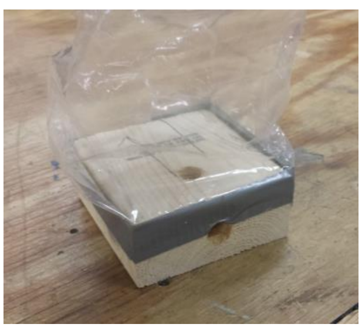


Figure 73. Bellow System Figure 74. Bellow with Guides Figure 75. Bellow System Twisting During Test

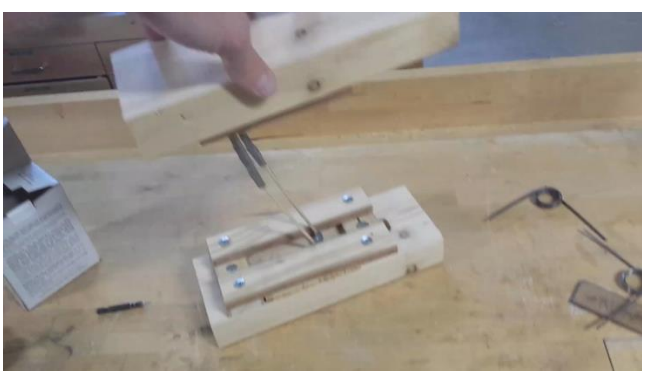


Figure 76. Trapped Spring

Figure 77. Wood Replica of Saw

Figure 78. Wooden Guide Arms

Figure 79. Guide Arm System Fit for Testing

The guide arm system was user tested. The system failed its test as the front lip would stay planted. There were more forces on the saw as the system was cutting concrete than tests on a smooth surface. The friction from the saw and the concrete translated into having the back of the LEV lift and pivot around the guide arm rods.

Figure 80. Guiding Rod Test With Back of LEV Lifting

Figure 81. Demonstration of the Physics

Next, this researcher met with the user, a machine shop specialist at Virginia Tech. Suggestions he had included using slippery material for a skid plate, three points of contact, and push and click lock like a tool chest or cabinet. Another SME with a man with a farming background took place and he suggested the use of pull springs.

More ideation occurred with the use of multiple variations of pull springs. Pull spring test determined they applied what appeared to be a large amount of downward pressure on the saw. The problem is the higher the saw is lifted, the less pressure the springs have on the downward force. This researcher created many variations of the guide arms and springs. The way to detach the arms was thought of and using a threated pipe were the end user could easily take the LEV system off from the saw was created.
A final design was made and during the user testing, the arms became too cumbersome and they did not create enough pressure to keep the LEV flat.

Figure 82. Triple Guides with Pull Springs 1

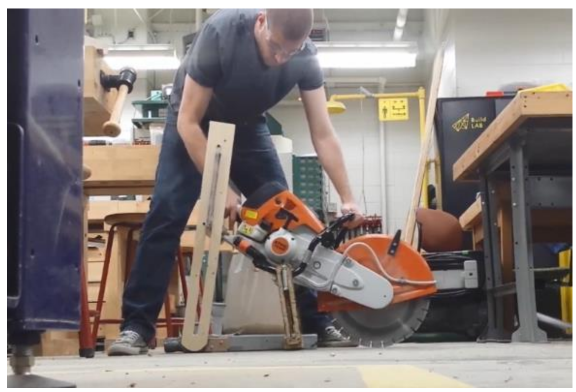


Figure 83. Triple Guides with Pull Springs 2

Figure 84. Triple Guides with Pull Springs 3

Figure 85. Triple Guides with Pull Springs 4

Figure 86. Detachment Mechanism

Figure 87. Multi-Arm Pull Spring Test

After the failed test, this researcher met with eight members of Virginia Tech's Civil Engineering Hands-on Construction Lab "Build Lab." Members of the Build Lab were used throughout the entire design cycle. This instantiation was a set meeting which also involved one professor, Dr. Goldsmith. After seeing what the researcher had been creating and presenting information which the students were not aware of already, the students started expressing possible ideas. The Build Lab ideas include a push like lawn mower (dolly), pneumatic system with a pivot point, a compression spring, a simple hinge, have the user manually move a pin to adjust for user height, have a pin that stays in the groove, have a scoop to redirect dust up into LEV, and putting a water tank on back to keep it weighed down.

The researcher tried to implement these suggestions but only found the water tank to be a viable option considering all the other design work that already took place, and instead two new ideas surfaced. One was a virtual pivot point, where the saw is not acting as a hinge at the end of the LEV. Instead, having rods out in front makes the LEV appear longer so the saw can pivot at a point where the blade is. The result was there would have to be a fixed depth the saw could cut which is problematic for use. The other idea was having a skid. This would allow the LEV to be longer and hopefully prevent the back from lifting off the concrete. The skid was placed vertically which would mean it would fall into grooves. Having a horizontal ski like a traditional snow ski was not prototyped but may have been a fruitful endeavor. Finally, modeling after the dolly system, the researcher added a wheel to the end of the ski. Unfortunately, having an arm with a wheel so close to the blade without the constraints that a dolly system affords are constraints in movement. By having a similar system but no constraints, it would cause a safety hazard.

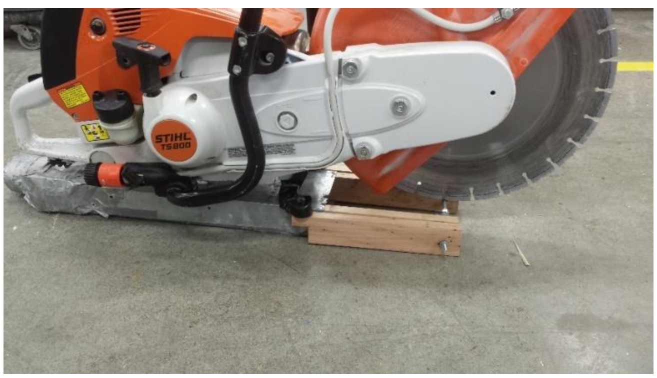


Figure 88. Virtual Pivot Point Design

Figure 89. Metal Ski Design Scratching Concrete

Figure 90. Metal Ski Design Falling into Cut

Figure 91. Ski with Wheel Design

Figure 92. Plastic Skid Plate

Figure 93. Ski with Wheel and Skid Plate

Figure 94. Final Design (Pull Springs not Pictured)

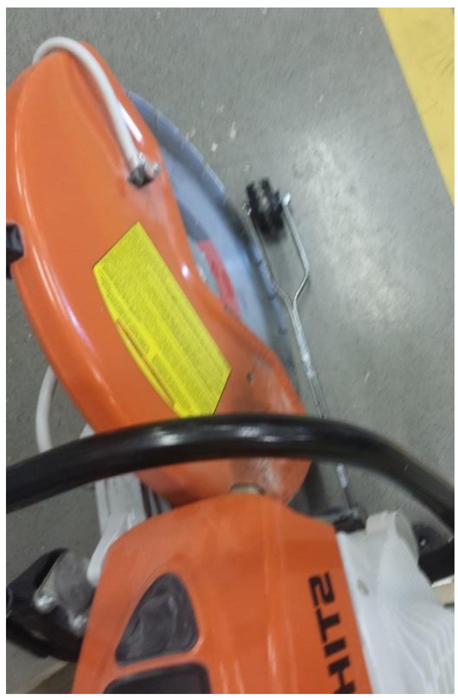


Figure 95. Final Design (Pull Springs not Pictured)

A final SME meeting with Bob Dickerson a mechanical engineer thought of a staple action and pneumatic system. Later he found a system similar to what the researcher was building.

Commercially Available Product

The Dust Cobra was found. This has a very similar dust capturing mechanism as the researcher had developed but the attachment mechanism is different. The Dust Cobra uses a simple hinge. This limits the vertical distance the user can raise the saw. One initial benefit of the open design on the bottom is a possible reduction in scratching. During prototyping and testing, it appeared the prototype LEV may scratch the finished concrete. The researcher decided to test the Dust Cobra in place of continuing to ideation, sketch, and prototype considering how many design iterations there were already. Due to resource constraints, a usability inspection and not a usability and dust level test was chosen.

Figure 96: Dust Cobra Attached to STIHL Saw Used in Usability Testing

Usability Testing

A heuristic evaluation (HE) was chosen as the usability testing for the Dust Cobra. HE is a qualitative method using a small group of evaluators to compare an interface to recognized design and usability principles, known as heuristics. In other words, it is applying the educated opinions of experts (Jeffries & Desurvire, 1992; Nielsen, 1994b). During a typical HE, the evaluators inspect the interface several times. It is recommended they do this at least twice, during which they focus on specific elements and compare them to the heuristics. It is possible for the research team to answer questions from the evaluators and to provide hints as needed. (Nielsen, 1994b; Nielsen & Mack, 1994).

Usability experts were recruited by the researcher. For a HE, Nielsen and Mack (1994) suggests 3-5 users. Possible participants were told about the study and sent a consent form two weeks ahead of time. On the day of the experiment, the researcher answered any question they may have and had them sign the form approved by the IRB.

Next, basic information on the participants was taken (Appendix F). Participants were told to bring corrective eyewear if needed. Height, weight, gender, hand dominance, expertise in usability, and expertise with the saw were self-reported. Kuczmarski, Kuczmarski, and Najjar (2001) showed self-reported height and weight could be used for those younger than 60 years old.

Eye dominance and head tilt interact with visual acuity. Eye dominance refers to which eye the user prefers to receive visual input from. The saw is not symmetrical and if one eye is dominant over the other, the way the operator uses the machine may be different. Eye dominance was tested in the manner of the procedure put forth by Greenberg (1960). Participants stood 10 feet away from a wall with a point drawn on it. Participants were given a pencil and told to hold it in their right hand, vertically, and in-line with the point on the wall. They were told to close their right eye and tell the researcher if the pencil stayed fixated on the point or if it jumped to the right. This was repeated four times. Next the participant was told to follow the same procedures but hold the pencil in their left hand and then told to close their left eye. The participants told the researcher if the pencil stayed in placed or shifted to the left. If the pencil was in the right hand and moved to the right when the right eye was closed, they were considered right eye dominant. If the pencil was in the left hand and moved to the left when the left eye was closed, they were recorded as left eye dominant. Head tilt can work synergistically with eye dominance and has been shown to highly correlate with eye dominance (G. Greenberg, 1960).

Head tilt was tested with similar procedures as eye dominance. The participant held the pencil vertical again and this time roughly 10 inches in front of his face. Two images of the pencil started to appear. The participant vocalize to the researcher which of the two images, if either, appear higher. Two trials were conducted. If the left image appeared higher on both trials a right head tilt was recorded. If on one of the trials the left image was higher and on the second trial both images were level, a right tendency was recorded. Likewise, if on both trials the right image was higher, a left head tilt is recorded. If on one trial the right image was higher but the second trial has both images level, a left tendency was scored. Ambiguous head tilt was recorded if one image was higher on one trial and the other side was higher on the other, or if in both trials the images are level. Results indicate if a user is right eye dominant, they have a left head tilt or left tendency, and vice versa. The reason head tilt is used is because the dominant eye is generally carried closer to the midline of the body.

They were told about the usage of the saw and how it was to be used and the researcher answered any question they may have had. A list of heuristics (Appendix E) was given to the participants. The list of heuristics was adapted from (Nielsen, 1995). The original list focuses on digital interfaces for its definitions. Therefore, definitions were updated by refining them with this researcher, two other human factors students, and using Muller, Matheson, Page, and Gallup (1998) definitions when appropriate.

Next the researcher gave the user a list of tasks. The user then assessed the saw individually, calling out issues to the researcher who recorded in real time and then having them list which heuristic the issue violated. Specifically, the user was able to move from one cut to the next to better understand how the movement worked. The participant also carried the saw for about 50 feet. Therefore, the researcher was able to understand the effects of carrying the saw. Though, the activity which was not tested is the movement from the saw in and out of a truck. Multiple heuristics could be violated for each usability problem identified. At the end, the participant answered emotional impact questions adapted from (Hartson & Pyla, 2012). Content analysis and inter-coder reliability was conducted on the open-ended response similar to Study 1 and 2.

Figure 97: HE testing (vacuum not shown)

There were a total of six usability experts used in the study, five of which were male. Cognitive walkthrough is another usability inspection method that evaluates a system. Though it is used to measure ease of learning by assessing the ease with which a user can perform a task with little or no coaching (Polson, Lewis, Rieman, & Wharton, 1992). The way to conduct a cognitive walkthrough can vary. A cognitive walkthrough can use individuals or groups. Cognitive walkthroughs are best done in groups because group dynamics can contribute to identifying problems (Smith-Jackson, 2005). In a group, the evaluators discuss the sequences that lead to the specific action sequence. Besides identifying more problems, a group walkthrough may be faster since all evaluators are evaluating at the same time. Sears (1997) showed that combining techniques can be effective, looking at the combination of heuristic walkthroughs, cognitive walkthroughs, usability walkthroughs, and ergonomic criteria. For instance, there exist a heuristic walkthrough. This researcher, possibly incorrectly, tried to combine the benefits of group cognitive walkthrough using a heuristic evaluation. Specifically, the first four participants were each tested separately, and the last two completed the heuristic evaluation as a pair.

There were a total of two double experts. Novices, single experts, or double experts can be used in a HE while end users are not used. Users are not used in heuristic evaluations because of their poor conceptual understating of usability (Nielsen, 1994a). A single expert is someone with usability expertise or domain expertise, while double experts have both usability and domain expertise (Nielsen, 1994b). In one study, novices, single experts, and double experts were able to find 22%, 41%, and 60% of the usability problems, respectively (Nielsen, 1992). Therefore, using double experts is best.

Table 45

HE Evaluator Participant Data

	Height	Weight (lbs.)	Gender	Hand-dominance	Eye Dominance	Head tilt	Double expert
Participant 1	5'10"	153	Male	Right	Right	Ambiguous	No
Participant 2	6'0"	158	Male	Right	Ambiguous	Left	No
Participant 3	5'3"	140	Female	Ambidextrous (Right hand gross, left hand precision)	Right	Ambiguous	No
Participant 4	6'5"	275	Male	Ambidextrous (natural left, trained at young age to be right)	Right (imposed from shooting guns)	Ambiguous	Yes
Participant 5	6'0"	189	Male	Right	Left	Ambiguous	Yes
Participant 6	6'1"	185	Male	Right	Right	Left Tendency	No

After all participants were finished, the researcher compiled all usability problems and sent them to the participants to record severity scores (Appendix G and H). Severity is a combination of, “frequency with which the problem occurs, impact of the problem if it occurs, and persistence of the problem” Severity scores are important because the can be used to use the most amount of resources on the most serious problems. They answered on a five point Likert scale, 0=I don’t agree that this is a usability problem at all, 4=usability catastrophe-imperative to fix this before product can be released (Nielsen & Mack, 1994).

Design Taxonomy

The design taxonomy was created by first looking at all the usability problems identified during the HE. These were then translated into design guidelines. The goal of the research is to generalize to the greater handheld power equipment such as the chain saw, gasoline powered jackhammer, and gasoline powered auger.

Results from the heuristic evaluation were used as the basis of the design taxonomy. The process closely follows that of Capra (2005). The usability problems were used as components to be sorted using open card sort. Open card sort was chosen to group the usability problems into categories. Unlike Study 1 and 2 where close card sort was implemented, open card sort has the participants organize the content and then name the group themselves (U.S. Department of Health and Human Services, 2016). This was beneficial as more labels could be attached to the responses. A total of 15 participants were recruited for the card sort based on Nielsen (2004) recommendations.

Participants recruited were either design professionals or human factors and ergonomics graduate students at Virginia Tech. Response categories were then assembled into an asymmetrical binary matrix where a “1” was marked each time a data problem was identified as being part of a specific category. The variables are asymmetrical because being in one category does not exclude it from being in another category (Kaufman & Rousseeuw, 2009) . For instance, if one of the participants created a hierarchy with his or her categories, a “1” would be marked for the child category as well as the parent category. Jaccard’s Coefficient of Community was used to measure the similarity of the binary variables (Jaccard, 1912). Jaccard’s scoring was calculated using equation 2.

$$J = \frac{C}{A+B+C} \qquad (2)$$

Where A =number of attributes present in the operational taxonomic unit a

B= number of attributes present in the operational taxonomic unit b

C = number of attributes present in both operational taxonomic units a and b

(Real, 1999)

A visual example of Jaccard scoring can be seen below. This example is measuring the similarity between usability problems #1 and #2 across seven categories. The appropriate J Score= 1/6, where D is the number of times both Usability Problem #1 and Usability Problem #2 have a “0.”

Table 46

Example Jaccard Score Calculation

	Categories with usability Problem #2	Categories without Usability Problem #2
Categories with Usability Problem #1	C=1	A=3
Categories without Usability Problem #1	B=2	D=1

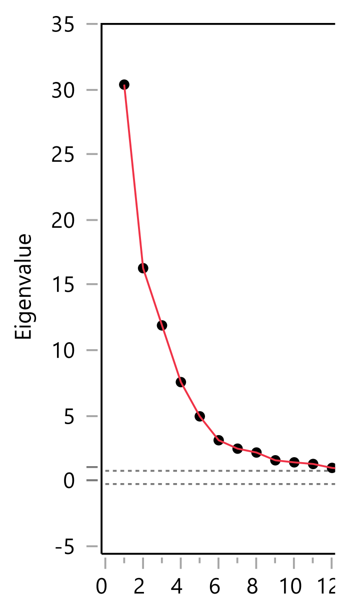


Figure 98. Scree plot

Next, the number of factors had to be determined before conducting factor analysis. Cattell (1966) says there is no true number of factors. Therefore, multiple methods were employed to give a reasonable estimation for the number of factors. Kaiser's stopping rule was first employed by looking at the number of components with an Eigenvalue of 1.0 or greater (Kaiser, 1960). Eigenvalues represent variance (Tabachnick & Fidell, 2007). From this initial judgement, we see that 13 components have at least a 1.0 or greater eigenvalue. Though, when there are a lot of variables, this can result in the overestimation in the number of factors (Fachel, 1986; Song & Belin, 2008). Tabachnick and Fidell (2007) says if the number of variables is 40 or fewer or the sample size is large enough, using Kaiser's method is "probably about right" but in other situations it will likely overestimate the number of factors. Next a scree plot was examined. A scree plot gives a visualization between eigenvalues and number of factors. One should look at where the line starts to level out/change slope, ignoring all the factors to the right of the plot including the transitional factor (Tabachnick & Fidell, 2007). Examining the scree plot in Figure 98 would indicate a five factor solution. From these two tests, it was determined that the number of factors most likely lies between five and 13.

Next this researcher determined the loading cut off value. Comrey and Lee (2013) says loadings of 0.71 or higher is excellent, 0.63 is very good. 0.55 is good, 0.45 is fair, and 0.32 is poor. Tabachnick and Fidell (2007) says the choice for cutoff is a matter of researcher preference. Therefore, 0.45 was chosen based on Comrey and Lee (2013). Finally, trivial factors were determined to come to the final conclusion on number of factors. Gorsuch (1983) defines trivial factors as, "all factors that do not have at least two or three loadings above a certain specified level." A factor analysis was run for each factor between 5 factors and 13 factors. A final set of nine factors was chosen as Factor 10 only loaded one component at 0.45 or above. Finally, factors were rotated to make the interpretation comprehensible and varimax rotation was chosen based on D. E. Johnson (1998) recommendations.

After the number of factors was determined, the PI named the factors. Next, Jaccard scoring was used to calculate the similarities between the factor and the category names provided by the participants. Measurements were taken between the similarity of a factor and each of the 81 categories. Jaccard Scores were multiplied by 100 and only category names with a value of 30 or over were considered (Capra, 2005).

Finally, the researcher interpreted the factors. The first sentence is a summary of the factor, including a mixture of the PI assigned category name and the most strongly associate categories with that factor. The remainder of the summary reflects the usability problems that loaded on that factor (Capra, 2005).

Results

Local Exhaust Ventilation Add-on System Requirements

Table 47

Requirements from WAAD

1. If the add-on system uses hoses, it must adjust to fit ≥1” hose diameters
2. Add-on system needs to still function even if shroud cover is adjusted
3. Add-on system must work with all major models and sizes
4. Add-on system must be as durable as the saws
5. Add-on system must be removable
6. Add-on system must be cleaned easily

Heuristic Evaluation

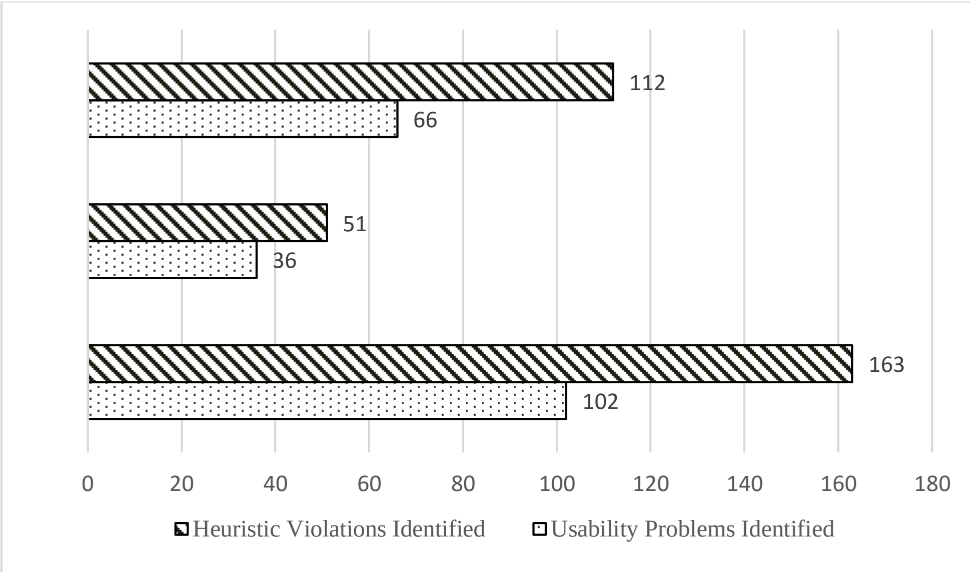


Figure 99: Number of Heuristic Violations and Usability Problems Identified

Some participants identified more than one heuristic that was violated per usability problem. Reflected in Figure 99, there were a total of 164 heuristic violations for 103 usability problems identified. Users identified problems for the saw by itself and for the saw and the dust collector as a system. More problems were identified for the saw and the dust collector as a system than for the saw itself, with 66 and 37 usability problems, respectively.

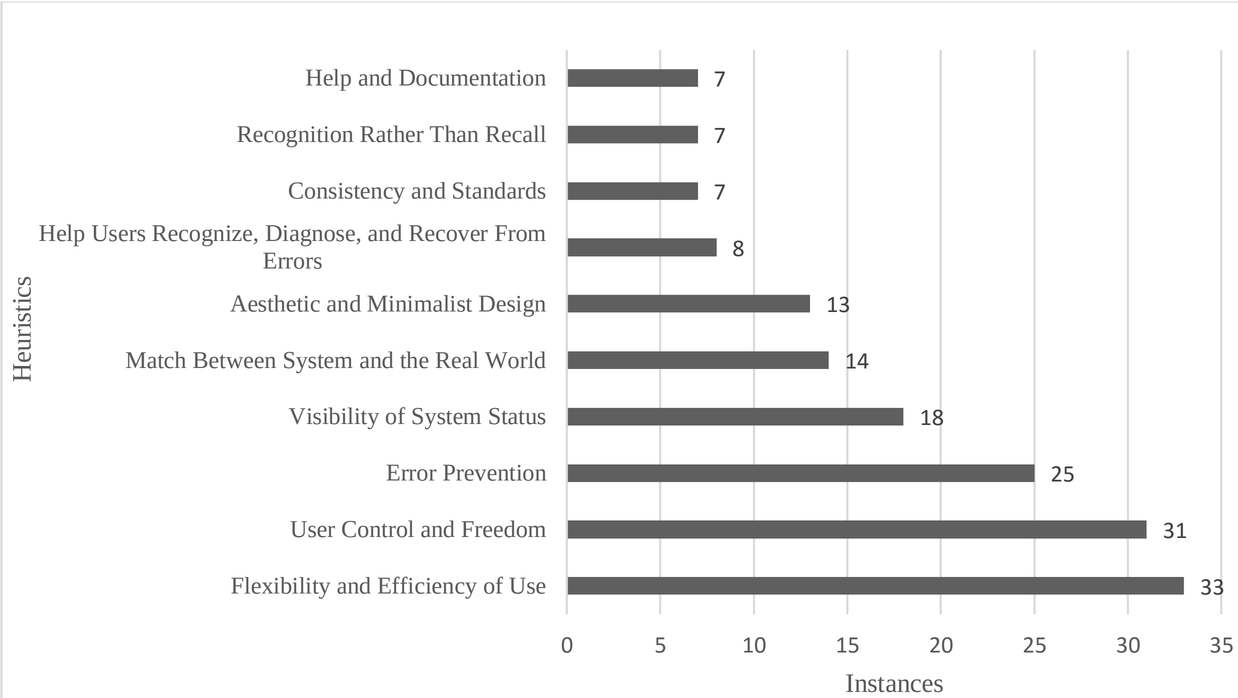


Figure 100. Rate of Heuristic Violations. For the total of 164 heuristic violations identified, the top three heuristics violated were flexibility and efficient of use, user control and freedom, and error prevention.

Table 48

Most Pressing Usability Issues Based on Average Severity Score

Usability Issue Number	**Usability Issues**	**Averaged Participant Scores**	**(Factor Number, J Score)**
10	There is back strain from using the system	3.33	(7,38)
44	The hinge makes the saw on the front sit higher, causing the blade to want to tilt forward	3.17	(7,36)
9	The user has to squat deeply to prevent the saw from putting pressure on his or her back	3.00	(5,33)
13	The wheels force the user to place his or her foot closer to the blade	3.00	(8,63)
30	To carry the system, the user has to take his or her back hand off the saw and put it on the dust collector to move the entire system together.	3.00	(5,70)
66	The user would want to turn off the saw to move to next cut but this is not practical for how long it takes to start the engine	3.00	(8,66)

All answers were 0- I don't agree that this is a usability problem at all and 4= Usability catastrophe, imperative to fix this before product can be released. Averaged over six participants. All problems identified that have a score of 3 or higher related to the saw and the dust collector as a system.

These top six usability issues can be broken into three of the nine categories in the taxonomy. They are evenly split between Factors/Design Guidelines 5, 7, 8. These are: ensure the saw is efficient in its design to reduce dangers posed by safety concerns, ensure the characteristics of the tool do not overexpose users to dangers associated with the tool, and ensure ease of movement.

<u>Emotional impact</u>

Table 49

Is Usage Fun Responses

<u>Response</u>
1) No, because it interrupts work flow (checking gasoline, connecting a gas powered saw to an electrical outlet, when lifting if it doesn't get a seal dust will go everywhere)
2) Seems like it can be
3) Unsure
4) No its cumbersome

Table 50

Is Usage Fun Frequencies

Response Code/Category	**Frequency**
No	2
Unsure	2

α = 1.0

Table 51

Is the visual design attractive and creative (colors, shapes, layouts)? Responses

Response
1) Yes, it has bright colors so it is easy to see even if there is dust 2) The color is good for safety 3) The shape is minimalist and easy to use 4) It has a great center of gravity 5) No, the symbols on the saw itself are confusing 6) I have concerns with attaching the equipment 7) The dust collector is easy to use and plug the hose in 8) There is too much going on visually with the saw itself, too many stickers and fine print 9) The dust collector is not the same shade of orange as the saw which is bothersome 10) It looks too big and bulky 11) Yes, but no real opinion

Table 52

Is the visual design attractive and creative (colors, shapes, layouts)? Frequencies

Response Code/Category	**Frequency**
Consistency Issues	5
Increased Safety	1
Minimalist	1
Not Minimalist	1
Balanced	1
Unsure	1

$\alpha = 0.85$

Table 53

Will the design delight the user visually, aurally, or tactilely? Responses

Response
1) Visually it is appealing 2) Pleasantly surprised by the feel as I though the plastic would shriek across the floor 3) No one enjoys saw sounds so probably not 4) Visually it is solid and minimalist and they may enjoy using it 5) With the vacuum it may add to the total noise which will be bothersome 6) Powered equipment and “delightful” are not words that match in my mind 7) Because of the weight, I couldn’t imagine using this for eight hours a day

Table 54

Will the design delight the user visually, aurally, or tactilely? Frequencies

Response Code/Category	**Frequency**
Visually Appealing	2
Noise Concern	2
Tactilely Appealing	1
Weight Concerns	1
Unsure	1

α = 1.0

Table 55

Does the product feel robust and good to hold? Responses

Response
1) Yes 2) Yes 3) Yes 4) yes

Table 56

Does the product feel robust and good to hold? Frequencies

Response Code/Category	**Frequency**
Yes	1

α = 1.0

Table 57

Can the product add to the user's self-esteem? Responses

Response
1) Yes, knowing that the product supports the weight of the saw 2) Yes, imagining seeing the dust go into the vacuum would make me feel the air is being cleaned as I work 3) Yes, because I don't have to carry the weight of the saw 4) Someone will probably be embarrassed to drag around on a construction site because of "tough man" syndrome

Table 58

Can the product add to the user's self-esteem? Frequencies

Response Code/Category	Frequency
Physical Benefits	2
Health Benefits	1
No	1

α = 1.0

Table 59

Are there opportunities to improve the emotional impact in any of the aforementioned areas? Responses

Response
1) Yes, improve the ease of lifting the saw 2) Add more adjustability 3) Reduce the weight of the saw 4) Simplify the process of attachment 5) Have stronger wheels 6) Have it look more robust 7) Yes, make it less cumbersome to move 8) Make the entire design smaller

Table 60

Are there opportunities to improve the emotional impact in any of the aforementioned areas? Frequencies

Response Code/Category	**Frequency**
Durability	2
Minimalist	2
Weight	1
Adjustability	1
Simplification	1

α = 0.85

Factor Loading

The output of the factor analysis shows loadings which are scores for how strongly associated the issue number was with the factor. Additionally, we can generate Jaccard scores for how similar two categories are with each other. In this case, the participant supplied categories and the factor number are compared to determine the Jaccard scores.

Factor interpretation uses these two results to name the final category name for the design taxonomy and to create the summary. Firstly, the category name is derived by comparing and combing the researcher's supplied name for the factor and looking at the participant supplied categories with the highest Jaccard Score. Secondly, the researcher based the summary off the usability issues with the highest factor loadings.

Table *61*

Factor 1 Loading "Symbols/Iconography"

Issue Number	Usability Issue	Factor 1 Loading
92	The symbol on the primer is confusing	97
85	The symbols on the gas cap are confusing	96
98	There is no indication of where the air filer is	96
78	The choke looks like the on/off button	96
90	The symbols on the pull release indicate it is for the pull chain but the placement is not intuitive	96
88	The symbols on the pull release don't indicate its purpose	95
91	The icons on the pull release may be too simplified which can inadvertently overcomplicate instructions	95
76	The 0 and 1 are not clear on the on/off button	94
89	The symbols on the pull release are hard to see	93
86	The gas cap doesn't list that mixed gasoline is required	92
80	There is no fuel level indicator	90
87	The sticker for the instructions of how to use the gas cap is not easily seen from other side	90
74	It is hard to find the on/off button	90
93	Not all safety symbols on the back are clear	89
84	Not knowing how much gas is in the saw doesn't allow the user to properly plan out how much fuel to put in it to accomplish the number of cuts the user needs to make	83
75	The only indication the saw is on is from the blade spinning and the noise	80
37	There is no feedback as to if the dust collector is flush on the ground	79
79	A user unfamiliar with equipment like this may question why there are three stages to a choke	78
81	The user has to open cap to look and see if there is fuel in it, or smell it, or shake the saw around	77
26	There is no instruction for the best way to move the saw system	71
45	The hinge bolt doesn't feel locked in	54

Table *62*

Factor 1 Participant-Supplied Category Jaccard Index

Participant-Supplied Category Name	**Score (J*100)**
Efficiency in design	100.0
Symbols and signals feedback	100.0
Information	95.2
Inconvenient	95.2
System Status	90.5
User/Saw Interface	90.5
Indicators symbolism	90.5
UI issues	90.5
Lack of clear instruction	85.7
Visual Indicators	85.7
Design issues	85.7
System Constraints	66.7
Difficulty/Ease of Use	52.4
Usability issues	47.6
Information Provider	38.1
Gas info	33.3

Design Guideline 1

Have clear symbols and efficiently provide information and feedback. Make sure symbols are clear. Ensure one feature cannot be confused for another. Have clear indication of where a feature is located. Make it clear what the purpose of a feature is. Indicate the status of the system.

Table 63

Factor 2 Loading "Positioning/Clearance"

Issue Number	Usability Issue	Factor 2 Loading
27	Only the orange rubber part of the dust collector touches the ground	91
20	The handle on the back of the saw hits the vacuum attachment on the dust collector	87
18	When removing the saw from the dust collector, the adapter to fit the hose diameter to the dust collector comes out	81
17	The dust collector sits directly under the saw but the blade is not centered on the saw itself	80
100	The user has to position the shroud before turning on the saw	79
96	The saw creates a lot of mess	74
19	There is no resting point for the back of the saw while on the dust collector	70
32	The rubber of the dust collector will get destroyed on rough surfaces, reducing its suction power especially when then moving from a rough surface to a smooth surface	68
64	The user has to remove the dust collector to refill it with fuel	68
33	The user can't just get to cutting, the user has to position the dust collector in the right spot first	67
16	The wheels do not turn well and the back right wheel doesn't work at all	65
101	Having the engine exhaust out the front can be issue with trying to capture the dust	65
25	The system moves slowly	64
82	There is not enough space for the user's hand to reach the gas cap	64
31	The user is effectively dragging the rubber instead of actually having the wheels carry the weight	61
24	It is hard to align the blade with the cut line until the blade is almost touching the ground	57
29	The wheels only go in one direction, so the user will be hesitant to move the entire system laterally to the next cut	56
63	The user has to empty the gasoline before removing the hinge attachment #1 for the saw	54
40	It takes a long time to screw in the hinge bolts	49
50	There is not place to store the hinge bolts when not in use	46
2	If the dust collector is not working, the user will have to stop intermediately to clean dust off him or herself because dust is hindering work flow	45

Table *64*

Factor 2 Participant-Supplied Category Jaccard Index

Participant-Supplied Category Name	Score (J*100)
Functions of the saw/characteristics	100.0
Efficiency in design	100.0
Inconvenient	95.2
Physical Problems/danger of saw and dust collector	85.7
Inconveniences	66.7
Usability issues	66.7
Time	61.9
Complications from dust collector	57.1
Design issues	57.1
Minor Inconveniences	57.1
Productivity	47.6
Hazards/Discomforts	42.9
Design issues x	42.9
System Constraints	38.1
Ease of Use	33.3

Design Guideline 2

The design should be functional so use is efficient and convenient. Ensure pieces which enable movement can move freely. No pieces of the tool should occlude the positioning and clearance of other parts. User should be able to easily and intuitively make adjustments to the system without deviating from their current workflow.

Table 65

Factor 3 Loading "Attachment Mechanism Feedback"

Issue Number	Usability Issue	Factor 3 Loading
39	The user does not know how far or tight the hinge bolts have to be	87
53	The hinge bolts look too long to screw in and the user may not know if they are screwing them in far enough	86
47	There is no way to know if the user is putting the bolts on backwards	80
55	There is no way to know if the hinge bolts are installed properly	73
45	The hinge bolt doesn't feel locked in	63
42	The user feels both bolts need to be in all the way to make sure the hinge doesn't break	63
52	The user doesn't have good visibility for lining up the hinge bolts	51
83	The way to unscrew the gas cap is not intuitive and it is difficult to unscrew	50

Table 66

Factor 3 Participant-Supplied Category Jaccard Index

Participant-Supplied Category Name	Score (J*100)
Ease of Use	100
Functions of the saw/characteristics	100
User/Saw Interface	100
Inconvenient	100
Attachment bolts	87.5
System Status	87.5
Efficiency in design	87.5
Dust Collector Status	75
Symbols and signals feedback	75
Ease of Operation	75
Information Provider	62.5
User inconveniences	62.5
UI issues	62.5
Hinge bolts	62.5
Feedback	50
Knowledge of system problems	50
Design issues	50
Hinge bolts install	50
Usability issues	37.5
Unnecessary actions the tool requires the user to unintentionally do	37.5

Design Guideline 3

Provide system status updates when attaching add-on systems. Provide feedback on how tight attachment mechanisms should be. Make screws and bolts the correct size. Provide feedback on how far to tighten bolts. Make it clear if the mechanism is attached correctly.

Table 67

Factor 4 Loading "Ease of Attaching Add-on Mechanism"

Issue Number	Usability Issue	Factor 4 Loading
38	It is difficult to put the hinge bolts in	90
43	After removing one hinge bolt, it is harder to remove the second bolt	86
48	It is hard to attach the black bolts for the hinge receiver #2	85
41	the user has to tilt the saw back and forth to take the weight off the hinge to be able to screw in the hinge bolts	82
56	To reduce pinching, the user has to start one bolt then another instead of tightening one all the way	81
57	The user has to tilt the saw forward when attaching the hinge bolts to prevent it from pinching	77
46	The user does not get any traction with the hinge bolts	76
52	The user doesn't have good visibility for lining up the hinge bolts	66
60	Tempted to lean the saw over to attach the hinge receiver #2	65
49	With the bolt receiver #1 attached to the saw, the saw is harder to pick up	62
21	It is difficult to drag the saw forward	60
63	The user has to empty the gasoline before removing the hinge attachment #1 for the saw	52
36	The back of saw does not attach to back of dust collector prohibiting the user from carrying the system effectively	50
40	It takes a long time to screw in the hinge bolts	50
35	When cutting, the dust collector hits the lip of uneven concrete and the user has to lift the entire system vertically to get it onto the higher elevation concrete	48
51	Before attaching the hinge bolts, it is hard for the saw to sit on the dust collector without slipping off	48
54	Even with small hands, the user hits his or her knuckles on the wheel while screwing in the hinge bolt	45

Table 68

Factor 4 Participant-Supplied Category Jaccard Index

Participant-Supplied Category Name	Score (J*100)
Functions of the saw/characteristics	100.0
Ease of Use	94.1
Inconvenient	94.1
Usability issues	88.2
Hazards/Discomforts	76.5
Ease of Operation	76.5
User task	70.6
Hinge bolts	70.6
Ergo/usability concerns	64.7
User inconveniences	58.8
Attachment bolts	52.9
Attachment Mechanisms	52.9
Hinge bolts install	52.9
Difficulty/Ease of Use	47.1
Physical Problems/danger of saw and dust collector	47.1
Physical exertions	41.2
Dexterity	35.3
Efficiency in design	35.3
Design issues x	35.3

Design Guideline 4

Make the process of attaching add-on systems easy. When attaching one part of the system, don't make the other parts harder to attach. Reduce pinching of the system on itself. Do not make the user support the weight of the system when attaching. Provide good visibility during the process of attaching the mechanism.

Table 69

Factor 5 Loading "Critical System Safety"

Issue Number	Usability Issue	Factor 5 Loading
102	As there is no water to cool the blade, there is a concern for the blade overheating, cracking, and getting concrete stuck to it	89
94	The exhaust is getting the shroud hot which introduces heat to the blade	88
59	Concerned saw is hot and gas will leak if want to unbolt the hinge receiver #2 after use	87
61	When there is gas in the saw, dangerous as have to tilt saw over to attach the dust collector	84
15	The dust collector does not support all the weight of the saw	73
44	The hinge makes the saw on the front sit higher, causing the blade to want to tilt forward	70
58	For attaching hinge receiver #2, the user doesn't know if it would be safe to turn the saw upside down effectively making it a two person operation	60
62	When try to flip the on/off switch, need to have hand on the front handle otherwise the blade tilts forward to the ground	54

Table 70

Factor 5 Participant-Supplied Category Jaccard Index

Participant-Supplied Category Name	Score (J*100)
Tool Characteristics	100
Safety	100
Physical Problems/danger of saw and dust collector	100
Functions of the saw/characteristics	100
Efficiency in design	100
Danger	100
Dangerous	87.5
Design issues x	75
System Constraints	75
Technical issues	62.5
Hazards	50
Attachment Mechanisms	50
Possible concerns	50
Complications from dust collector	37.5
Effectiveness	37.5
Safety	37.5
Information	37.5

Design Guideline 5

Ensure the saw is efficient in its design to reduce dangers posed by safety concerns. Make sure the integrity of the part making contact with the material is always intact. Do not introduce unnecessary heat to the system. Make sure all gas is contained and cannot spill out of the system. Do not allow the system to be unsupported when the user is doing another action.

Table 71

Factor 6 Loading "Visibility During Workflow"

Issue Number	Usability Issue	Factor 6 Loading
12	It is difficult to see the cut line with the saw is attached to the dust collector	82
99	The user tends to look to the far side of the blade to see where cutting is taking place and on the right side of the saw, there is an arm which occludes vision	79
23	If the dust collector lifts off the ground, the user won't be able to see the cuts he or she is making	78
73	The user has to lean over the side to see the saw cutting	71
2	If the dust collector is not working, the user will have to stop intermediately to clean dust off him or herself because dust is hindering work flow	48
24	It is hard to align the blade with the cut line until the blade is almost touching the ground	45

Table 72

Factor 6 Participant-Supplied Category Jaccard Index

Participant-Supplied Category Name	**Score (J*100)**
Inconveniences	100.0
Functions of the saw/characteristics	100.0
Complications from dust collector	100.0
Alignment/cutting	83.3
Information Provider	83.3
Hazards/Discomforts	83.3
Design issues x	83.3
Danger	83.3
Visibility	66.7
Mission Critical problems	66.7
Efficiency in design	66.7
Ergo/usability concerns	66.7
System Status	50.0
User inconveniences	50.0
Productivity	50.0
Difficulty/Ease of Use	33.3
User task	33.3
Design issues	33.3
Major inconveniences	33.3
Minor Inconveniences	33.3
Information	33.3
System Constraints	33.3

Design Guideline 6

Make sure all necessary parts of the tool are visible to the user. Give the user full visibility of the tool while it is in action. Parts of the tool cannot occlude the user's vision. Make sure the system does not interfere with the user's visibility or natural movements.

Table 73

Factor 7 Loading "Safety Issues from Saw Characteristics"

Issue Number	Usability Issue	Factor 7 Loading
95	The saw is loud	63
62	When try to flip the on/off switch, need to have hand on the front handle otherwise the blade tilts forward to the ground	51
58	For attaching hinge receiver #2, the user doesn't know if it would be safe to turn the saw upside down effectively making it a two person operation	47
67	The saw is heavy	45

Table 74

Factor 7 Participant-Supplied Category Jaccard Index

Participant-Supplied Category Name	Score (J*100)
Tool Characteristics	100
Safety	100
Functions of the saw/characteristics	100
Danger	100
System Constraints	100
Usability issues	80
Design issues x	80
Hazards/Discomforts	60
User/saw interaction/movement	60
Efficiency in design	60
User inconveniences	60
Dangerous	60
Inconveniences	40
Misc. Inconveniences	40
Ease of Use	40
Physical Problems/danger of saw and dust collector	40
User task	40
Reasons and user wouldn't want to purchase	40
annoyances	40
Unnecessary actions the tool requires the user to unintentionally do	40
UI issues	40
Minor Inconveniences	40

Design Guideline 7

Ensure the characteristics of the tool do not overexpose users to dangers associated with the tool. Reduce noise hazards. Ensure the system is stable without user intervention. Make all attachment movements safe. Reduce weight of the tool

Table 75

Factor 8 Loading "Movement of System"

Issue Number	Usability Issue	Factor 8 Loading
66	The user would want to turn off the saw to move to next cut for safety reasons but this is not practical for how long it takes to start the engine	66
30	To carry the system, the user has to take his or her back hand off the saw and put it on the dust collector to move the entire system together.	63
29	The wheels only go in one direction, so the user will be hesitant to move the entire system laterally to the next cut	50
28	The user will have to learn to move the saw and the dust collector together rather than it being intuitive	45

Table 76

Factor 8 Participant-Supplied Category Jaccard Index

Participant-Supplied Category Name	Score (J * 100)
Ease of Use	100
Ease of movement	100
Functions of the saw/characteristics	100
User/saw interaction/movement	100
Efficiency in design	100
Usability issues	75
User inconveniences	75
Dangerous	75
Difficulty/Ease of Use	50
Time	50
Physical Problems/danger of saw and dust collector	50
Hazards/Discomforts	50
Symbols and signals feedback	50
Unnecessary actions the tool requires the user to unintentionally do	50
Unnecessary steps	50
Inconvenient	50
Danger	50
Productivity	50
Ease of Operation	50

Design Guideline 8

Ensure ease of movement. Allow tool to be easily turned on and off when moving between areas. Make the entire system move as one piece. Allow freedom of movement in as many directions to enable natural and intuitive movement during workflow. Make movement intuitive.

Table 77

Factor 9 Loading "Difficulty Associated with Use"

Issue Number	Usability Issue	Factor 9 Loading
70	The saw is not set up for right-handed and left-handed users	67
36	The back of saw does not attach to back of dust collector prohibiting the user from carrying the system effectively	66
54	Even with small hands, the user hits his or her knuckles on the wheel while screwing in the hinge bolt	58
72	Because system forces some users to stand to turn on the saw, it is not designed for right-handed people to pull start it	47

Table 78

Factor 9 Participant-Supplied Category Jaccard Index

Participant-Supplied Category Name	Score (J*100)
Ease of Use	100
Physical Problems/danger of saw and dust collector	100
User/saw interaction/movement	100
Usability issues	100
User task	100
Dexterity	100
Reasons and user wouldn't want to purchase	100
Ergo/usability concerns	75
UI issues	75
Inconvenient	75
Ease of Operation	75
System Constraints	75
Handedness	50
Flexibility of Use	50
User's positions	50
Functions of the saw/characteristics	50

Design Guideline 9

Make properties of the system accessible for all user sizes. Make system for both right, left, and ambidextrous users. Allow the user to complete tasks easily. Ensure clearances for various sizes of hands. Both right and left handed users should be able to turn on the system easily.

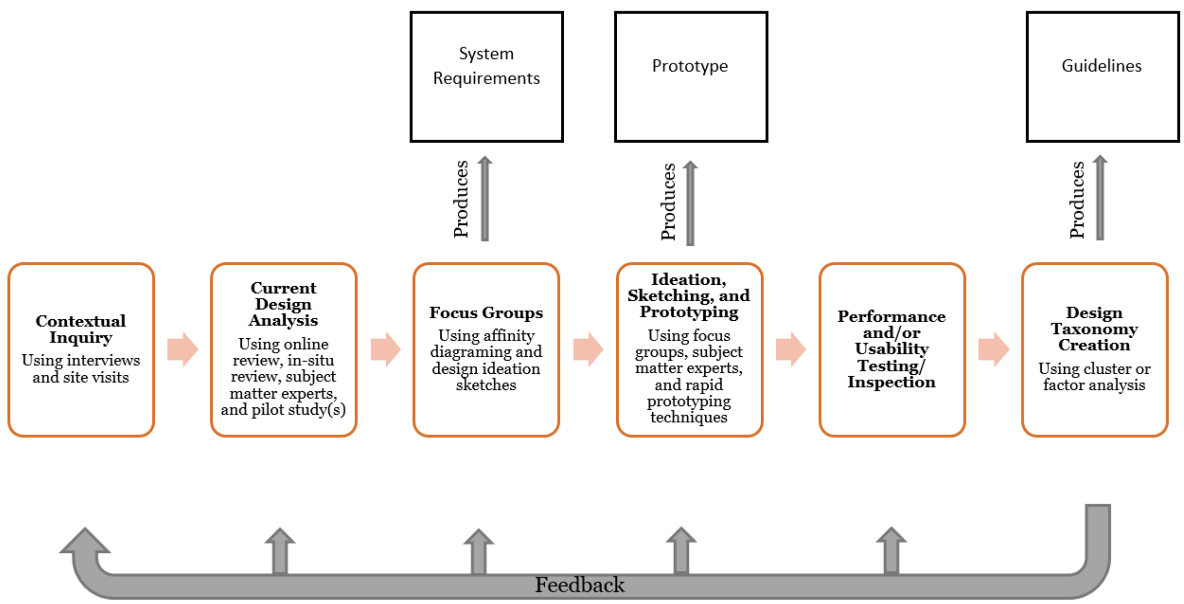


Figure 101. Process for Designing and Evaluating Handheld Tools. Where at any point in the design process one can revisit previous steps based on feedback.

Table 79

Study 3 Summary of Findings

1. LEV Design Process Steps • Contextual Inquiry • Subject Matter Experts • Current design analysis • Pilot testing • Focus groups and WAAD for design requirements • Develop system constraints

- Ideate, sketch, prototype, and test: an iterative process revisiting any previous steps along the way

2. **Constraints identified ahead of time**
    - Do not use dolly system
    - No moving parts
    - Allow user full range of motion they would have if there were no LEV attached
3. **Pilot Testing Results**
    - Durability
    - Maneuverability
    - Visibility
    - The Saw Muzzle GP moving is distracting and may be dangerous
    - Redirection of dust upwards may be ineffective.
4. **Requirements for add-on vacuum based systems for the handheld cut-off saw**
    - If the add-on system uses hoses, it must adjust to fit ≥1" hose diameters
    - Add-on system needs to still function even if shroud cover is adjusted
    - Add-on system must work with all major models and sizes
    - Add-on system must be as durable as the saws
    - Add-on system must be removable
    - Add-on system must be cleaned easily
5. **Heuristic Evaluation**
    - The variation in gender, height, weight, eye dominance, head tilt, and handedness may have enabled more problems to be found.
    - The most severe problems violated design guidelines 5, 7, and 8
    - The top heuristics violated were flexibility and efficiency of use, user control and freedom, and error prevention
6. **Emotional Impact**
    - Experts were divided between usage not being fun and being unsure if it is fun
    - Consistency issues, especially visual clutter was the most frequently cited reason for the design not being attractive or creative
    - The design is visually and tactilely appealing but there are noise and weight concerns
    - All experts think the saw and LEV feels robust
    - Safety and health benefits would add to the user's self-esteem
    - Making the design more durable, minimalist, and reducing the weight could improve the emotional impact of the system
7. **Design Taxonomy for Large Handheld Powered Equipment**
    - **Design Guideline 1**
        - **Have clear symbols and efficiently provide information and feedback.** Make sure symbols are clear. Ensure one feature cannot be confused for another. Have clear indication of where a feature is located. Make it clear what the purpose of a feature is. Indicate the status of the system.

- **Design Guideline 2**
    - **The design should be functional so use is efficient and convenient.** Ensure pieces which enable movement can move freely. No pieces of the tool should occlude the positioning and clearance of other parts. User should be able to easily and intuitively make adjustments to the system without deviating from their current workflow.
- **Design Guideline 3**
    - **Provide system status updates when attaching add-on systems**. Provide feedback on how tight attachment mechanisms should be. Make screws and bolts the correct size. Provide feedback on how far to tighten bolts. Make it clear if the mechanism is attached correctly.
- **Design Guideline 4**
    - **Make the process of attaching add-on systems easy.** When attaching one part of the system, don't make the other parts harder to attach. Reduce pinching of the system on itself. Do not make the user support the weight of the system when attaching. Provide good visibility during the process of attaching the mechanism.
- **Design Guideline 5**
    - **Ensure the saw is efficient in its design to reduce dangers posed by safety concerns.** Make sure the integrity of the part making contact with the material is always intact. Do not introduce unnecessary heat to the system. Make sure all gas is contained and cannot spill out of the system. Do not allow the system to be unsupported when the user is doing another action.
- **Design Guideline 6**
    - **Make sure all necessary parts of the tool are visible to the user**. Give the user full visibility of the tool while it is in action. Parts of the tool cannot occlude the user's vision. Make sure the system does not interfere with the user's visibility or natural movements.
- **Design Guideline 7**
    - **Ensure the characteristics of the tool do not overexpose users to dangers associated with the tool.** Reduce noise hazards. Ensure the system is stable without user intervention. Make all attachment movements safe. Reduce weight of the tool
- **Design Guideline 8**
    - **Ensure ease of movement**. Allow tool to be easily turned on and off when moving between areas. Make the entire system move as one piece. Allow freedom of movement in as many directions to enable natural and intuitive movement during workflow. Make movement intuitive.
- **Design Guideline 9**
    - **Make properties of the system accessible for all user sizes.** Make system for both right, left, and ambidextrous users. Allow the

	user to complete tasks easily. Ensure clearances for various sizes of hands. Both right and left handed users should be able to turn on the system easily.

Discussion

A prototype fit for testing was not created using the design procedure. This researcher believes the design process followed is beneficial. The author believes the design was not successful as it is difficult to create such a product by oneself. Many outside resources were used but a small core design team may have been beneficial. Additionally, the final design was similar to a product already on the market which qualitatively validates the convergence of the design process upon a successful product. The only reason it was not arrived at sooner was the constraint of allowing the user full range of motion. This practically translates to allowing the user to freedom to take on different postures.

The diversity of usability experts in the heuristic evaluation was beneficial for uncovering problems. The biggest discrepancy in height and weight were between participants three and four, with participant four being over a foot taller and 130lbs. heavier. For instance, the saw is usually used by males in construction but there was a female in the study. She noticed things that were not found by other participants. For instance, she has small hands and still hit her knuckles as well as having to switch hands and stances more than others due to its weight. Participant four being as big as he is pointed out other things such as having to bend over much more to start the motor and because of his size, he is powerful enough to stand erect while starting the saw, albeit this is unsafe. Additionally, there were two participants who were ambidextrous and there was much variation on eye dominance and head tilt. These differences may have allowed more problems to be found. Though only ¼ of the participants were double experts, it was beneficial that most had power tool experience/mechanical aptitude even though most were digital interface designers/engineers.

The usability experts had mixed emotions regarding the saw and LEV system. They did not find using the saw to be fun. The reason why the experts did not find the visual design attractive and creative was consistency issues such as different shades of orange, too many stickers, and visual clutter. Though, users did find the color helpful for safety reasons. The design of the saw had mixed reviews. One users remarked "it looks too big and bulky" while another said, "the shape is minimalist". Durability, minimalist, and weight were the three opportunities to improve the emotional impact. It is interesting that the experts all viewed the system to be robust but still feel the durability can be improved. Though, they did not use the system so its true durability is still to be determined. The participants said safety and health benefits would add to the user's self-esteem. By taking the weight of the saw and also visually seeing the dust being cleared away. There were only a few experts to assessed this system. Therefore, this researcher believes it would be interesting to determine the emotional impact of safety and health benefits in construction and how it relates to tool design in future research.

Constraints identified during the design process were justified during the usability inspection. Flexibility and efficiency of use and user control and freedom were the two heuristics most violated. This was because of the hinge system. Additionally, two of the top five most severe usability problems as identified by users refer to postural/weight issues. This author recommends any future design iterations on the cut-off saw to be focused on using the dolly system when possible. The dolly is a built in constraint but it allows for the weight to be offset. The dolly is not as versatile though which still may mean there is need for other controls with the system not attached to the dolly but which does not add any safety hazards and still enables the user to have flexibility and control over the system.

This study further validates the use of factor analysis when creating a design taxonomy (Capra, 2005). This process was unique because it used factor analysis instead of clustering which enabled issues to be in more than one category. Modern taxonomies originated from creating mutually exclusive categories for species (Manktelow, 2010). Using this technique better lent itself to this organic process of design. The process was made more unique by the use of health hazard usability violations from a heuristic violation to create the categories and ultimately the factors.

The process for this study can be used in future studies investigating powered tools. Contextual inquiry was important for understanding how the saw was used in context. The exploratory cutting revealed information about how the dust manifests when a cut is made and the strengths and weaknesses of one type of add-on system design. Combining the site visits, current design analysis, and exploratory cutting informed the focus group. Not only were design requirements made from the focus group meeting but also LEV designs and complete saw redesigns were sketched. During prototyping, many design paths were taken which all may be promising for this type of tool. The main outcome of the process was an understanding of how difficult it is to create add-on systems for such a large and powerful tool. When controlling for health hazards it became apparent to ensure there were no undue safety hazards or physical ergonomic stressors present. Gee (2001) found usability testing to be an appropriate tool for not only evaluation but also redesign. The use of heuristic evaluation is fast, cheap, and uncovers many usability issues (Nielsen & Mack, 1994). Thus the heuristic evaluation can be used to uncover problems and also inform redesign.

The literature is not exhaustive for LEV systems or the handheld cut-off saw but many studies do exist. Performance and effectiveness of LEV systems for the saw (Carlo et al., 2010; Middaugh et al., 2012; Thorpe et al., 1999), LEV for handheld grinders (Akbar-Khanzadeh & Brillhart, 2002; Akbar-Khanzadeh et al., 2007; Akbar-Khanzadeh et al., 2010; Collingwood & Heitbrink, 2007; Meeker et al., 2009), using water during abrasive blasting (Old & Heitbrink, 2007), LEV systems on hammer drills (S. Shepherd et al., 2008), vacuum sanders (Liverseed, Logan, Johnson, Morey, & Raynor, 2013), dry and wet cutting with the cut-off saw (Shepherd & Woskie, 2013), and multiple cutting and grinding activities with LEV systems (G. A. Croteau et al., 2002) were assessed. Other studies have investigated usability characteristics of handheld tools but they all dealt with physical ergonomic stressors and most were for smaller handheld tools. These include powered screwdriver assessment (S. L. Johnson & Childress, 1988), foam rubber grips (Fellows & Freivalds, 1991), pistol grips and trigger sizes (Oh & Radwin, 1993), ergonomic aids for screwdrivers (Freund et al., 2000), the usability of orbital sanders (Spielholz et al., 2001), wire twisting tasks (Dempsey et al., 2002), meat hook handle shapes (Kong & Freivalds, 2003), comfort and discomfort in hand tools (Kuijt-

Evers, Groenesteijn, De Looze, & Vink, 2004; Kuijt-Evers, Twisk, Groenesteijn, De Looze, & Vink, 2005), rebar tying machines (Schneider & Vi, 2005), vibrations in power tools and users' perceptions (Vergara et al., 2008), and usability and aesthetics of tin snips (Mohamed, 2011). Most of the aforementioned studies analyzed comfort and discomfort. Finally, even fewer studies have investigated both performance and usability. These include their ergonomic evaluation of handle types for garden tools (Rok Chang et al., 1999), axial pipettes (Sormunen & Nevala, 2013),bent hand files (Hsu & Chen, 2000), and usability of drywall sanding tools (Young-Corbett & Nussbaum, 2009; Young-Corbett et al., 2010). This study did not directly test the performance of LEV systems but previous literature and the work from study 1 gives an indication as to the effectiveness of such systems.

Study 3 Limitations

There were two primary tradeoffs made for this study. One was the focus on dust collection equipment instead of water based controls. From the first study, it is clear wet-method systems are used more frequently. From analyzing current cut-off saw designs, many of the saws have an integrated water system. Therefore, this researcher wanted to see if there could be potential for vacuum-based systems as manufacturers are already providing a competitive advantage for wet-method systems. LEV systems are good because they have been shown to be effective for reducing dust concentration levels tools used in concrete and masonry (G. A. Croteau et al., 2002). Though, cutting without water causes high cutting temperatures, high noise levels, and reduced life of the blade (Wang et al., 2003). Additionally, a generator may be needed to run the vacuum attached to the dust collector (Thorpe et al., 1999). Middaugh et al. (2012) analyzed dust concentrations with LEV systems on cut-off saws and mentions the advantage of year-round usability. Study 1 demonstrated the potential for vacuum-based systems and this study sought to investigate how viable of an option it may be for large handheld tools.

The other main tradeoff was focusing on health hazards instead of safety. This researcher has identified multiple safety and health hazards. Safety concerns include kick-back, push-back, and pull-in, flying saw fragments, out of control machines, falling material, and slips and electrocutions (Government of Western Australia, 2010; Occupational Safety and Health Administration (OSHA), n.d.-a). Health concerns include noise, vibration, emissions, ergonomic stressors, and dust (Government of Western Australia, 2010; Kroemer, Kroemer, & Kroemer-Elbert, 1994; Meeker et al., 2009; Missouri Employers Mutual Insurance Company, 2011). This researcher decided to study only one hazard, being dust. There are ethical, scientific, and practical trade-offs from only picking one hazard (Levine, 1982; National Institue for Occupational Safety and Health (NIOSH), 2011; Nord, 1993). The biggest reason dust was chosen was a practical trade-off. There are the feasibility concerns in conducting the research which include limitations in resources and time (Matthews & Kostelis, 2011). Specifically, Study 1 and 2 were funded by a research grant and its scope encompassed health hazards. These studies were influential in determining the direction of this study. Additionally, this researcher's advisor's expertise pertains to health concerns in construction. Finally, if every hazard is attempted to be solved, it may not actually address the root cause of the problem. In the end this causes the problem to reappear and creates dependence on the intervener. The purpose of a system is to maintain itself, but trying to address too many variables may make it hard for this to happen. Therefore, not everything is about quantity (Meadows & Wright, 2008). Though choosing to study one hazard, it could not create or exacerbate a different problem. Though this study pertained to one hazard, the techniques developed in this research can be applied to study other hazards.

The focus group could have been approved by altering the number of participants, the number of groups, and the participants themselves. Krueger and Casey (2014) says there should be between six and eight participants per group. The number of focus groups needed depends on the information needed. Stewart and Shamdasani (2014) says most studies don't use less than two or more than four groups. The study may have been improved by having more participants per group and more groups. For the focus group, a real end user of the saw may have been better. The construction student had intimate knowledge of the saw but as he was not working with the saw on a day to day basis, he couldn't express some of the nuances that may have been important for ideation. Also, someone who had used the saw for a longer time could also express trends in the industry they've witnessed.

The heuristic evaluation used a mix of single participants and group participants. This shows it was not consistent. Though, the information extracted from the group participants enabled more of a discussion and at least one problem was identified which probably wouldn't have been found otherwise, primarily the possible use of two people to attach the hinge receiver. The study only used a heuristic evaluation of the tool but did not run it for dust concentration levels or empirical usability testing. The information regarding the dust concentrations levels would be interesting to try to draw conclusions about the efficacy and the overall adoption potential of this type of LEV design. Additionally, an empirical usability test may yield slightly different results as the saw is actually running and cutting. Another limitation is the saw was not turned on and while the engine still running and blade still spinning, moved to the next cut. The only reason the noise and the mess was listed as a usability problem was from one evaluator's previous experience. This researcher believes there would be more information about vibration and noise and how well the LEV supports the weight during actual cutting procedures using a cutting test.

Though this study aimed to understand the UX of the saw, it used emotional impacts and contextual inquiry to do so. There were only six participants for the heuristic evaluation which does not lend itself to much data regarding the emotional impact.

Conclusion

Integrating multiple design processes into one may present an easily followed roadmap for future designs of large handheld powered equipment. Studies 1 and 2 were important to understand which industries in construction had high adoption readiness characteristics and which controls could be improved. Running the design procedures demonstrates that this researcher found it difficult to have a successful product come out of the design process but that does not mean the same process cannot be helpful or that future design processes can solve the same issues. Because of how difficult it was to enable freedom of movement with the LEV system, this researcher recommends a dolly system for making long cuts in concrete. The usability inspection methods chosen were quick and had usable outcome in creating the design recommendations. Taking into considering the research available, the results from study 1 and 2, and these recommendation, it gives a more complete picture of how to design for this type of equipment.

The author does not know of any studies which have looked at the usability of LEV systems. Most other studies which looked at tool design for usability characteristics only looked at a segment of the user experience. The author does not know of any other extensive study which attempted to design a system and run a usability evaluation on current designs to come up with design recommendations for large handheld tools.

Final Recommendations

In addition to the design recommendations summary in Table 79, one should consider other factors when creating control designs for large handheld tools. These include barriers to adoption, firm size, cues to action, social interactions, exposure limits, and other design guidelines already produced.

Barriers to adoption should be considered. From study 1 LEV are second frequently used in concrete and masonry. The open ended responses reveal the main reason decision makers do not use dust collection equipment is because they use wet-method systems. There are not many LEV systems on the marketplace considering most new saws come with an integrated water system. Previous research has identified barriers and incentives for implementing engineering controls during concrete grinding operations (Shepherd & Woskie, 2010). These key factors include a cooperative relationship between the general contractor and subcontractors, the effects of dust levels on the work flow of other subcontractors, public relations issues associated with high dust levels in densely populated areas, and the subcontractor's perceived benefits which exceed the short term cost. The barriers from study 1 and those by Shepherd and Woskie (2010) should be considered in conjunction when implementing an engineering control in the concrete and masonry trades.

Getting the product adopted by large companies may be difficult even though they have the necessary resources and long term vision. Kramer et al. (2009) attempted to have a ladder lift adopted which would reduce ergonomic stresses. The authors encountered more resistance from large companies. This is because the larger companies would have to put the ladder lift on all their vans, which is a large investment.

Cues to action were used recently by our laboratory for better awareness of drywall dust (J. Weidman, 2012). Cues to action serve as reminders to enable behavior change (Elder, Ayala, & Harris, 1999). This can be important in successful technological adoption. Lingard (2001) says workers feel they have no control over the health and safety risks they are exposed to. The key is to have people aware of the hazards, and enable workers to feel they are in control over the hazards they are exposed to.

The PtD ARM (Figure 3) shows that adoption readiness predicts actual usage but importantly, social system influences influence actual usage as well. Social systems include both individuals and groups. Individuals who have a strong influence over other individual attitudes and behaviors are called change agents (E. M. Rogers, 2003). These change agents have an influence on other to adopt or not adopt. Additionally, decisions may be left to an individual or the consensus of a group (J. Y.-C. Weidman, Deborah, 2012). For greater adoption, authoritative decisions passed down influence the adoption of control technologies (E. M. Rogers, 2003). This is in line with the results from Studies 1 and 2. Decision makers were asked whether there was an increase in jobs specifying fume or dust control and what percentage of their work required fume or dust control. This means that site requirements may be a forcing function for adoption. The more that job sites require vapors and fumes or dust control, the more the use must increase. This researcher's opinion is the more job sites that require hazard control, the more pressure there will be on creating better controls. It is also this researcher's opinion that getting more job sites to require health hazard controls may have multiple downstream effects. The more it is required, the more they are used, the more that users demand better designs.

Even with controls available, multiple studies have shown dust levels exceeding permissible exposure limits, therefore many still use respirators as the primary dust control device (Flanagan et al., 2003; Middaugh et al., 2012). The effectiveness of dust control technologies has been advancing and still will. One way to ensure they will be adopted, hoping that they can lower levels safe enough to not require the use of additional controls (respirators) would be to increase the usability. When designing, the guidelines from this study can be used to ensure the user has a positive experience with the tool.

Finally, the design process created in Figure 101 can be used in future studies. This author would be remiss to not repeat other guidelines for hand tools found in Chapter 1 (L. Greenberg & Chaffin, 1977; Kadefors et al., 1993; Meagher, 1987; Mital & Kilbom, 1992; Putz-Anderson, 1988; Young-Corbett et al., 2010). Depending on the need, the design guidelines put forth in Table 79 could be used in conjunction or be supplemented with any of the aforementioned guides.

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Appendix A: Predetermined Site Visit Questions

Objective of research: To model decision making in concrete, masonry, and asphalt roofing. To determine what is valued the most when deciding what tools, materials, or processes to use.

Objective of meeting: To get an overview of how the business side of construction works in regards to who makes the decisions. I will then apply this knowledge to understand who to survey.

1. Have you always worked for Holder and have you worked in different states?
2. Can you explain the levels of workers? (i.e. apprentices, journey-level, etc.)?
3. Can you generally define the roles of these in your company?
    a. Purchasing agent
    b. Pre-construction people
    c. Architect
    d. Owner
    e. CM
    f. Super intendant
    g. Foreman
    h. Am I missing an important role?
4. Do you use purchasing agents? If so, is their main objective to make deals with suppliers?
5. Who decides what materials to use on the site?
6. If you disagree with the specified material, who do you tell? Architect, owner?
7. What dictates what tools or processes to use? (For instance, to use wet methods for certain tools or types of cuts as opposed to dry to vacuum)
8. Are tools and process changes generally a function of experience?
9. If you saw a subcontractor doing something in an unsafe manner, do you have the authority to correct them?
10. Considering that I am trying to reach the decision makers, which job title should I look for? or do you think it may vary company to company?

Appendix B: Concrete, Masonry, and Asphalt Roofing Survey Question Elimination Card Sort Results

Number	Question	Score out of 10 from card sort
TRUST IN TECHNOLOGY		
1)	I trust ventilated tools	9
2)	I feel ventilated tools work well	8
PERCEIVED RISK		
3)	Working in the concrete industry is a risk factor for certain illnesses	10
4)	My employees are susceptible to major health problems from exposure to concrete dust	10
5)	Exposure to concrete dust poses a potential health risk to workers	10
6)	Concrete dust can cause severe health effects	10
PERCEIVED BENEFIT		
7)	Ventilated tools are beneficial to the health of my workers	9
8)	Ventilated tools reduce dust exposure	9
9)	When using ventilated tools, less dust(vapors and fumes) is produced	6
10)	Ventilated tools increase the quality of life of my workers	7
PERCEIVED USEFULNESS		
11)	Ventilated tools are useful tools for working with concrete	8
12)	Ventilated tools are useful in controlling dust	6
13)	Ventilated tools improve job performance	8
RELATIVE ADVANTAGE		
14)	Ventilated tools save my company time	6
15)	My workers are faster with ventilated tools compared to conventional tools	6
16)	More work gets done when using ventilated tools	9
17)	Ventilated tools allow my workers to accomplish more work than would otherwise be possible	8
ADOPTION READINESS		
18)	I anticipate my company will use/continue to use ventilated tools in our work	8

19)	My company is eager to adopt new technologies relating to dust control on our projects	7
20)	My company is likely to spend time and money to implement dust control technology to reduce worker exposure to concrete dust	6
21)	My company tends to adopt new tools, processes, or materials after they have been proven to work	7
22)	My company looks forward to using ventilated tools	8
23)	I would use ventilated tools if they had a cheaper up-front cost	7
24)	I am more likely to use ventilated tools after a regulation violation	6

Appendix C: Concrete/Masonry Survey

Hello, my name is ____ ____ and I'm calling from Virginia Tech on behalf of the Industrial and Systems Engineering department. As a member of the concrete or masonry industry, we are interested in your feelings about your work with concrete or masonry. There are no right or wrong answers; we are looking only for your individual opinion. All answers will remain anonymous.

1	Please indicate your level of agreement with the following statements: Exposure to concrete or masonry dust poses a potential health risk to workers. Do you strongly agree, somewhat agree, somewhat disagree, or strongly disagree?	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
2	Concrete or masonry dust can cause severe health effects.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF

3	How familiar are you with dust collection equipment? Would you say very familiar, somewhat familiar, slightly familiar, or not at all familiar?		VERY FAMILIAR	SOMEWHAT FAMILIAR	SLIGHTLY FAMILIAR	NOT AT ALL FAMILIAR *(skip to Q15)*	DK/RF *(skip to Q15)*
4	How often do your employees use dust collection equipment? Would you say always, regularly, sometimes, rarely, or never?	ALWAYS	REGULARLY	SOMETIMES	RARELY	NEVER	DK/RF

If 4 IS NEVER/DK/RF: Please tell me why your employees do not use dust collection equipment? *(Skip to Q15)*

5	Please indicate your level of agreement with the following statements: I trust dust collection equipment will get the job done well.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
6	I feel dust collection equipment work well.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
7	Dust collection equipment is beneficial to the health of my workers.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
8	Dust collection equipment reduces concrete or masonry dust exposure.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
9	Dust collection equipment is a useful tool for working with concrete or masonry products.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
10	Dust collection equipment improves job performance.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
11	More work gets done when using dust collection equipment.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
12	Dust collection equipment allows my workers to accomplish more work than would otherwise be possible.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
13	I anticipate my company will use, or continue to use, dust collection equipment in our work.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
14	My company looks forward to using, or continuing to use, dust collection equipment.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF

15	How familiar are you with wet-method systems?		VERY FAMILIAR	SOMEWHAT FAMILIAR	SLIGHTLY FAMILIAR	NOT AT ALL FAMILIAR (*skip to Q27*)	DK/RF (*skip to Q27*)
16	How often do your employees use wet-method systems?	ALWAYS	REGULARLY	SOMETIMES	RARELY	NEVER	DK/RF

If 16 IS NEVER/DK/RF: Please tell me why your employees do not use wet-method systems? (*skip to Q27*)

17	Please indicate your level of agreement with the following statements: I trust wet-method systems will get the job done well. Do you strongly agree, somewhat agree, somewhat disagree, or strongly disagree?	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
18	I feel wet-method systems work well.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
19	Wet-method systems are beneficial to the health of my workers.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
20	Wet-method systems reduce concrete or masonry dust exposure.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
21	Wet-method systems are useful equipment for working with concrete or masonry products.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
22	Wet-method systems improve job performance.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
23	More work gets done when using wet-method systems.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
24	Wet-method systems allow my workers to accomplish more work than would otherwise be possible.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
25	I anticipate my company will use, or continue to use, wet-method systems in our work.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
26	My company looks forward to using or continuing to use wet-method systems.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF

27	Isolation systems entail either isolating the workers from dust producing activities, isolating dust producing activities from the workers, or enclosure systems for certain tools. How familiar are you with isolation systems?	VERY FAMILIAR	SOMEWHAT FAMILIAR	SLIGHTLY FAMILIAR	NOT AT ALL FAMILIAR *(skip to Q39)*	DK/RF *(skip to Q39)*

28	How often do your employees use isolation systems?	ALWAYS	REGULARLY	SOMETIMES	RARELY	NEVER	DK/RF

If 28 IS NEVER/DK/RF: Please tell me why your employees do not use isolation systems? *(skip to Q39)*

29	Please indicate your level of agreement with the following statements: I trust isolation systems will get the job done well. Do you strongly agree, somewhat agree, somewhat disagree, or strongly disagree?	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
30	I feel isolation systems work well.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
31	Isolation systems are beneficial to the health of my workers.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
32	Isolation systems reduce concrete or masonry dust exposure.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
33	Isolation systems are useful methods for working with concrete or masonry products.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
34	Isolation systems improve job performance.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
35	More work gets done when using isolation systems.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
36	Isolation systems allow my workers to accomplish more work than would otherwise be possible.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
37	I anticipate my company will use, or continue to use, isolation systems in our work.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
38	My company looks forward to using or continuing to use isolation systems.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF

39	How familiar are you with sweeping compound?		VERY FAMILIAR	SOMEWHAT FAMILIAR	SLIGHTLY FAMILIAR	NOT AT ALL FAMILIAR (*skip to QI*)	DK/RF (*skip to QI*)
40	How often do your employees use sweeping compound?	ALWAYS	REGULARLY	SOMETIMES	RARELY	NEVER	DK/RF

If 40 IS NEVER/DK/RF: Please tell me why your employees do not use sweeping compound? (*skip to QI*)

41	Please indicate your level of agreement with the following statements: I trust sweeping compound will get the job done well. Do you strongly agree, somewhat agree, somewhat disagree, or strongly disagree?	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
42	I feel sweeping compound works well.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
43	Sweeping compound is beneficial to the health of my workers.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
44	Sweeping compound reduces concrete or masonry dust exposure.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
45	Sweeping compound is a useful material for working with concrete or masonry products.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
46	I anticipate my company will use, or continue to use, sweeping compound in our work.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
47	More work gets done when using sweeping compound.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
48	Sweeping compound allows my workers to accomplish more work than would otherwise be possible.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
49	I anticipate my company will use, or continue to use, sweeping compound in our work.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
50	My company looks forward to using or continuing to use sweeping compound.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF

I. What business factors would affect the way you address dust-control on your projects...

(CHECK ALL THAT APPLY)
- ☐ Insurance Premiums?
- ☐ Government Regulations?
- ☐ Productivity?
- ☐ Worker Safety?
- ☐ Other? (please specify the other business factors:)

II. Have you seen an increase in projects specifying dust-control methods?

- ☐ Yes
- ☐ No

III. In the past year what percent of your work specifies using dust -control methods?
- ☐ 0-25%
- ☐ 26-50%
- ☐ 51-75%
- ☐ 76-100%

IV. Concrete or masonry dust-control technologies currently available are dust collection equipment, wet-method systems, isolation systems, and sweeping compound. What are some other dust-control methods that you know about or have used?

V. If you could imagine an ideal way of controlling concrete or masonry dust that does not currently exist, what would it be and why?

VI. Now just a few final questions about you. What is your job title?

VII. How many full-time employees work for you?

VIII. In what year were you born?

IX. Gender.

Appendix D: Asphalt Roofing Survey

Hello, my name is ____ ____ and I'm calling from Virginia Tech on behalf of the Industrial and Systems Engineering department. As a member of the asphalt roofing industry, we are interested in your feelings about your work with hot asphalt. There are no right or wrong answers; we are looking only for your individual opinion. All answers will remain anonymous.

1	Please indicate your level of agreement with the following statements: Exposure to asphalt fumes poses a potential health risk to workers. Do you strongly agree, somewhat agree, somewhat disagree, or strongly disagree?	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
2	Asphalt fumes can cause severe health effects.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF

3	How familiar are you with liquid asphalt tanker delivery systems? Would you say very familiar, somewhat familiar, slightly familiar, or not at all familiar?		VERY FAMILIAR	SOMEWHAT FAMILIAR	SLIGHTLY FAMILIAR	NOT AT ALL FAMILIAR *(skip to Q15)*	DK/RF *(skip to Q15)*
4	How often do your employees use liquid asphalt tanker delivery systems? Would you say always, regularly, sometimes, rarely, or never?	ALWAYS	REGULARLY	SOMETIMES	RARELY	NEVER	DK/RF

If 4 IS NEVER/DK/RF: Please tell me why your employees do not use liquid asphalt tanker delivery systems? *(Skip to Q15)*

5	Please indicate your level of agreement with the following statements: I trust liquid asphalt tanker delivery systems will get the job done well.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
6	I feel liquid asphalt tanker delivery systems work well.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
7	Liquid asphalt tanker delivery systems are beneficial to the health of my workers.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
8	Liquid asphalt tanker delivery systems reduce asphalt fume exposure.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
9	Liquid asphalt tanker delivery systems are useful equipment for working with asphalt.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
10	Liquid asphalt tanker delivery systems improve job performance.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
11	More work gets done when using liquid asphalt tanker delivery systems.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
12	Liquid asphalt tanker delivery systems allow my workers to accomplish more work than would otherwise be possible.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
13	I anticipate my company will use, or continue to use, liquid asphalt tanker delivery systems in our work.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
14	My company looks forward to using or continuing to use liquid asphalt tanker delivery systems.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF

15	How familiar are you with hot luggers, mechanical spreaders, and felt-laying machines?		VERY FAMILIAR	SOMEWHAT FAMILIAR	SLIGHTLY FAMILIAR	NOT AT ALL FAMILIAR *(skip to Q27)*	DK/RF *(skip to Q27)*
16	How often do your employees use hot luggers, mechanical spreaders, or felt-laying machines?	ALWAYS	REGULARLY	SOMETIMES	RARELY	NEVER	DK/RF

If 16 IS NEVER/DK/RF: Please tell me why your employees do not use hot luggers, mechanical spreaders, or felt-laying machines?

17	Please indicate your level of agreement with the following statements: I trust hot luggers, mechanical spreaders, and felt-laying machines will get the job done well. Do you strongly agree, somewhat agree, somewhat disagree, or strongly disagree?	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
18	I feel hot luggers, mechanical spreaders, and felt-laying machines work well.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
19	Hot luggers, mechanical spreaders, and felt-laying machines are beneficial to the health of my workers.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
20	Hot luggers, mechanical spreaders, and felt-laying machines reduce asphalt fume exposure.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
21	Hot luggers, mechanical spreaders, and felt-laying machines are useful equipment for working with asphalt.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
22	Hot luggers, mechanical spreaders, and felt-laying machines improve job performance.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
23	More work gets done when using hot luggers, mechanical spreaders, and felt-laying machines.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
24	Hot luggers, mechanical spreaders, and felt-laying machines allow my workers to accomplish more work than would otherwise be possible.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
25	I anticipate my company will use, or continue to use, hot luggers, mechanical spreaders, and felt-laying machines in our work.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
26	My company looks forward to using or continuing to use hot luggers, mechanical spreaders, and felt-laying machines.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF

27	How familiar are you with insulated kettles or insulated hot luggers?		VERY FAMILIAR	SOMEWHAT FAMILIAR	SLIGHTLY FAMILIAR	NOT AT ALL FAMILIAR *(skip to Q39)*	DK/RF *(skip to Q39)*
28	How often do your employees use insulated kettles or insulated hot luggers?	ALWAYS	REGULARLY	SOMETIMES	RARELY	NEVER	DK/RF

If 28 IS NEVER/DK/RF: Please tell me why your employees do not use insulated kettles or insulated hot luggers? *(skip to Q39)*

29	Please indicate your level of agreement with the following statements: I trust insulated kettles or insulated hot luggers will get the job done well. Do you strongly agree, somewhat agree, somewhat disagree, or strongly disagree?	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
30	I feel insulated kettles or insulated hot luggers work well.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
31	Insulated kettles or insulated hot luggers are beneficial to the health of my workers.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
32	Insulated kettles or insulated hot luggers reduce asphalt fume exposure.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
33	Insulated kettles or insulated hot luggers are useful equipment for working with asphalt.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
34	Insulated kettles or insulated hot luggers improve job performance.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
35	More work gets done when using insulated kettles or insulated hot luggers.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
36	Insulated kettles or insulated hot luggers allow my workers to accomplish more work than would otherwise be possible.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
37	I anticipate my company will use, or continue to use, insulated kettles or insulated hot luggers in our work.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
38	My company looks forward to using, or continuing to use, insulated kettles or insulated hot luggers.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF

39	Low-fuming asphalt, also known as odor-reducing asphalt, is a material which when heated in a kettle forms a skim on top. How familiar are you with low-fuming asphalt?		VERY FAMILIAR	SOMEWHAT FAMILIAR	SLIGHTLY FAMILIAR	NOT AT ALL FAMILIAR *(skip to Q51)*	DK/RF *(skip to Q51)*
40	How often do your employees use low-fuming asphalt?	ALWAYS	REGULARLY	SOMETIMES	RARELY	NEVER	DK/RF

If 40 IS NEVER/DK/RF: Please tell me why your employees do not use low-fuming asphalt? *(skip to Q51)*

41	Please indicate your level of agreement with the following statements: I trust low-fuming asphalt will get the job done well. Do you strongly agree, somewhat agree, somewhat disagree, or strongly disagree?	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
42	I feel low-fuming asphalt works well.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
43	Low-fuming asphalt is beneficial to the health of my workers.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
44	Low-fuming asphalt reduces asphalt fume exposure.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
45	Low-fuming asphalt is a useful material.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
46	Low-fuming asphalt improves job performance.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
47	More work gets done when using low-fuming asphalt.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
48	Low-fuming asphalt allows my workers to accomplish more work than would otherwise be possible.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
49	I anticipate my company will use, or continue to use, low-fuming asphalt in our work.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
50	My company looks forward to using or continuing to use low-fuming asphalt.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF

51	How familiar are you with kettle fume guards?		VERY FAMILIAR	SOMEWHAT FAMILIAR	SLIGHTLY FAMILIAR	NOT AT ALL FAMILIAR (*skip to I*)	DK/RF (*skip to QI*)
52	How often do your employees use kettle fume guards?	ALWAYS	REGULARLY	SOMETIMES	RARELY	NEVER	DK/RF

If 52 IS NEVER/DK/RF: Please tell me why your employees do not use kettle fume guards? (*skip to I*)

53	Please indicate your level of agreement with the following statements: I trust kettle fume guards will get the job done well. Do you strongly agree, somewhat agree, somewhat disagree, or strongly disagree?	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
54	I feel kettle fume guards work well.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
55	Kettle fume guards are beneficial to the health of my workers.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
56	Kettle fume guards reduce asphalt fume exposure.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
57	Kettle fume guards are useful equipment for working with asphalt.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
58	Kettle fume guards improve job performance.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
59	More work gets done when using kettle fume guards.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
60	Kettle fume guards allow my workers to accomplish more work than would otherwise be possible.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
61	I anticipate my company will use, or continue to use, kettle fume guards in our work.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF
62	My company looks forward to using or continuing to use kettle fume guards.	STRONGLY AGREE	SOMEWHAT AGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	DK/RF

I. What business factors would affect the way you address fume-control on your projects…

(CHECK ALL THAT APPLY)
☐ Insurance Premiums?
☐ Government Regulations?
☐ Productivity?
☐ Worker Safety?
☐ Other? (please specify the other business factors:)

II. Have you seen an increase in projects specifying fume-control methods?

☐ Yes
☐ No

III. In the past year what percent of your work specifies using fume-control methods?
☐ 0-25%
☐ 26-50%
☐ 51-75%
☐ 76-100%

IV. Asphalt roofing fume-control technologies currently available are liquid asphalt tanker delivery systems, hot luggers or mechanical spreaders or felt-laying machines, insulated kettles or insulated hot luggers, fume-suppressing asphalt, and kettle fume guards. What are some other fume-control methods that you know about or have used?

V. If you could imagine an ideal way of controlling asphalt fumes that does not currently exist, what would it be and why?

VI. Now just a few final questions about you. What is your job title?

VII. How many full-time employees work for you?

VIII. In what year were you born?

IX. Gender.

Appendix E: Heuristics Used in Heuristic Evaluation

Code	Heuristic	Heuristic Definition
A	Visibility of System Status	The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.
B	Match between system and the real world	Follow real-world conventions.
C	User control and freedom	Users can select and sequence tasks (when appropriate) rather than the system taking control of the users' actions. The users have control over their positioning.
D	Consistency and standards	Follow conventions
E	Error prevention	Careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.
F	Recognition rather than recall	Minimize the user's memory load by making objects, actions, and options visible.
G	Flexibility and efficiency of use	Allow users to tailor frequent actions.
H	Aesthetic and minimalist design	Uses pared-down design elements which are visually attractive and are only the essentials.
I	Help users recognize, diagnose, and recover from errors	Errors should be expressed through the design of the system and precisely indicate a problem and through the design constructively suggest a solution
J	Help and documentation	Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

Appendix F: Study 3 Participant Data Form

Height ________________

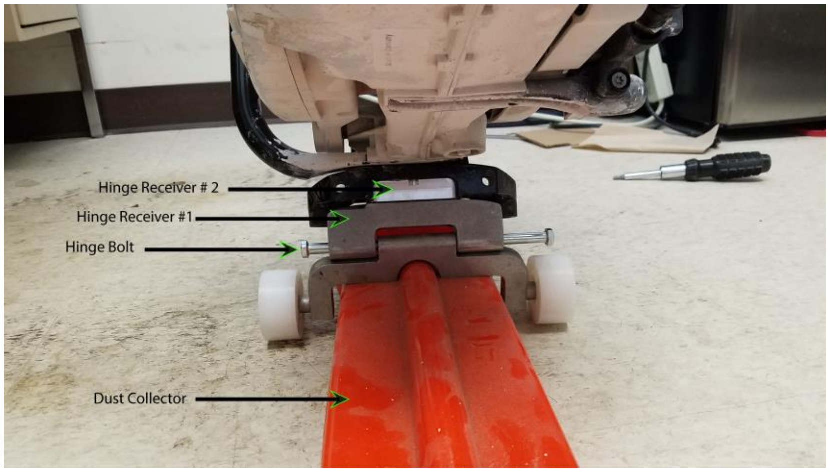
Weight ________________

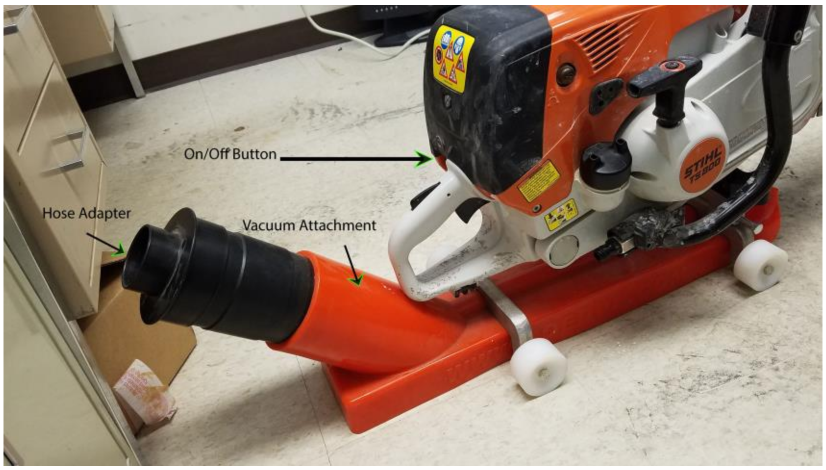
Eye dominance________________

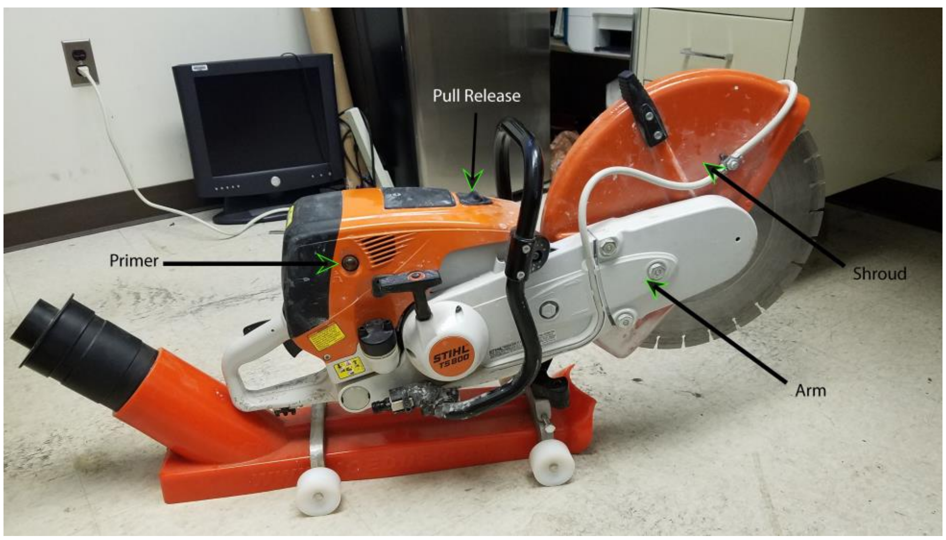
Head tilt________________

*Participant number*__________________

Appendix G: Images Sent to Participants for Severity Evaluation







Appendix H: Usability Issues, Average Severity Rating, and Accompanying Heuristics Violated

Please rate each usability issue from 1 to 5 based on the scale below
0 = I don't agree that this is a usability problem at all
1 = Cosmetic problem only: need not be fixed unless extra time is
2 = Minor usability problem: fixing this should be given low priority
3 = Major usability problem: important to fix, so should be given high
4 = Usability catastrophe: imperative to fix this before product can be

Usability Issue Number	Usability Issues	Averaged Participant Scores	Heuristic Violation 1	Heuristic Violation 2	Heuristic Violation 3	Heuristic Violation 4	Heuristic Violation 5	Heuristic Violation 6
	The Saw and Dust Collector as a System							
	Weight and Posture							
1	The user will not only feel the weight of the saw but also the drag of dust collector	2.00	C	G				
2	If the dust collector is not working, the user will have to stop intermediately to clean dust off him or herself because dust is hindering work flow	2.17	I					
3	The stance the dust collector makes the user take is uncomfortable	2.67	C					
4	The stance the dust collector makes the user take forces him or her to take baby steps which effects how smoothly a cut can be made	2.33	A					
5	The stance the dust collector makes the user take reduces his or her control over the system	2.00	G					
6	When the dust collector is attached it forces the user to stand to the side or straddle the saw	1.83	C	G	E			
7	The user is less able to take on different stances when the dust collector is attached	1.83	C					
8	The user has to put all the weight of the system in his or her lead leg to prevent the weight of the system being placed on his or her back	2.00	G					
9	The user has to squat deeply to prevent the saw from putting pressure on his or her back	3.00	G					
10	There is back strain from using the system	3.33	G					
11	The user is in an awkward position when using the system	2.33	C	G				
12	It is difficult to see the cut line with the saw is attached to the dust collector	2.50	H	C	A			
13	The wheels force the user to place his or her foot closer to the blade	3.00	G	E				

32	The rubber of the dust collector will get destroyed on rough surfaces, reducing its suction power especially when then moving from a rough surface to a smooth surface	2.67	A	B	C	G	H	E
33	The user can't just get to cutting, the user has to position the dust collector in the right spot first	2.50	B	G				
34	When cutting, the user has to use his or her foot to move the dust collector when it needs adjustment in order to keep both hands on the saw itself	2.50	C					
35	When cutting, the dust collector hits the lip of uneven concrete and the user has to lift the entire system vertically to get it onto the higher elevation concrete	2.67	E	I	C			
36	The back of saw does not attach to back of dust collector prohibiting the user from carrying the system effectively	2.33	C					
37	There is no feedback as to if the dust collector is flush on the ground	1.83	B	H	C	E		
	Bolts							
38	It is difficult to put the hinge bolts in	1.67	G					
39	The user does not know how far or tight the hinge bolts have to be	2.00	A	F	G			
40	It takes a long time to screw in the hinge bolts	1.67	C					
41	the user has to tilt the saw back and forth to take the weight off the hinge to be able to screw in the hinge bolts	2.17	G	E	I			
42	The user feels both bolts need to be in all the way to make sure the hinge doesn't break	1.83	A	E				
43	After removing one hinge bolt, it is harder to remove the second bolt	2.00	G					
44	The hinge makes the saw on the front sit higher, causing the blade to want to tilt forward	3.17	G	H	E			
45	The hinge bolt doesn't feel locked in	2.00	E					
46	The user does not get any traction with the hinge bolts	1.67	A					
47	There is no way to know if the user is putting the bolts on backwards	1.67	J					
48	It is hard to attach the black bolts for the hinge receiver #2	1.67	C					
49	With the bolt receiver #1 attached to the saw, the saw is harder to pick up	1.50	G					
50	There is not place to store the hinge bolts when not in use	1.50	H					

51	Before attaching the hinge bolts, it is hard for the saw to sit on the dust collector without slipping off	2.33	G		
52	The user doesn't have good visibility for lining up the hinge bolts	2.17	A		
53	The hinge bolts look too long to screw in and the user may not know if they are screwing them in far enough	1.67	A	D	
54	Even with small hands, the user hits his or her knuckles on the wheel while screwing in the hinge bolt	1.67	G		
55	There is no way to know if the hinge bolts are installed properly	2.17	A		
56	To reduce pinching, the user has to start one bolt then another instead of tightening one all the way	1.83	G		
57	The user has to tilt the saw forward when attaching the hinge bolts to prevent it from pinching	1.83	G		
58	For attaching hinge receiver #2, the user doesn't know if it would be safe to turn the saw upside down effectively making it a two person operation	2.50	E	J	H
59	Concerned saw is hot and gas will leak if want to unbolt the hinge receiver #2 after use	2.67	E		
60	Tempted to lean the saw over to attach the hinge receiver #2	2.17	C		
	Fuel				
61	When there is gas in the saw, dangerous as have to tilt saw over to attach the dust collector	2.50	I	E	
62	When try to flip the on/off switch, need to have hand on the front handle otherwise the blade tilts forward to the ground	2.50	E		
63	The user has to empty the gasoline before removing the hinge attachment #1 for the saw	2.33	C		
64	The user has to remove the dust collector to refill it with fuel	2.00	C		
	Misc.				
65	As this is a gas powered saw and an electric vacuum, it may be difficult to use as the user will not always have electricity on the work site, unlike portable water canisters	2.83	B	C	G
66	The user would want to turn off the saw to move to next cut for safety reasons but this is not practical for how long it takes to start the engine	3.00	E		

	The Saw itself				
	Weight and Posture				
67	The saw is heavy	1.50	C	H	
68	Because the saw is strength based, the user may want to switch hand grips from a right hand dominant to a left handed dominant hold often	2.00	C		
69	Even short individuals need to bend over to use the saw which will be worse for taller users	2.33	C		
70	The saw is not set up for right-handed and left-handed users	1.83	C		
71	The system forces some users to turn the saw on while standing to avoid back pain	2.33	I		
72	Because system forces some users to stand to turn on the saw, it is not designed for right-handed people to pull start it	1.50	I		
73	The user has to lean over the side to see the saw cutting	2.50	I		
	On/Off				
74	It is hard to find the on/off button	1.67	A		
75	The only indication the saw is on is from the blade spinning and the noise	1.50	A		
76	The 0 and 1 are not clear on the on/off button	1.67	D		
77	The kill switch requires the user to push up instead of a normal kill switch where a user pushes down which is easier	2.00	F	I	A
	Choke				
78	The choke looks like the on/off button	2.17	D	J	
79	A user unfamiliar with equipment like this may question why there are three stages to a choke	1.83	J	C	
	Fuel				
80	There is no fuel level indicator	2.00	A	G	
81	The user has to open cap to look and see if there is fuel in it, or smell it, or shake the saw around	2.00	A	G	
82	There is not enough space for the user's hand to reach the gas cap	1.67	G		
83	The way to unscrew the gas cap is not intuitive and it is difficult to unscrew	1.50	C	F	
84	Not knowing how much gas is in the saw doesn't allow the user to properly plan out how much fuel to put in it to accomplish the number of cuts the user needs to make	2.00	D		

85	The symbols on the gas cap are confusing	1.67	B	E
86	The gas cap doesn't list that mixed gasoline is required	2.17	B	F
87	The sticker for the instructions of how to use the gas cap is not easily seen from other side	1.50	A	B
	Pull Release			
88	The symbols on the pull release don't indicate its purpose	1.83	F	J
89	The symbols on the pull release are hard to see	1.67	H	
90	The symbols on the pull release indicate it is for the pull chain but the placement is not intuitive	1.83	F	D
91	The icons on the pull release may be too simplified which can inadvertently overcomplicate instructions	1.33	H	
	Misc.			
92	The symbol on the primer is confusing	1.50	B	H
93	Not all safety symbols on the back are clear	1.67	J	
94	The exhaust is getting the shroud hot which introduces heat to the blade	2.33	E	
95	The saw is loud	1.50	H	
96	The saw creates a lot of mess	1.33	E	
97	It is hard to adjust the shroud	2.17	E	G
98	There is no indication of where the air filer is	1.83	D	
99	The user tends to look to the far side of the blade to see where cutting is taking place and on the right side of the saw, there is an arm which occludes vision	2.17	A	
100	The user has to position the shroud before turning on the saw	2.00	C	
101	Having the engine exhaust out the front can be issue with trying to capture the dust	2.33	G	
102	As there is no water to cool the blade, there is a concern for the blade overheating, cracking, and getting concrete stuck to it	2.67	E	

Table I: Factor Loading

Issue Number	Factor 1 Loading	Factor 2 Loading	Factor 3 Loading	Factor 4 Loading	Factor 5 Loading	Factor 6 Loading	Factor 7 Loading	Factor 8 Loading	Factor 9 Loading
92	0.97	-0.08	0.05	-0.11	-0.11	-0.08	0.02	-0.06	-0.04
85	0.96	-0.07	0.09	-0.14	-0.07	-0.09	0.01	-0.07	-0.01
98	0.96	-0.06	0.10	-0.14	-0.07	-0.10	0.02	-0.07	-0.01
78	0.96	-0.07	0.10	-0.14	-0.06	-0.09	0.01	-0.07	0.00
90	0.96	-0.07	0.04	-0.11	-0.10	-0.08	0.03	-0.07	-0.03
88	0.95	-0.08	0.12	-0.16	-0.08	-0.06	0.02	-0.08	0.00
91	0.95	-0.05	0.04	-0.09	-0.10	-0.08	0.06	-0.08	-0.03
76	0.94	-0.07	0.19	-0.18	-0.01	-0.06	-0.04	-0.10	-0.04
89	0.93	-0.08	0.16	-0.21	-0.08	-0.05	0.03	-0.09	0.00
86	0.92	-0.09	0.19	-0.22	-0.05	-0.10	-0.02	-0.08	-0.06
80	0.90	-0.11	0.24	-0.26	-0.07	-0.02	-0.03	-0.10	-0.05
87	0.90	-0.11	0.23	-0.25	-0.07	-0.04	-0.02	-0.10	-0.05
74	0.90	-0.06	0.22	-0.21	-0.11	-0.01	-0.07	-0.02	-0.03
93	0.89	-0.18	0.11	-0.25	0.06	-0.03	0.05	-0.08	-0.03
84	0.83	-0.11	0.20	-0.16	-0.19	0.00	-0.13	0.11	-0.23
75	0.80	-0.10	0.44	-0.17	0.00	0.02	-0.13	-0.01	-0.04
37	0.79	0.00	0.33	-0.32	-0.07	0.06	-0.16	-0.08	-0.09
79	0.78	-0.21	0.24	0.01	-0.16	-0.07	-0.12	0.19	-0.16
81	0.77	-0.11	0.35	0.07	-0.06	0.06	-0.15	0.15	-0.18
26	0.71	0.15	0.19	-0.19	0.09	-0.17	-0.32	0.14	-0.01
45	0.54	0.16	0.63	-0.02	-0.14	-0.08	0.29	-0.06	0.14
47	0.41	-0.17	0.80	0.13	-0.03	0.10	-0.03	0.01	-0.03
24	0.40	0.57	0.05	-0.05	0.00	0.45	0.08	-0.23	-0.12
83	0.34	0.16	0.50	0.44	-0.10	0.02	0.10	0.24	0.01
77	0.34	-0.14	0.31	-0.15	0.43	-0.07	-0.18	0.39	-0.15
55	0.32	-0.06	0.73	0.38	0.08	0.00	-0.10	-0.06	-0.03
39	0.25	-0.12	0.87	0.21	-0.07	-0.07	0.00	-0.02	-0.05
53	0.23	-0.15	0.86	0.23	-0.12	-0.04	0.05	0.04	-0.04
82	0.13	0.64	0.16	0.14	-0.03	-0.20	0.31	-0.06	0.33
42	0.12	0.04	0.63	0.25	0.19	-0.38	0.33	0.03	-0.12
19	0.04	0.70	0.24	-0.08	0.11	-0.26	0.14	0.10	0.18
17	0.04	0.80	0.00	-0.14	0.15	0.07	0.00	-0.24	-0.04
12	0.03	0.28	0.03	-0.13	0.12	0.82	-0.06	-0.05	-0.11
20	0.02	0.87	0.02	-0.06	0.14	0.11	0.20	-0.10	0.10
29	-0.02	0.56	0.15	0.07	0.01	-0.35	-0.01	0.50	0.12
51	-0.05	0.41	0.36	0.48	0.36	-0.16	-0.26	-0.10	0.04
18	-0.07	0.81	-0.03	-0.08	0.25	0.10	-0.11	-0.20	-0.17
27	-0.09	0.91	0.02	-0.12	-0.07	0.04	-0.03	0.10	-0.03
28	-0.09	0.27	0.23	0.19	-0.40	-0.15	0.11	0.45	-0.13
100	-0.11	0.79	0.03	0.13	0.05	0.10	-0.17	0.14	-0.25
16	-0.11	0.65	-0.14	-0.17	0.26	-0.24	0.06	-0.18	0.10
48	-0.12	0.12	0.34	0.85	0.01	0.01	-0.02	0.11	0.06
32	-0.13	0.68	0.08	-0.13	0.43	0.08	-0.23	-0.20	-0.13
52	-0.13	-0.19	0.51	0.66	-0.21	0.17	0.02	-0.10	0.16
58	-0.17	-0.10	0.10	0.07	0.60	-0.22	0.47	0.29	0.02

95	-0.17	0.29	-0.18	0.00	0.33	0.23	0.63	0.05	0.03
31	-0.18	0.61	-0.20	0.28	0.01	0.17	-0.22	0.05	0.15
41	-0.19	0.13	0.13	0.82	-0.13	-0.20	-0.12	0.01	0.05
23	-0.19	0.14	0.32	-0.17	0.07	0.78	-0.01	-0.02	-0.10
64	-0.19	0.68	0.06	0.30	-0.04	-0.03	0.19	0.24	0.08
96	-0.20	0.74	-0.09	0.16	-0.13	0.39	0.01	0.10	-0.01
94	-0.21	0.16	-0.07	-0.17	0.88	-0.10	0.10	-0.11	-0.08
97	-0.22	0.37	-0.40	0.38	-0.24	0.37	0.20	-0.21	0.25
38	-0.22	0.06	0.08	0.90	-0.06	0.06	-0.03	-0.03	0.18
102	-0.22	0.04	-0.04	-0.18	0.89	-0.07	0.05	-0.08	-0.10
57	-0.22	0.00	0.00	0.77	-0.30	-0.18	0.11	-0.02	-0.06
101	-0.23	0.65	0.15	-0.02	0.37	0.05	-0.38	-0.05	-0.16
36	-0.23	0.04	-0.07	0.50	-0.21	-0.11	-0.14	0.19	0.66
33	-0.24	0.67	-0.01	0.30	-0.11	0.17	-0.05	0.33	-0.25
40	-0.24	0.49	0.23	0.50	-0.06	-0.22	-0.02	0.23	0.01
15	-0.25	0.18	-0.21	-0.26	0.73	-0.09	0.18	-0.10	-0.10
50	-0.25	0.46	0.35	0.39	0.14	-0.18	-0.12	-0.03	0.21
63	-0.26	0.54	0.03	0.52	-0.08	0.05	-0.04	0.22	-0.24
56	-0.26	-0.06	0.16	0.81	-0.31	-0.12	-0.01	0.10	-0.09
59	-0.26	-0.05	0.05	-0.06	0.87	0.01	-0.13	0.08	-0.09
21	-0.28	0.03	-0.31	0.60	-0.29	0.05	0.05	0.21	0.43
25	-0.29	0.64	0.04	0.21	-0.11	-0.09	0.06	0.41	0.25
22	-0.30	0.04	-0.31	-0.30	-0.42	-0.38	0.07	-0.09	-0.24
72	-0.30	-0.13	-0.32	0.05	-0.46	-0.35	0.10	-0.06	0.47
62	-0.30	0.13	-0.12	-0.11	0.54	-0.05	0.51	0.25	-0.06
65	-0.31	0.43	0.07	0.08	0.44	0.10	-0.47	-0.09	-0.08
2	-0.32	0.45	-0.03	-0.23	-0.07	0.48	0.15	0.16	-0.12
43	-0.32	0.02	-0.06	0.86	-0.07	0.07	-0.06	0.06	0.17
46	-0.34	-0.15	0.17	0.76	-0.01	0.07	0.02	-0.10	0.00
73	-0.35	-0.14	-0.19	0.02	-0.10	0.71	0.21	-0.22	-0.07
30	-0.35	0.01	-0.06	0.38	0.20	-0.03	0.09	0.63	0.27
14	-0.36	-0.14	-0.30	-0.03	0.35	-0.04	-0.04	0.40	0.16
99	-0.36	-0.13	-0.06	0.12	-0.05	0.79	-0.10	-0.02	0.00
70	-0.37	-0.22	-0.32	0.10	-0.21	-0.16	0.12	0.06	0.67
61	-0.37	0.02	0.01	-0.13	0.84	0.07	-0.08	0.10	-0.08
3	-0.38	-0.25	-0.55	0.03	-0.54	-0.17	0.12	-0.20	0.23
4	-0.38	-0.23	-0.47	0.15	-0.60	-0.07	-0.04	0.00	0.10
7	-0.38	-0.28	-0.52	-0.02	-0.56	-0.23	0.16	-0.12	0.04
54	-0.40	0.10	-0.06	0.45	-0.23	-0.24	0.05	-0.06	0.58
44	-0.40	0.17	0.00	-0.08	0.70	0.05	0.28	0.01	0.06
49	-0.40	-0.06	-0.25	0.62	0.03	-0.05	0.14	0.19	0.04
13	-0.40	-0.33	-0.38	-0.30	0.33	-0.09	0.30	0.08	-0.05
10	-0.41	-0.39	-0.64	0.02	-0.04	-0.05	0.36	0.00	0.17
35	-0.41	0.16	-0.26	0.48	-0.27	0.13	0.05	0.23	0.02
60	-0.41	-0.19	0.03	0.65	0.27	0.02	0.26	0.21	-0.07
5	-0.42	-0.40	-0.48	-0.14	-0.42	-0.15	0.17	-0.08	0.00
8	-0.43	-0.45	-0.62	0.03	-0.16	-0.06	0.33	-0.02	0.03
1	-0.44	-0.34	-0.57	0.25	-0.28	0.02	0.05	0.16	0.24
67	-0.44	-0.18	-0.58	0.16	0.04	0.12	0.44	-0.03	0.23
66	-0.45	-0.09	-0.13	0.20	0.26	-0.09	0.30	0.66	-0.04
9	-0.46	-0.43	-0.59	-0.08	-0.08	-0.11	0.38	0.04	-0.02
11	-0.46	-0.41	-0.54	-0.06	-0.44	-0.11	0.18	-0.09	0.10
6	-0.47	-0.20	-0.31	-0.06	-0.61	-0.09	-0.09	-0.14	-0.21
71	-0.47	-0.48	-0.58	0.09	-0.09	-0.08	0.16	0.07	-0.02
69	-0.48	-0.45	-0.53	0.03	-0.40	-0.10	0.07	0.02	0.03
34	-0.53	-0.36	-0.19	0.04	0.12	-0.10	0.42	0.15	0.03
68	-0.54	-0.39	-0.43	0.18	-0.11	-0.15	0.10	0.25	0.25