ASSESSING FLOOR SLIPPERINESS IN CAMPUS DINING HALLS USING OBJECTIVE AND SUBJECTIVE MEASURES

by

Kevin Johnson

Fall 2017

Director of Thesis: Michael Behm, PhD

Major Department: Occupational Safety

Floor slipperiness is a critical issue in slip and fall incidents which are a major source of occupational injuries. The objectives of this study were to investigate if the protocols used in a field study conducted in Taiwan could be used in similar environments and whether consistent results could be obtained. Protocols used in the field study to investigate floor slipperiness in western-style fast-food restaurants in Taiwan, included both objective and subjective measurements. Using the same methods as in Taiwan, friction was measured on tiles in five major working areas of 4 university campus dining hall kitchens as an objective measurement of slipperiness; the subjective measurement was employees' ratings of floor slipperiness of the same areas. The Pearson's correlation coefficient in the dining halls between the averaged friction coefficients and subjective ratings for all 20 evaluated areas across four dining halls was 0.64, which was higher than the correlation of 0.49 obtained in Taiwan. Cultural differences, the amount of water on the floors in the sink areas, and the use of college campus dining halls over fast-food restaurants might be contributors to the higher correlation coefficients in this study. However, the current study confirmed the results obtained in Taiwan, that average friction coefficient and perception values are in fair agreement, suggesting that both might be reasonably good indicators of slipperiness.

ASSESSING FLOOR SLIPPERINESS IN CAMPUS DINING HALLS USING OBJECTIVE AND SUBJECTIVE MEASURES

A Thesis

Presented to the Faculty of the Department of Technology Systems

East Carolina University

In Partial Fulfillment of the Requirements for the Degree

Master of Science in Occupational Safety

Kevin Patrick Johnson

Fall 2017

ASSESSING FLOOR SLIPPERINESS IN CAMPUS DINING HALLS USING

OBJECTIVE AND SUBJECTIVE MEASURES

by

Kevin Johnson

APPROVED BY:

DIRECTOR OF
THESIS: ____
(Michael Behm, PhD)

COMMITTEE MEMBER: ______________________________________
(Ricky Castles, PhD)

COMMITTEE MEMBER: ______________________________________
(Kanchan Das, PhD)

CHAIR OF THE DEPARTMENT
OF TECHNOLOGY SYSTEMS: __________________________________
(Tijjani Mohammed, PhD)

DEAN OF THE
GRADUATE SCHOOL: ____
(Paul J. Gemperline, PhD)

ACKNOWLEDGEMENTS

I would like to thank Dr. Mike Behm, Dr. Hamid Fonooni, and Dr. Sandra Cole for my acceptance into the MS, Occupational Safety program at East Carolina University and for their guidance along the way. I would also like to thank Dr. Kanchan Das and Dr. Ricky Castles for being a part of the committee for this thesis. Last, I would like to thank my parents for providing me with the opportunity to gain this tremendous education and the necessary tools to succeed in life.

Table of Contents

List of Tables

List of Figures

CHAPTER I

Introduction

Slips, trips, and falls constitute most general industry accidents, as they are attributed to 15% of all accidental deaths in the United States, and are the second leading cause of fatalities, with death by motor vehicle being the first. In 2013 alone, falls from the same level cost companies $7.94 billion (OSHA, 2015). There are a variety of contexts of which slips, trips and falls may occur, and it imperative to understand their greatest potential for danger. Many hazards associated with slip, trip and fall injuries include floor cleaning, leaks, and incidents which occur because of materials and debris left in walkways. Examples include protruding nails and boards, bunched floor mats, uneven carpeting, holes or depressions in working surfaces, and step-risers on stairs that are not uniform in height (Copeland, 2016). As such, uneven floors or working surfaces increase the potential of trips.

In recent years, there have been major advances in the scientific research surrounding the topic of slips, trips, and falls in an occupational setting. More specifically, research has unveiled a correlation between the measurements taken by a new measuring instrument referred to as a tribometer, and actual human slip experiences. A tribometer, often referred to as a slip meter, is an instrument which measures the slipperiness of walkway surfaces, through friction measurements, known as the coefficient of friction (COF). Building codes, safety codes, and accessibility regulations require adequate walkway slip resistance, without any specification of how to properly confirm whether the traction of a walkway is sufficient, an issue which could potentially be resolved by utilizing a tribometer. Demonstrating that a walkway surface will provide sufficient traction is a complex task, therefore it is important to note that before an individual is permitted to use a tribometer, their expertise and experience of using such an instrument is warranted. Altogether, this advancement in research not only continues to improve and build upon existing methods, but also aids in establishing credible data for future research (Leffler, 2015).

The National Floor Safety Institute (NFSI) reported a variation of noteworthy statistics, related to the incidence of accidents caused by slips, trips, and falls (NFSI, 2016). This report highlights the negative impact of such accidents in employee settings, and states that while slips and falls are not the primary cause of fatal occupational injuries, they are deemed as being the primary cause of lost days from work. Among individuals aged 55 years and older, slips and falls are the leading cause of both workers' compensation claims and occupational injury, and approximately 85% of workers' compensation claims are attributed to employees slipping on slick floors. Further, 22% of incidents caused by slips and falls resulted in more than 31 days away from work, while falls on the same level, accounted for roughly 60% of all compensable fall cases. Interestingly, falls in general, were found to be the leading cause of all hospital emergency room visits, with over 8 million (21.3%) reported visits. Moreover, slips and falls account for over 1 million (12%) of these visits, with 5% resulting in a fracture, which is the most serious consequence of falls (NFSI, 2016).

The Liberty Mutual Research Institute for Safety (LMRIS) stated that the annual direct cost of disabling occupational injuries in the United States, due to slips, trips, and falls, is estimated to exceed $11 billion (LMRIS, 2016). The LMRIS also stated that falls on same level are the second costliest occupational injury, with an estimated annual cost of $6.7 billion, just behind overexertion. Liberty Mutual shows that bodily reaction, which comprises injuries from slipping or tripping without falling, is the third highest injury category, followed by falls to lower level, which costs $4.6 billion. These injuries may result in employee absence, lost productivity, high workers' compensation claims, and reduced employee morale. In 2005, falls in the work-place accounted for more than 700 deaths and more than 200,000 injuries involving days away from work.

When specifically analyzing the amount of slips, trips, and falls in U.S. restaurants, the Bureau of Labor Statistics (BLS) reports that there were 13,660 total events or exposures leading to injury in 2015. Of those 13,660 events, 9,980 (73%) were reported to be from falls on the same level. The same report also specified that in limited-service restaurants, the category that includes fast-food restaurants, that limited-service restaurants comprised 5,460 of the 13,660 (39%) total restaurant events and 4,010 of the 9,980 (40%) total from falls on the same level restaurant total (BLS, 2015). This shows the importance of analyzing the slipperiness of fast food, or in this case campus dining halls, flooring in further prevention of these incidents.

This study aims to analyze the potential for employee injuries from slips, trips, and falls from slippery walking and working surfaces, by investigating subjective and objective slippery measurements in common kitchen working areas of dining halls located in a university campus setting. This study will follow methods which are similar to those used in previous studies conducted in the kitchens of fast-food restaurants located in Taiwan and the United States (Chang et al., 2006). The objective floor slipperiness results were obtained using a Brungraber Mark IIIB tribometer, when determining COF measurements. Employee perceptions of slippery work areas in the kitchens, were obtained using a survey, with scale ratings from 1-4 for each observed area. The subjective and objective results are compared to find mathematical correlations to establish relationships. Positive correlations between the two will help validate the findings of previous studies that human perception of floor slipperiness coincides with friction measurements, and is a viable option when investigating and mitigating the risks of slippery walkway surfaces for employees.

CHAPTER II

Literature Review

Types of Slips

In reference to pedestrian slip events, there are two main types of which occur on walking and working surfaces, including heel slips and toe slips. Heel slips, which are the most common cause of slip-related falls, occur at the end of the leg swing phase of the walking stride, as the leading heel contacts the walkway and slides forward. The possibility of an individual suffering a fall increases simultaneously with their momentum, as this increases the force of the slip and thus, the leading leg is unable to support their body weight. The second type of slip are toe slips, which occur when the trailing foot of an individual slips at push off when walking. In contrast, toe slips typically do not cause an individual to fall, as most of their body weight has already shifted to the leading leg (Redfern et al., 2001). Hsiao and Robinovitch (1998) studied common protective movements associated with falls from standing height, and found that when compared to posterior or lateral translations (i.e., forward falls), a fall was more than twice as likely to occur after anterior translations of the feet (i.e., backward falls). As such, this backward fall mechanism appears to be a common injury mechanism, due to slipping after heel contact when walking (Leclercq, 1999).

Figure 1 depicts a conceptual scenario of the events leading to slipping and falling after heel contact is initiated and the measurement of slipperiness processes prior to and during slipping: static friction coefficient (ms), transitional kinetic friction coefficient (mt), and steady-state kinetic friction coefficient (mk) relate to the shoe/floor interaction, while center of body mass (COM), base of support (BOS), and center of foot pressure (COP) relate to postural balance and stability (Gronqvist et al., 2001).

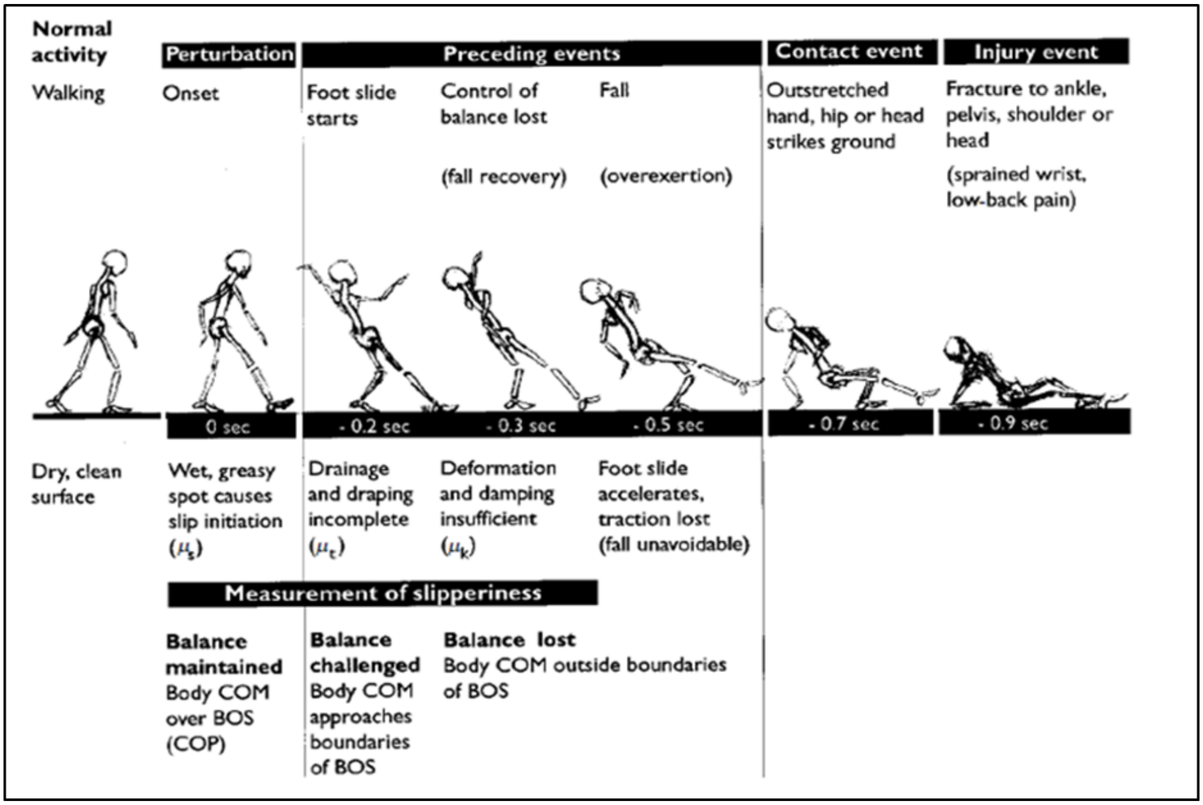


Figure 1- A conceptual scenario of the events leading to slipping and falling after heel contact. (Gronqvist et al., 2001).

(Reproduced with permission by UK Book Permissions).

Friction and Measurement

Friction, defined as the force resisting the relative motion of adjacent contacting materials (Leffler, 2015), is the most commonly used approach when measuring slipperiness, and past studies have demonstrated a strong correlation between friction and slipperiness (Chang et al., 2001). A known quantifier in measuring walkway friction and traction is the coefficient of friction (COF). The COF is defined as a force ratio between 0 and 1, of the quotient of the horizontal force, and the vertical force (i.e., gravity) between the surface, and the shoe material when walking (Leffler, 2015). To prevent a slip, the resisting friction force should be at least as high as the horizontal component of the force applied by the foot of which is against the ground. Walking can be deemed as safe when the measured friction coefficient is greater than the ratio of the horizontal and vertical components of the ground reaction force for the actual shoe/floor condition. (Gronqvist et al., 2001). Figure 2 shows the minimum friction requirement for slip avoidance based on the equilibrium of forces at heel contact: friction force (F_{μ}), normal force (F_N) and the friction coefficient (μ), as well as the horizontal (F_H) and vertical (F_V) force components applied by the foot are shown together with the locations of the center of body mass (COM) and the center of foot pressure (COP).

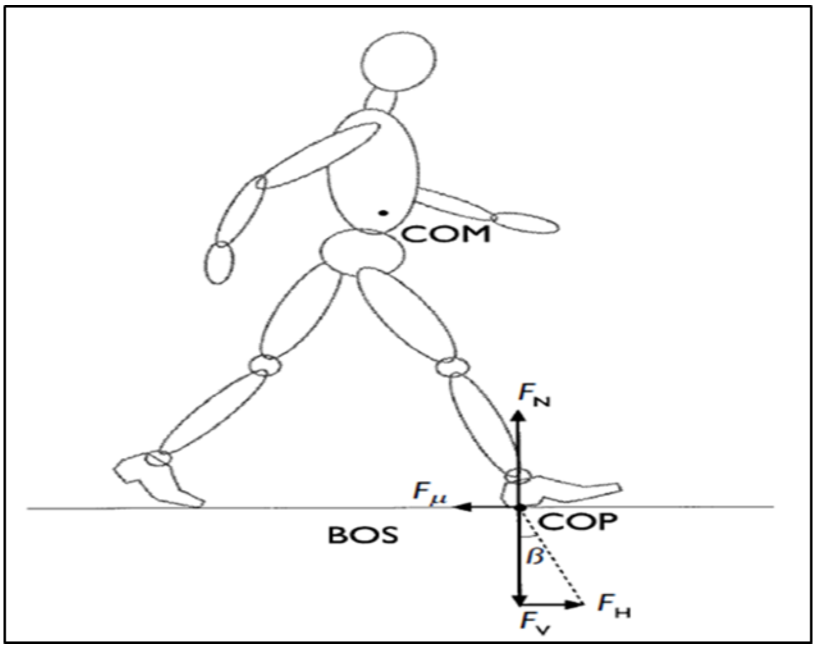


Figure 2- The minimum friction requirement for slip avoidance. (Gronqvist et al., 2001).

(Reproduced with permission by UK Book Permissions).

Research surrounding friction measurement is scant, and is currently an empirical study, meaning there are no formulas that can perfectly predict frictional interaction, so friction must be measured. Leffler (2015) describes how walkway traction measurements may be obtained using several methods, which are defined below:

Tribometer testing. A walkway tribometer is a mechanical or electromechanical device used to measure the frictional forces acting at the interaction of a walkway surface and a test foot footwear material surface.

Human subject traction demand testing. In this testing, human test subjects walk along a laboratory walkway that includes a force-plate. This thick metal plate is mounted flush to the walkway and is supported by electronic force sensors. These measure the vertical, lateral, and longitudinal walking forces applied to it by the human test subjects. These force measurements are used to calculate the traction required by that pedestrian. This testing typically does not involve the pedestrian slipping as adequate traction is provided on the force plate surface.

Human subject slip testing. In this testing, human test subjects walk along a slippery walkway. In level walkway slip testing, a force-plate is often used to evaluate applied walkway forces at the point of slipping. Ramped walkway slip testing is also done, in which a slippery ramp surface is traversed by a human test subject while the ramp angle is increased up to the point of slip – and the friction measurement is derived from the ramp angle.

It is also important to consider the contributing physical elements when measuring friction between the walking surface and the foot material. These elements include: surface roughness, asperities, slope, contours, draping, contact force magnitude, contact velocity and acceleration, hysteresis, damping, tearing, mechanical interlocking, molecular bonding, plastic deformation, wear, and contaminants (Chang et al., 2001). Two of the most influential, surface roughness and asperities, are discussed below:

Surface roughness. Evaluated at a microscopic scale, roughness is expressed as the average height of walkway surface features. Though traction is related to the surface roughness of both the walkway and the footwear (or foot), the averaging that is necessary for roughness calculations reduces its usefulness – disparate microscopic walkway surface “profiles” may nevertheless have the same roughness value (Chang et al., 2001).

Asperities. Individual features that protrude above the basic “average” surface. High, sharp asperities may protrude above contaminants for more mechanical interlocking with the footwear or foot. The height, sharpness, and distribution of asperities may vary widely across a walkway surface, particularly with broom-finished concrete, natural slate, and some textured ceramic tiles. Hard-surface walkways without significant roughness or asperities, such as polished marble or terrazzo, rely more on molecular bonding and less on mechanical interlocking with the footwear or foot. (Chang et al., 2001).

Traction Testing Terms

There are several different types of coefficient of friction (COF) that are referred to in pedestrian walkway analysis. Leffler (2015) defines the following:

Static (SCOF). The COF calculated when the object is stationary but at the point of incipient slipping.

Dynamic (DCOF). The COF calculated when the object is sliding along the surface. The maximum value of DCOF is typically at a steady velocity where the moving object is almost stopping.

Transitional (TCOF). The COF calculated at the transition from static friction to steady state dynamic friction resulting from simultaneous vertical & horizontal contact force application.

Required (RCOF). The COF calculated from measured walkway forces applied by a pedestrian from force plate readings in a controlled laboratory environment. Also called Utilized Coefficient of Friction (UCOF).

Available (ACOF). The COF calculated from tribometer testing of the frictional properties inherent in a walkway surface.

Just as there are elements that affect the physical environment of the friction between the walking surface and footwear, walkway traction often also involves contaminants, which introduce possible additional surfaces between the two. A more relevant term for pedestrian walkway traction is slip resistance. This term is sometimes used interchangeably with COF, though its definition goes beyond that of COF (Leffler, 2015):

Slip resistance. The relative force that resists the tendency of the shoe or foot to slide along the walkway surface. Slip resistance is related to a combination of factors including the walkway surface, the footwear bottom, and the presence of foreign materials between them (ASTM F1646).

Laws and Standards

There are enforceable codes and regulations that require that walkways be slip resistant, but they do not specify any means for determining if a walkway truly is slip resistant. These include both the National Fire Protection Association (NFPA) 101 Life Safety Code, and the Americans with Disabilities Act (ADA) Accessibility Guidelines for Buildings and Facilities. Prior to 2004 the ADA recommended a COF of 0.6 for level surfaces and 0.8 for ramps using an ASTM C1028 horizontal pull slip-meter. These values are widely misquoted as being current requirements, though they are neither current nor are they requirements. For example, compliance to NFPA codes and standards are not required by law, except for a few instances where in some cases federal or state Occupational Safety and Health (OSHA) agencies have incorporated wording from NFPA standards into regulations (NVFC, 2012). Further, these values were also based on research conducted using a tribometer testing configuration, which was later found to be improper, as the soft, silicone rubber test foot, used on the tribometer, was intended to simulate barefoot pedestrians, not pedestrians in footwear (Leffler, 2015).

The Occupational Safety and Health Administration (OSHA) does not have any standards that mandate a set coefficient of friction (COF) for walking and working surfaces. While there are devices to measure the COF, no OSHA standard specifically requires that employers use or have them. OSHA also recognizes that slip resistance can vary from surface to surface, or even on the same surface, depending upon surface conditions and employee footwear, making it difficult for them to have a set standard (OSHA, 2005).

-International Code Commission (ICC) International Building Code (IBC): This standard uses ANSI/ICC A117.1 Accessible and Usable Buildings and Facilities. Both documents require walkways to be slip resistant.

Just as there are enforceable codes, there are also non-enforceable consensus standards, which recommend that walkway surfaces have a certain amount of traction. These include:

-American National Standards Institute (ANSI) / American Society of Safety Engineers (ASSE) A1264.2 Provision of Slip Resistance on Walking/Working Surfaces: This standard suggests a slip resistance of 0.5, and states that traction testing shall be done using a tribometer that meets ASTM F2508 Standard Practice for Validation, Calibration, and Certification of Walkway Tribometers Using Reference Surfaces. However, this still does not establish a methodology for verifying a slip resistance of 0.5, as ASTM F2508 is not a traction testing methodology (Leffler, 2015).

-ASTM F1637 Standard Practice for Safe Walking Surfaces.

-ANSI / Tile Council of North America (TCNA) A137.1 Specification for Ceramic Tile: This standard covers a variety of factors with ceramic tile, including COF. It specifies a test procedure for DCOF testing and a recommended minimum value for tiles tested using specific tribometers.

-ANSI / National Floor Safety Institute (NFSI) B101.1 Test Method for Measuring Wet SCOF of Common Hard-Surface Floor Materials: This standard specifies three different SCOF measurement ranges for different levels of walkway traction. This is only possible due to the standard's reliance on a restricted set of specific tribometer models. As will be discussed, differences in tribometer designs will result in different measurement values on the same surface – precluding the possibility of having one standard threshold slip resistance value that works with all tribometers (Leffler, 2015).

-ANSI/NFSI B101.3 Test Method for Measuring Wet DCOF of Common Hard-Surface Floor Materials: This standard specifies three different DCOF measurement ranges for different levels of walkway traction. As with B101.1, this is only possible due to the standard's reliance on a restricted set of specific tribometer models.

-Underwriters Laboratory (UL) 410 Slip Resistance of Floor Surface Materials: This standard specifies that floor covering materials, floor treatment materials, and walkway construction materials shall have a static COF of 0.5 under material-specific test conditions – all measured using a James Machine in a specific methodology. The James Machine is a non-portable lab-only machine weighing over one hundred pounds (Leffler, 2015).

-ASTM D2047 Standard Test Method for Static Coefficient of Friction of Polish-Coated Flooring Surfaces as Measured by the James Machine: This standard specifies that floor polishes and coatings shall have a dry SCOF of at least 0.5 using the methodology and equipment specified in the standard only.

Traction Requirements

Although there are no official requirements for walkway traction, for decades the commonly referenced safe traction threshold was a measured static COF value of 0.5. This value was recommended in 1945 by UL's Sidney James. ASTM D2047 dates from 1964, mentioning data as far back as 1942, is the only active ASTM test method that establishes 0.5 as a traction requirement, but only for floor polishes. It has been widely stated in both general publications and court decisions that ASTM requires a traction value of 0.5 in general, without the qualifiers documented in D2047.

In *Phelps v. Stein Mart* (2011), two opposing experts agreed that ASTM requires a COF of 0.5 even though they were testing a ceramic tile and that they both used a test device completely different from a James Machine. The Phelps case is further illustrative in that the opposing experts also agreed that OSHA, ANSI, and UL all require a COF of 0.5. OSHA did have a requirement for a slip resistance of 0.5, but this was only for structural steel walking surfaces, and this requirement was rescinded in January of 2006. The sole OSHA walkway traction requirement (i.e., 0.5 COF), is for man lift platforms in 29 CFR1910.68(c)(3)(v), a regulation which lacks a methodology for verification. UL410 requires a COF of 0.5, but only for surfaces being tested with a James Machine, to a specific methodology. It is important to note however, that ANSI is a standards development organization accreditor, not a standards development organization itself. ANSI cannot require a COF value. The ANSI accredited American Society of Safety Engineers (ASSE) committee that created A1264.2 does suggest a slip resistance value of 0.5, but without a methodology for verification.

As to other foundations with a traction value of 0.5, human slip research with force plate analysis of required COF, typically results in RCOF values of roughly 0.20-0.30. As such, many practitioners use a 2X safety factor to help bring this value up to 0.5. Despite the arbitrariness of this safety factor magnitude, a value of 0.5 is treated as a hard number, and thus a value of 0.48 is considered as being dangerous to pedestrians, whereas a value of 0.52 is not. Lastly, treating 0.5 as a universal threshold is not defensible across the wide range of tribometer designs, and devices that are currently in use today (Leffler, 2015).

Pedestrian Traction

There have been studies conducted to quantify the traction among pedestrians of all ages, and this research shows how much they require for walking without concern for traction and how much traction they use when they have some expectation of reduced traction on walkway surfaces. Redfern et al. (2001) calculated RCOF values of 0.17-0.22 for level surface walking. Burnfield et al. (2005) studied young and elderly pedestrians with and without a disability, calculating a mean RCOF of 0.23 in level walking. As previously mentioned, these values are commonly referenced in the context of safety thresholds for traction in tribometer testing, doubling the RCOF values to get 0.5. The problem with these is that the amount of traction used by a pedestrian is not directly comparable to the amount of traction that can be measured by a machine. A study by Powers et al. (1999) compared tribometer forces measured on a force plate with the tribometer readings themselves, but the force onset magnitudes and durations are completely different between humans and tribometers when compared to the results found in Redfern et al. (2001).

Slip Testing with Tribometers

Due to the complications of the elaborate testing methods, as well as ethical concerns, human slip research and human slip testing methods are not a practical way to conduct field testing of walkway surfaces. Therefore, we use tribometers. The primary struggle with tribometers is finding a direct correlation between their measurements and actual human slips. European ramp slip studies have formed the basis for some ANSI standards, using slip measurement results with a safety factor, and applicable to certain tribometers. New ASTM standards have been based on research at the University of Southern California (USC) (Powers et al. 2010), where human subjects were used to rank four standardized reference tiles by the type and number of slips on each.

Tribometers that can properly rank and statistically differentiate the four reference tiles can be compared with the USC research. In pedestrian slip research studies, the human subjects typically wear a safety harness with an overhead lanyard attached, to prevent them from falling if they slip. This brings up the issue of human expectation of the slippery surface. Beringer et al. (2014) demonstrated that pedestrians modify their walking gait if they have some expectation they might slip. In COF testing, there may be visual warnings of a potentially slippery surface, such as walkway glossiness, or the potential hazard may be known to the test subjects in advance. Cham and Redfern (2002) found a 16-33% reduction in RCOF for pedestrians of whom were unsure of which walkway contaminant conditions they would encounter. In ramp traction testing, the pedestrians know they will slip, and they are in fact trained to walk in certain ways that may not be representative of normal human gait. Level walkway traction testing may be configured to reduce both the test subjects' expectations that they may slip and their knowledge of slippery conditions (Powers et al., 2010).

Tribometers

Tribometers contact the walkway surface with a test foot to mimic the bottom sole of a shoe. Some tribometers use a laboratory grade standardized rubber called Neolite as the test foot material, while others use styrene butadiene rubber (SBR), which is a common polymer used for footwear outsoles. Some older tribometers are used with leather test feet despite the inconsistencies with leather being an organic material (Leffler, 2015).

When testing, the test foot material must contact the walkway surface for the measurements to be meaningful. Using a tribometer to test surfaces such as gravel or broken glass particles is typically not scientifically supportable or likely to be backed up by human slip research. Hard particles of gravel or glass raise the test foot above the walkway surface, and the resultant rolling friction will vary with the distribution of the particles. Broken glass and other crushable contaminants will disintegrate to varying degrees, depending upon the contaminant and the tribometer forces applied. This affects both the relevance and reliability of such testing (Leffler, 2015).

The tribometers described below by Leffler (2015) are portable, common, and available for purchase in the United States. A few of the tribometers may be used on stairs, but may only work in specific areas or directions on the stair treads when measuring. Templer (1995) details certain tribometers may be used on ramps and slopes, though measurements usually need to be adjusted for the effects of gravity through trigonometry based correction factors.

Drag Sled Tribometers. Drag sled tribometers work as their name states, by dragging a weighted test foot across the walkway surface. There are both manually operated and motorized drag sleds. Manual drag sleds, in addition to many motorized drag sleds, calculate static COF (SCOF) when the test foot becomes motionless against the walkway surface. Brungraber (1976) stated that this can affect the accuracy of measurement because of the possible molecular bonding or adhesion of the test foot to the walkway surface while stationary. Adhesion is problematic in wet testing, as it can result in high measurement values, causing walkways to be tested as being safer than they are. Some tribometer standards and manufacturers state that SCOF tribometers are only to be used on dry walkway surfaces. Additionally, an important problem with manual drag sleds is that the operator can affect the measurement results by varying the way the device is actuated, whether intentionally or not. Some of the motorized drag sleds can perform dynamic COF (DCOF) testing, which typically is not affected by adhesion (Leffler, 2015). Defined below, are examples of various drag-sled models:

Horizontal Dynamometer Pull-Meter. This manual drag sled is described in the withdrawn ASTM C1028 standard test method. For years, it was the main device for SCOF testing of ceramic tiles. It uses a 3” x 3” test foot beneath a 50-pound weight. Many traction specifications for tiles still reference ASTM C1028 testing, even though tile industry standards no long reference SCOF measurements.

Figure 3- Horizontal dynamometer drag sled pull-meter (Slip Doctors, 2017).

(Reproduced with permission by Slip Doctors).

Regan Scientific: BOT-3000 and BOT-3000E. This is a motorized drag sled which uses powered wheels to travel across the walkway. It uses a 0.12” x 1.1” test foot. It can be used in both static and dynamic COF modes. The BOT-3000 is specified as the tribometer to use for dynamic COF testing in the ANSI/TCNA A137.1 standard for ceramic tile. It is also an approved tribometer for the ANSI/NFSI B101 standards published by the National Floor Safety Institute.

Figure 4- BOT 3000E motorized drag sled tribometer (Slip Doctors, 2017).

(Reproduced with permission by Slip Doctors).

CSC Force Measurement: Horizontal Pull Slipmeter (HPS). This SCOF tribometer uses a cable and winch system to pull a manual drag sled. It uses three ½" diameter discs for test feet. ASTM F609 specifies its use for dry walkway testing. The device measures "slip index", which is a multiple of SCOF.

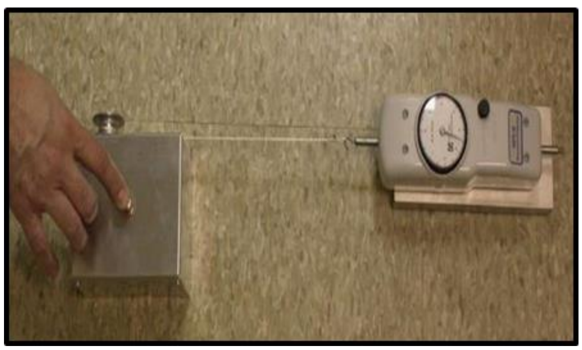


Figure 5- CSC force measurement horizontal pull slipmeter (C.S.C Force Measurement, 2017).

(Reproduced with permission by C.S.C Force Measurement, Inc.).

American Slip Meter: ASM 825 and 825A. This manual drag sled uses three 1/2" diameter discs as test feet, and measures static COF.

Figure 6- American Slip Meter ASM 825A manual drag sled (Slip Doctors, 2017).

(Reproduced with permission by Slip Doctors).

Articulated-Strut Tribometers:

Articulated strut tribometers use angled struts that kick out when a test foot slip occurs. The designs avoid adhesion in testing by simultaneously applying the horizontal and vertical forces of the walkway surface load to the test foot. Defined below, are examples of articulated-strut tribometer models:

Slip-Test Walkway Tribometers: Mark IIB and Mark IIIB Portable Inclinable Articulated-Strut Slip Tester (PIAST). These tribometers use a sliding 10-pound weight (Mark IIB) or compression spring (Mark IIIB) for actuation of a 3” x 3” test foot. These tribometers measure transitional COF (TCOF) and can be used on sloped walkway surfaces.

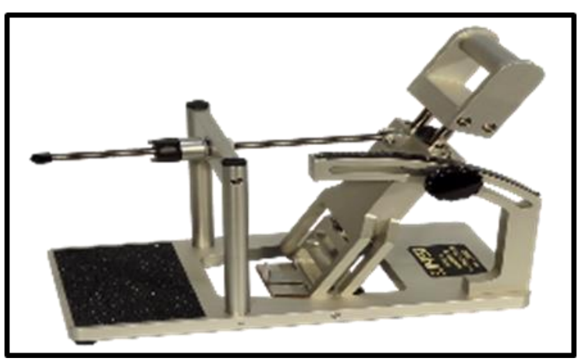


Figure 7- Mark IIIB portable inclinable articulated-strut slip tester (Slip Doctors, 2017).

(Reproduced with permission by Slip Doctors).

Excel Tribometers: English XL Variable Incidence Tribometer (VIT). This tribometer uses a CO_2 cylinder for pneumatic actuation of its 1.25" diameter test foot. There are two primary models, one with a manual pneumatic trigger and one with a sequencer that automates some aspects of trigger actuation. The device measures slip index and can be used on sloped walkways.

Figure 8- English XL variable incidence tribometer (Slip Doctors, 2017).

(Reproduced with permission by Slip Doctors).

The layouts, test feet sizes, and functional characteristics of these tribometers are all different. Because of these differing characteristics, the empirical friction measurements from each tribometer can be expected to vary, even when used on the same walkway surfaces. These are what makes standardizing a set COF value for walkways so difficult when using different tribometers. Despite each device having its own calibration, they differ in methodology, so not only would all tribometer designs have to provide identical results on the same surfaces, but all individual units of each tribometer design would need to provide identical results as well (Leffler, 2015).

Powers et al. (2010) demonstrated this by performing tests using eleven different tribometer designs on the same four surfaces. On the safest surface, the traction measurements varied drastically from 0.24 to 0.94. This proves that it is impossible to simply specify a coefficient of friction value for a surface without also specifying the tribometer and the test method. Moreover, Phelps v. Stein Mart (2011) further demonstrated that there are instances when tribometer operators, and sometimes the manufacturers themselves, will claim that their tribometer can test a walkway surface in accordance with a standard that requires a different tribometer.

Elements of Tribometer Results

Leffler (2015) discusses how other than comparative studies, the usefulness of a tribometer is dependent on the extent that it is correlated to human slips. There are several key elements Leffler (2015) further describes using a tribometer to evaluate the walkway traction available to a human. These elements include the following:

"**Element 1**. Is there a reliable correlation between the tribometer's measurements and actual human slip experiences?

Element 2. Has the tribometer undergone studies to evaluate how repeatable its measurements are – will it provide consistent measurements test after test?

Element 3. Has the tribometer undergone studies to evaluate how reproducible its measurements are – from user to user and machine to machine?

Element 4. Was the tribometer used for an analysis operated per the methodology applicable to the repeatability and reproducibility studies?" (Lefler, 2015)

Element 1: Is there a reliable correlation between the tribometer's measurements and actual human slip experiences?

European researcher (Sebald, 2009) has defined reference tiles that have known traction values based on human slip testing on ramps and measurements with specific tribometers. Sebald then required the use of specific tribometers capable of measuring these "known" surfaces as having the “correct” value. The previously mentioned ANSI/TCNA A137.1 and ANSI/NFSI B101.3 standards rely on this research and certain associated tribometers.

Another method of correlation has been through the previously mentioned level walkway traction studies conducted at the University of Southern California (Powers et al. 2010). The research involved test subjects walking across four different standardized walkway tiles, with each tile having a different wet traction. The number of no-slips, heel-slips, and toe slips on each tile was recorded. The human subjects then ranked the surfaces based on slipperiness and the researchers compared that information with the tribometer results. ASTM F2508 is based on this research and formalizes that tribometer validation is achieved when a tribometer model can rank and differentiate a duplicate set of the four standardized tiles in the same manner the subjects in the Powers study did. Tribometers that claim validation to ASTM F2508, are certain models of the English XL, Mark IIB, and Mark IIIB. It is important to note, that each method is predicated on the assumption that the standardized tiles are duplicates of the ones used in the Powers study.

Element 2: Has the tribometer undergone studies to evaluate how repeatable its measurements are – will it provide consistent measurements test after test?

Per Leffler (2015), all tribometers will have random and systematic error, and these measurement errors must be understood if claims about the safety of a walkway are based on those measurements. Statistical analysis of repeatability can be done through repetitive tribometer measurements taken in one sitting by one operator. For example, the validation procedure in ASTM F2508 requires 40 tribometer test foot slips on each of the four standardized reference tiles, assuming a Gaussian distribution of the data points. The standard deviation of the mean can then be calculated for each reference tile. A large repeatability standard deviation points to significant variability in these measurements. Many tribometer models have yet to undergo a published repeatability study.

Element 3: Has the tribometer undergone studies to evaluate how reproducible its measurements are – from user to user and machine to machine?

Repeatability, as mentioned in Element 2, deals with the measurement results gathered by one operator using one tribometer in one session of testing. This does not mean that different operators or even different units of the same tribometer model will provide comparable results. Many researchers use inter-laboratory studies (ILS) to obtain both the repeatability and the reproducibility of the test methods. The test methods will include the tribometer operating method, walkway surface preparation methods, and contaminants to use. This shows that the ILS is evaluating the variability in the entire methodology, not just the tribometer. In the ILS for ASTM E691, 6 to 30 independent labs test the same samples with each lab using different operators and different units of the tribometer and test foot. The reproducibility statistics, assuming a normal distribution, will show the scatter of measurement results due to the variability between different operators and different units of the tribometer. A high value for the reproducibility standard deviation can lessen the certainty of the conclusions that can be drawn from analyses using that tribometer model (Leffler, 2015).

Element 4: Was the tribometer used for an analysis operated per the methodology applicable to the repeatability and reproducibility studies?

For the human slip correlations and the repeatability/reproducibility studies to be useful in an analysis, they must all have been performed with a consistent setup of the tribometer and test foot used with a consistent methodology. If the tribometer and test foot setup is not the one correlated to human slips, or if the referenced human slip research is technically questionable, then claims about a walkway's traction are compromised. Also, if there is no reproducibility analysis, or if the ILS method used was questionable, the ability of the operator to claim their tribometer measurements relate to any benchmark is reduced (Leffler, 2015).

Subjective vs. Objective Research

Chang et al. (2004) investigated floor slipperiness in seven kitchen areas of 10 western-style fast-food restaurants in Taiwan using both objective and subjective measurements, conducted by tribometer testing (objective) and employees' ratings of floor slipperiness through a survey (subjective). The employees were asked to rate each area based on a 4-point Likert scale, with 1 being "extremely slippery" and four "not slippery at all." The friction measurement results showed that the sink area had the lowest average friction in the kitchens, while the employees rated both the sink and back vat (chicken fry) areas as the most slippery locations. Their results indicated that average friction coefficient and perception are in fair agreement, suggesting that both may be reasonably good indicators of slipperiness.

Chang et al. (2006) conducted a similar study at fast-food restaurants in the United States to compare to the previously mentioned Taiwan study to see if they could obtain consistent results. They found that the average objective and subjective ratings were lower in the United States, citing variables such as cultural differences, the amount of water on the floors, and the existence of a slip resistant shoe program in some U.S. restaurants as possible contributors to the lower U.S. results. However, this study confirmed the results from the Taiwan study (Chang et al., 2006), that average friction coefficient and perception values both might be reasonably good indicators of slipperiness.

Brungraber Mark IIIB

The tribometer used for this study is the Brungraber Mark IIIB. As previously noted, the Brungraber Mark IIIB is a portable inclinable articulated-strut slip tester (PIAST). It uses an internal compression spring for actuation of a 3” x 3” test foot, usually made of Neolite, and measures transitional coefficient of friction (TCOF). The validation procedure for the Brungraber Mark IIIB is the ASTM F2508. This requires 40 tribometer test foot slips on each of the four standardized reference tiles, assuming a Gaussian distribution of the data points. The standard deviation of the sample can then be calculated for each reference tile to determine variability. This slip meter meets all four elements of tribometer results noted by Leffler (2015).

This study was based on the Chang fast food experiments, which utilized an older model, the Brungraber Mark II, however for this study, the Brungraber Mark III was utilized. Lia, Chang, and Chang (2009) conducted a study to test the relationship between the Brungraber Mark III and the previous model Brungraber Mark II. The researchers compared force platform based coefficient of friction readings with those found from the two tribometers. The calculated regression coefficients indicated the COF value obtained with each slip meter was closely predicted by the coefficient of friction value based on the force platform measurement. The results also showed that the force platform values were closer to the ones obtained with the Brungraber Mark III than with the Brungraber Mark II. This implied that the friction values obtained with the Brungraber Mark II slightly underestimated the actual COF values based on the data from the force platform.

The researcher also found that the Brungraber Mark II generated a significantly higher normal force than the Brungraber Mark III when the coefficient of friction value was low, but the difference of the normal force between the two slip meters became small when the coefficient of friction value was high. The results of this study indicated that the Brungraber Mark III has the same repeatability as those of the Brungraber Mark II under the test conditions (Lia, Chang, and Chang, 2009).

Litigation Considerations

As previously noted, the possibility of having one standard threshold slip resistance value that works with all tribometers makes it difficult to determine whether walkway testing with tribometers should be accepted as tangible legal evidence in a court of law. The issue of reproducibility is important in litigation, as to whether other parties can reproduce the testing of one expert, highlighting the importance of repeatable standardized reliability comparison methods for individual tribometers. Advances in tribometers and research have proven past methods can be flawed and manipulated by experts (Leffler, 2015), causing difficulties in using prior court hearings as baselines for future legal cases. One such case as an example where some tribometry methods, now known to be subpar and possibly flawed, were thought of as technological advances at the time, is *Phelps v. Stein Mart* (2011). This case involved a customer suing Stein Mart for negligence when they suffered an injury after slipping on the floor tiles near the entrance of the store. Stein Mart defended themselves using COF results obtained by a technician using a horizontal pull slip meter on the same floor tiles. The court determined the testing to be reliable and Stein Mart won the case. The problem is now knowing that the horizontal pull slip meter has proven to be unreliable because the operator can affect the way the device is actuated, whether intentional or not (Leffler, 2015). It is important for judicial systems to be aware that there isn't one right answer or one right way of testing walkway traction. By taking advantage of the various research and methodologies, tribometry experts should have no excuses in not only understanding their own trade, but their competitors as well for comparisons.

Effectively countering obsolete expertise will further the causes of establishing defensible methods as the new state of the art, and reaching just resolutions to claims and lawsuits (Leffler, 2015).

CHAPTER III

Methods

This study was conducted at four dining halls at the main campus of a university. Both friction measurements and subjective ratings were conducted in each dining hall during common downtime hours after peak serving times, to ensure that both the results reflected the slipperiness of the floors in their most hazardous state, and the safety of the dining hall employees. The attempt was to capture lunchtime conditions as closely as possible for comparisons. The lunchtime conditions in which testing occurred for this study were chosen due to the high amount of contaminants and traffic on the floors in the kitchen areas during peak serving times and immediately following. To ensure the floors were in their highest risk conditions, there was no major floor cleaning in these restaurants between the breakfast or lunch periods and the time when friction was measured.

Major Working Areas

The general kitchen areas investigated in this study included the cooking, food preparation and front counters/service areas. Five major working areas, including fryer/back vat, oven, sink, front counter, and walk through, were identified in each dining hall. These are work areas for most employees and include most of the commonly highly-contaminated areas, along with some less-contaminated areas for comparison. The fryer areas are for frying French-fries, chicken, etc. The front counter is the area to take customers' orders and payments and to deliver food. The oven is used for baking and roasting. The walk-through area is the entrance where employees enter and exit the kitchen. Kitchen flooring within these dining halls were comprised of 6" x 6" and 8" x 8" quarry tiles. The tiles in three of the four dining halls had grit particles embedded on the surface originally, however most of the grit surface appeared to be worn. The tiles in Dining Hall 4 were similar quarry tiles as the other three, but had diamond plate patterned grip protrusions to increase traction. The ages of the tiles were unknown, but the tiles in Dining Hall 4 appeared to be newer than the tiles in the other three dining halls. Only areas found in all dining halls were used for this study. Table 1 illustrates the floor tiles found in each dining hall and Appendix B shows the floor tiles at each location from each dining hall.

Table 1- Measured tile descriptions of each dining hall.

Dining Hall	Tile Photograph	Tile Description
Dining Hall 1		6" x 6" Quarry Tile Worn Grit Particulates
Dining Hall 2		8" x 8" Quarry Tile Worn Grit Particulates
Dining Hall 3		8" x 8" Quarry Tile Worn Grit Particulates
Dining Hall 4		8" x 8" Quarry Tile Diamond Plate Grip Protrusions

Friction Measurement

A Brungraber Mark IIIB Slipmeter, with a Neolite test liner as a footwear pad, was used to measure friction. To eliminate any variation in friction measurements, devices and test pads, the slip meter was operated by the same operator with the same Neolite pad throughout the study. During a measurement, the footwear pad of this slip meter impacts the floor surface at an inclined angle with the vertical direction. If a non-slip occurs at the interface upon the impact, meaning the pad stalls or is delayed prior to slipping across the surface, the inclined angle is increased. Conversely, the angle is decreased if a slip occurs. The dynamic coefficient of friction (DCOF) value is determined by the angle at which a non-slip is changed to a slip.

Pre-Measurement Training

The operator received a walkway auditor training course, and operator training for the slip-test Mark IIIB slip meter from a qualified Forensic Mechanical Engineer, the sole developer of the Mark IIIB tribometer on November 14, 2016. Experience was acquired through various floor measurements conducted at multiple facilities on a university campus since the training occurred.

Surface Conditions

Any loose, gross contaminants on the floor surfaces, such as food, were removed prior to making friction measurements. Wet measurements were conducted at the sink areas by applying water to the floor surface to simulate actual floor slipperiness conditions while dishwashing tasks are being performed. Notwithstanding loose debris and wet testing, the surface conditions were not altered prior to these measurements.

Areas and tiles of friction measurements of the floor are highly location dependent. The more tiles measured, the better the floor slipperiness may be represented. To reflect what employees might encounter when walking through an area, multiple tiles across the area were measured in the selected areas. The line of measurement in the direction of traffic, represent the walk path through the areas with an offset of one foot from the wall or edge of the cooking equipment for the fryer, oven and front counter and 18” for the sink, as employees typically do not walk near these areas. After the line of tiles were selected, friction was measured with a Neolite test foot in both directions along the line. On each tile measured, there was one friction measurement for each direction. The Neolite pad was sanded prior to the friction measurement of each area to maintain a consistent surface condition on the pad. The sanding protocol from the corresponding ASTM F2508-13 standard was used.

Survey of Floor Slipperiness

A floor slipperiness survey, developed by the principal researcher based on those from the aforementioned Chang studies, was used to assess floor slipperiness perceived by employees. All participants who agreed to participate in the survey were individually interviewed. Each participant answered the survey questions anonymously. Participants rated the slipperiness of the same floor areas measured with the tribometer per their experiences. A four-point rating scale was used, with 1 as ‘‘extremely slippery,’’ 2 being “more slippery”, 3 as “less slippery,” and 4 as ‘‘not slippery at all.’’ The complete survey is presented in Appendix E.

Data Analysis

When assessing the correlation between friction readings and employee perception, it is important to have variation in both friction values and perception ratings, based on the selection of participating dining halls and the evaluated areas. As such, various statistical analysis methods, as those conducted in previous similar studies (e.g. Chang et al., 2004, & Chang et al., 2006), were conducted to compare the objective and subjective results of the dining halls and their employees for correlation.

A two-way univariate analysis of variance (ANOVA) was used to determine whether restaurant and area made a significant difference in the measured friction values and perception ratings. A Tukey's honest significant difference (HSD) post hoc test was used to identify if the two-way ANOVA results revealed any sample means that were potentially significantly different from each other. Fisher’s exact test was used to determine whether a relationship exists between the perception results of the different areas at the dining halls. The Pearson’s correlation coefficients between the average friction coefficients and the employees’ subjective ratings were computed.

CHAPTER IV

Results

Friction Measurement

A total of 28 tiles were measured at each dining hall resulting in a total of 112 measured tiles. Table 2 shows the numbers of tiles measured in each area with their corresponding means and standard deviations. The oven and walk through areas had the highest average friction readings, indicating they are the least slippery areas. The fryer and sink areas had the lowest average friction coefficients, indicating they are the most slippery areas.

In addition to the mean friction coefficient, it is also essential to examine the variation of friction on the floors. Although it is not clear about the level of friction variation necessary to increase the potential of slipping and falling, the coefficients of variation (CV), obtained by dividing the standard deviation by its mean value, for friction coefficients of all the areas in the restaurants were calculated. On average, the fryer and walk-through areas had the highest CV values in COF, while the oven and sink areas had the lowest CV values. Table 2 presents the means, standard deviations, coefficients of variation, and sample sizes (N) of the friction coefficients for the five areas in all four dining halls.

Table 2- Means, standard deviations, and coefficients of friction values of the friction coefficients for the areas of all dining halls.

Location	Mean	Standard Deviation	CV	N
Front Counter	0.4138	0.10494	0.2536	16
Fryer	0.3621	0.13906	0.3840	24
Oven	0.4925	0.08704	0.1767	24
Sink	0.3934	0.08392	0.2133	32
Walk-through	0.5425	0.15511	0.2859	16
Total	**0.4321**	**0.12794**	**0.3284**	**112**

For the measure friction, the results of the two-way ANOVA determined the difference among locations and dining halls and the measured results. The location and dining hall are the independent variables and the measured results are the dependent variable. The results of the two-way ANOVA are presented in Table 3. These results indicated that both participating dining halls and evaluated areas were not significant factors (p=0.079), meaning that the results were comparable at each location for each dining hall to enable comparisons among the four separate dining hall locations. When analyzing each friction coefficient mean to determine if any dining halls had extreme upper or lower mean results at each area, it was determined that the floor at the fryer area was the lowest at dining halls 1 and 3, while the sink was the lowest of the areas in dining halls 2 and 4. Also, the walk-through area was the highest in dining halls 1, 2, and 4, but in the middle of the values in Dining Hall 3. The low mean results can be expressed by the upper and lower bounds presented in Table 3.

Table 3- Two-way ANOVA results for location and dining hall (independent variables) and the measured results (dependent variable).

Dining Hall	Location	Mean	Standard Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	Front Counter	0.425	0.018	0.389	0.461
	Fryer	0.237	0.015	0.207	0.266
	Oven	0.423	0.015	0.394	0.453
	Sink	0.489	0.013	0.463	0.514
	Walk-through	0.578	0.018	0.541	0.614
2	Front Counter	0.408	0.018	0.371	0.444
	Fryer	0.402	0.015	0.372	0.431
	Oven	0.408	0.015	0.379	0.438
	Sink	0.275	0.013	0.249	0.301
	Walk-through	0.498	0.018	0.461	0.534
3	Front Counter	0.273	0.018	0.236	0.309
	Fryer	0.250	0.015	0.220	0.280
	Oven	0.582	0.015	0.552	0.611
	Sink	0.411	0.013	0.386	0.437
	Walk-through	0.345	0.018	0.309	0.381
4	Front Counter	0.550	0.018	0.514	0.586
	Fryer	0.560	0.015	0.530	0.590
	Oven	0.557	0.015	0.527	0.586
	Sink	0.399	0.013	0.373	0.424
	Walk-through	0.750	0.018	0.714	0.786

Subjective Rating of Floor Slipperiness

Sixteen females (80%) and four males (20%) from all four dining halls working during the peak service periods immediately after breakfast or lunch participated in the survey. All 20 participants (100%) identified themselves as African American. The sex and demographics from the participants was an accurate representation of the entire staff at each dining hall. The means and standard deviations of age, length of tenure, and working hours per week of the participants were 38.8 (14.50), 71.7 (62.19) months and 6.1 (5.11) years, and 36.3 (2.66), respectively. Similar to the objective measurement results, the oven (3.60) and walk through (3.25) areas had the highest perception means, while the fryer (2.90) and sink (2.90) had the lowest perception means. Table 4 shows the subjective results ranked by means and standard deviations from most slippery to least slippery.

Table 4- Subjective survey results ranked from most slippery to least slippery.

Subjective Totals (Ranked)			
Location	**Rank**	**Mean (avg.)**	**Standard Dev. (avg.)**
Sink	1	2.90	0.86
Fryer	2	2.90	0.77
Front Counter	3	2.95	0.67
Walk-through	4	3.25	0.45
Oven	5	3.60	0.36

Fisher's exact test was performed to determine whether there is a relationship between the perception results of the different areas at the different dining halls. The results show that there was no significant difference between the perceived results of the fryer (p=0.456), oven (p=7.770), sink (p=12.567), and walk-through (p=0.195) areas, meaning that the employees' perceptions of these areas were statistically similar. The front counter area (p=0.012) was statistically significant, possibly resulting from skewed data collected from surveys administered to Dining Hall 3 participants who seemingly rushed through the survey process and similarly ranked each area, adding to the intrigue of the subjectivity of the matter. Moreover, while Dining Hall 1 (100%), Dining Hall 2 (80%), and Dining Hall 4 (60%) had most results within the 3 ("A Little Slippery") or 4 ("Not Slippery at All") categories, 100% of Dining Hall 3 results fell into the 1 ("Extremely Slippery") or 2 (More Slippery) categories, an event of which did not occur at any other location. Table 5 presents Fisher's exact test cross tabulation results of the subjective survey responses.

Table 5- Fisher's exact test cross tabulation results of the survey responses.

Location	Value	Exact Sig. (2-sided)	N of Valid Cases
Fryer Area	8.649	0.456	20
Oven Area	7.770	0.063	20
Sink Area	12.567	0.080	20
Front Counter Area	15.868	0.012	20
Walk-through Area	7.611	0.195	20

Correlation Between Friction and Perception

The subjective rating was correlated with the measured friction coefficient across all of the evaluated areas by calculating Pearson's correlation coefficient. Each area in each restaurant was treated as an individual sample with its mean coefficient of friction value and subjective score from Tables 2 and 4. The relationship between the average friction coefficient and the average subjective score is shown in Figure 9. The Pearson's correlation coefficient was 0.664 respectively, with a sample size of 20. The correlation coefficient shows a moderately positive association of 0.664, meaning that there was a positive relationship between the subjective (SUM) and objective (OBM) results, as shown in Table 6 and Figure 8.

Table 6- Pearson's correlation results comparing objective and subjective results.

		Objective	Subjective
Objective	Pearson Correlation	1	0.664
	Sig. (2-tailed)		0.001
	N	20	20
Subjective	Pearson Correlation	0.664	1
	Sig. (2-tailed)	0.001	
	N	20	20

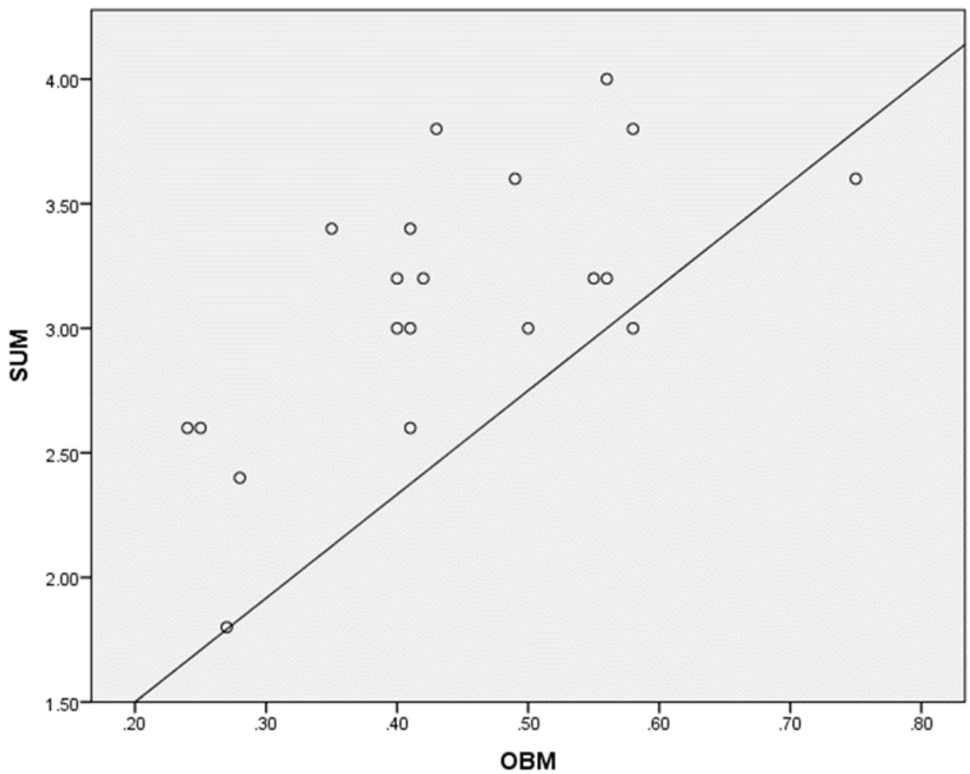


Figure 9- Scatterplot illustration of Pearson's correlation coefficient results of objective (OBM) vs. subjective (SUM) results.

CHAPTER V

Discussion

Despite speculations that friction variation can play a significant role in the perception of slipperiness (Strandberg, 1985), the results from the current study indicate that the mean values of the measured coefficient of friction results had fair agreement with the surveyed perception ratings. It is important to measure friction on several tiles in the areas and use the average to represent the friction in that area because of possible variations among common areas, and reproductions of these results (Chang et al., 2004).

The friction values of the tiles in the kitchens are not only time-dependent, but also location-dependent. Contaminants such as water, oil, sauce, powder, or other debris are very likely to be present on the floors of the major food processing and cleanup areas such as those where the fryer, oven, and sink are used. The tiles in these particular areas are more likely to have a low COF. The fryer areas had the lowest mean COF values in the dining halls, most likely due to the excess amount of grease and cooking oils. Due to water contamination, the sink areas had the second lowest mean COF value in the kitchens of the dining halls.

The mean friction coefficients in the fryer area for dining halls 1 and 3 were as low as 0.18 and 0.21, respectively, which were the lowest COF values measured in this study. The oven and walk through areas are less likely to experience floor contamination since there are fewer sources of contamination and any spillage is normally removed as soon as possible. The results shown in Table 2 indicated that the tiles in the walk through and oven areas had high COF values. The friction coefficients in the walk through and oven areas were, in general, higher than 0.5, the somewhat widely applied standard mentioned earlier. These coincided with the subjective ratings, as the employees rated, on average, both the oven and front counter areas between ratings of 3 and 4. This implies that the employees perceived the floors in those areas as being between ‘‘somewhat slippery” and “not slippery at all.” Generally, grease and oil were observed on tiles in the fryer and front counter areas of the dining halls. The effects of the contaminants on friction were as expected, as those two areas, along with the wet tested sink areas, were the lowest. Also, accumulation of grease on the Neolite pad during repeated strikes, as reported by Chang and colleagues (2003), could potentially affect the results of friction measurements in these greasy areas.

The correlation between the subjective and objective measurements of floor slipperiness was statistically significant; however, some disagreements were noted as some employees rated low friction coefficient areas as not slippery while others rated high friction coefficient areas as slippery. An example of the former situation was found in the walk through area of Dining Hall 3 where the friction coefficient was low (mean = 0.35) but the subjective rating was high (mean = 3.40). There were very few examples of the later situation, as the majority of subjective means (75%) averaged above a subjective rating of 3.0. Situations, especially in the case of the former, may be explained by the high friction variation of the areas where the participants experience certain low friction tiles and tended to rate the whole area as more slippery.

Spillage of water, oil, and/or mixtures of both are very likely, especially in the fryer and sink areas. Spillage on the floor is normally transferred to other areas under the shoes of the employees walking from one area to another. Repeatedly walking on spillage also reduces the amount of the contaminants in an area. In addition, spillage of water may be further reduced due to evaporation. The thickness of the film of oil on the floor may also become very thin and eventually invisible to the naked eye. It is for this reason that friction measurement results may be quite different if conducted at different times. The friction measurement results of the current study may reveal only the friction status at the time of measurement, but the results of the perception survey reflected the floor conditions throughout the entire working period.

There were several other limitations in this study. The sample sizes for the ANOVA of the measured friction and perception ratings were small due to the limited numbers of employees at these dining halls. Friction in different dining halls was measured with identical Neolite pads on different days. The results reported by Chang and colleagues (2002) indicated that friction variations with identical pads measured at different times could be statistically significant. Also, employees wore different kinds of slip resistant shoes with different degrees of wear, but friction measurements were conducted with smooth Neolite pads. Since the shoe material and tread pattern on the shoe bottoms would affect the perception rating, not being able to control what employees wore certainly induced variations in perception and affected its correlation with friction. Of note, employees' rating standards could also differ.

In contrast to a laboratory study in which a calibration procedure could be used to control the base of the rating scale, employees used their break time to participate in the survey in this study, and space and time were limited due to the nature of this study. In addition, cross contaminations such as water in the sink area trapped under shoes contaminating the fryer area could alter employees' perception of the fryer area, but wet testing was not performed in the fryer areas to account for this possibility. Loose, gross contaminants could affect the perception ratings, but they were removed before the friction measurements. Therefore, its impact on the correlation should be very limited. It is known that the Brungraber Mark III has more squeeze-film effect, leading to lower COF values on liquid contaminated surfaces, than other slip meters with similar measurement characteristics (Chang et al., 2001). In this experiment, the COF values measured in the sink areas were lower than those in other areas which could help reduce the correlation coefficients between friction and perception.

Taiwan - Chang Study Comparison

The results obtained in the current study show a fair degree of consistency with the results of the prior Chang study using similar design and protocol in Taiwan. This degree of replication indicates that the design approach was effective when tested in a substantially different region of the world and across a variety of languages and cultures. Despite the consistency of results, there are several differences between the current and prior studies. Comparing the Pearson's correlation coefficient between the averaged friction coefficients and subjective ratings in this study was 0.64, respectively, which was higher than those obtained in Taiwan of 0.45, respectively. This indicated that the average perception rating score from the participants in Taiwan was less sensitive to the level of friction than that from the participants in this study.

Several factors that were different between these two studies could affect the sensitivity of perception to the coefficient of friction. Cultural differences towards employment and risk perception could account for some of the difference in perception ratings of slipperiness. Factors that could impact the results in this regard include the cultural beliefs, languages, ages of the working population, and common practices in the society. Another factor could be that more participants in this study wore slip resistant shoes than in Taiwan. Slip resistant shoes were mandatory in all four dining halls. The shoe requirements for the participants in Taiwan were less restrictive. The participants there were only required to wear black colored shoes to work (Chang et al., 2004).

In addition to the potential differences in cultural attitude and slip resistant footwear use, another factor could have been the amount of water on the floors in the sink areas which could not be quantified during the study. Initial walkthrough observations indicated that the sink area was typically wet, hence the values of wet measurements in the sink area have been reported here. As a part of the protocol in the sink areas, the amount of water used in the wet friction measurements was the maximum amount allowed by the surface tension and it was added onto the tile surfaces. This amount of water might not be the same as that in actual operations. The amount of water could affect the friction coefficient measured (Chang et al., 2001) and perception rating scores. The measured results of the sink areas in this study (0.39) were higher than that of Taiwan (0.28), while the subjective results of the sink areas in this study (2.90) were similar to Taiwan (2.70). The discrepancy in average friction coefficients in the sink areas could be caused by different amounts of water during the friction measurements and during actual operations. Not being able to quantify the amount of water on each tile in the sink areas over the course of the measuring periods prevented the researchers in these studies from documenting the floor conditions in these areas.

There were several additional differences between the studies. There were 7 working areas in each restaurant in the study conducted in Taiwan, while there were only 5 working areas in each restaurant in this study. There were fewer tiles measured in this study (112) over 5 working areas than in Taiwan (414) over 7 working areas. The mean dynamic (DCOF) values in the front counter, walk through, oven, and fryer areas in this study (0.41, 0.54, 0.49, and 0.36, respectively) were much lower than those in the same areas in Taiwan (0.90, 0.90, 0.72, and 0.79), but the mean perception rating scores for these areas in this study (2.95, 3.25, 3.60, and 2.90) were only slightly lower than those in Taiwan (3.74, 3.74, 3.15, and 2.96). The sink area in this study had a higher mean COF (0.36) than the Chang study (0.28), but the mean perception rating scores for the sink areas in this study (2.90) were on average slightly higher than those in Taiwan (2.70).

There were more participants in the perception rating survey in Taiwan (56) than in this study (20). There were small differences in the training of team members assigned to operate the slip meters prior to data collection in both studies. Two different Neolite samples were used in Taiwan, but only one was used in this study. The results of Chang and Matz (2001) indicated that different samples of the same materials could lead to a statistically significant difference in the measured COF. In this study, only one slip meter was used over the areas, but particular slip meters were used in particular areas in Taiwan. All the participating dining halls this study were owned by one company, but those in Taiwan belonged to several chains due to difficulties in recruiting restaurants in Taiwan (Chang et al., 2004). Therefore, the floor conditions across participating dining halls in this study might be more consistent than those in the restaurants participating in the Taiwan study.

Chapter VI

Recommendations and Future Research

Measurements should be taken at the dining halls to mitigate the potentially hazardous conditions at the more slippery work areas. The results showed that the most slippery areas were the ones with the most anticipated hazards such as grease and water near the fryer and sink. The overall higher measured coefficient of friction results, aside from the sink area, from Dining Hall 4 show that the newer tile with the protruding diamond plated grips make a difference in the slipperiness of the floor. It is highly recommended that Dining Halls 1, 2, and 3 replace their current tile for newer, less worn tile with the diamond plated protrusions. Also, cheaper options such as slip resistant mats, continuous training and hazard analysis, and enhanced cleaning methods could potentially reduce the hazardous conditions as well.

The limitations discussed in the comparison of this study and the Chang (2004) study in Taiwan, are the suggested points that should be emphasized in future research and implications of this study. While the kitchens in the dining halls closely resemble those of fast-food restaurants, there are still some possible limitations in not performing the replication methods in more similar environments. The smaller number of dining halls (4), tiles measures (112), and survey participants (20) as compared to those in Taiwan (10, 414, and 58) may have affected the results and comparisons and a much closer number in comparison is recommended. Also, the use of multiple slip meters and Neolite test pads should be emphasized rather than using the same for all areas in all locations as performed in this study.

Conclusion

This study provided a unique opportunity to explore the relationship between the average friction coefficient and perception over five major working areas in a college campus dining hall field environment. The results of the current study showed that the levels of friction in different areas in the kitchens of these dining halls were significantly different. This coincides with the general perception that certain areas in a kitchen are more slippery than others. The friction coefficients in the fryer and sink areas were significantly lower than those of the other areas and hence were the most slippery areas in the dining halls. The average friction coefficient of the walk through areas were higher than the commonly used reference of 0.5, even though they were perceived as slippery areas by the employees. The subjective ratings of floor slipperiness showed that the employees perceived the front counter, sink and fryer as the most slippery areas in the kitchens. The correlation coefficients between the friction coefficients and the subjective ratings indicate that the average friction coefficient and perception are in fair agreement, suggesting both might be reasonably good indicators of slipperiness. Discrepancy between the measured friction value and the perception of floor slipperiness may increase the difficulties in effectively identifying slippery areas for interventions.

The research performed and results obtained in both this study and the Chang (2004) study could assist in not only hazard awareness of slippery conditions for employees in the dining industry, but potentially through the concept of prevention through design. Governmental agencies, such as the previously mentioned Occupational Safety and Health Administration (OSHA), could use the results from these and similar studies from various industries to implement laws and regulations to prevent potentially hazardous conditions during the design phase of construction. For example, preventing the implementation and construction of slippery flooring materials such as marble and granite at or near entrances and walkways, as seen at many decorative hotels and entertainment venues, by making it illegal during the design phase when materials are first selected. Eliminating the hazards prevents any hazardous conditions from occurring altogether.

Lastly, the results obtained in the current study indicated that the protocols used in a field study conducted in Taiwan could be used in similar work environments in the USA and consistent results could be obtained in the correlation between the tested objective and subjective measurements of slipperiness. The Pearson's correlation coefficient between the averaged friction coefficients and subjective ratings for all 20 evaluated areas across all 4 college campus dining halls in this study was 0.64 respectively. These correlation coefficients obtained in this study were somewhat higher than those obtained in Taiwan. The amount of water on the floors in the sink areas, cultural differences and a greater use of slip resistant shoes might be some contributors to the higher correlation coefficients since the participants in this study gave slightly lower perception rating scores. However, the current study confirmed the results obtained in Taiwan that the average friction coefficient and perception are in fair agreement, suggesting that both might be reasonably good indicators of slipperiness.

REFERENCES

ANSI ASC A108. 2012. ANSI/TCNA A137.1 Specifications for ceramic tile. Anderson, SC: Tile Council of North America.

ANSI ASC A1264. 2012. ANSI/ASSE A1264.2 Provision of slip resistance on walking/working surfaces. Des Plaines, IL: American Society of Safety Engineers.

ANSI ASC B101. 2012. ANSI/NFSI B101.3 Test method for measuring wet DCOF of common hard-surface floor materials. Southlake, TX: National Floor Safety Institute.

ASTM D21. 2011. ASTM D2047 Standard test method for static coefficient of friction of polish-coated flooring surfaces as measured by the James Machine. West Conshohocken, PA: ASTM International.

ASTM E11. 2011. ASTM E691 Standard practice for conducting an interlaboratory study to determine the precision of a test method. West Conshohocken, PA: ASTM International.

ASTM F13. 2012. ASTM F1646 Standard terminology relating to safety and traction for footwear. West Conshohocken, PA: ASTM International.

ASTM F13. 2013. ASTM F2508 Standard practice for validation, calibration, and certification of walkway tribometers using reference surfaces. West Conshohocken, PA: ASTM International.

Brungraber R. 1976. An overview of floor slip-resistance research with annotated bibliography. National Bureau of Standards Technical Note 895, US Government Printing Office.

Bureau of Labor Statistics (BLS). (2015). Injuries, illnesses, and fatalities. Case and demographic characteristics for work-related injuries and illnesses involving days away from work: Detailed industry by selected events or exposures 2015.

Chang, W.R., Kim, I.J., Manning, D. and Bunterngchit, Y. (2001). The role of surface roughness in the measurement of slipperiness, Ergonomics, 44, pp. 1200 -1232.

Chang, W.R., Li, K.W., Huang, Y.H., Filiaggi, A., Courtney, T.K. (2004). Assessing floor slipperiness in fast-food restaurants in Taiwan using objective and subjective measures. Applied Ergonomics, 35, pp. 401–408.

Chang, W.R., Filiaggi, A., Li, K.Y., Huang, Y.H., Courtney, T.K. (2005). A field assessment of potential friction variation in a fast-food restaurant in the USA. In: Bust, P.D., McCabe, P.T. (Eds.). Contemporary Ergonomics. Taylor and Francis, London, pp. 519–523.

Chang, W.R., Li, K.W., Huang, Y.H., Filiaggi, A., Courtney, T.K. (2006). Objective and subjective measurements of slipperiness in fast-food restaurants in the USA and their comparison with the previous results obtained in Taiwan. Safety Science, 44, pp. 891–903.

Chang, W.R., Matz, S. (2001). The slip resistance of common footwear materials measured with two slip meters. Applied Ergonomics. 32, 540–558.

Copeland, J (2016). Painful Statistics on Slips, Trips, and Falls. Accessed from: http://www.arbill.com/arbill-safety-blog/bid/203028/Painful-Statistics-on-Slips-Trips-and-Falls.

C.S.C Force Measurement. (2017). C.S.C. horizontal pull slipmeter: HPS slipmaster. Accessed from: http://www.cscforce-express.com/C.S.C.-Force-Measurement-Horizontal-Pull-Slipmeter-HPS.html. Images reproduced with permission by the publisher or copyright owner.

Gronqvist, R. Abeysekera, J. Gard, G. Hsiang, S. Leamon, T., Newman, D. Gielo-Perczak, K., Lockhart, T., Pai, C. (2001). Human-centered approached in slipperiness measurement. Ergonomics, 44, pp. 1167-1199.

Hsiao, E. T. and Robinovitch, S. N. (1998). Common protective movements govern unexpected falls from standing height. Journal of Biomechanics, 31, pp. 1-9.

Lia, K.W., Chang, W.R., Chang, C., C. (2009). Evaluation of two models of a Slipmeter. Safety Science, Vol. 47, Issue 10, pp.1434-1439.

Leclercq, S. (1999). The prevention of slipping accidents: a review and discussion of work related to the methodology of measuring slip resistance. Safety Science, 31, pp. 95-125.

Leffler, J. (2015). The changing world of slip-and-fall analysis. ASSE Safety 2015 Technical Conference, Session No.550.

Liberty Mutual Research Institute for Safety. (2016). Pace yourself: what you should know about slips, trips, & falls. From Research to Reality, Vol. 10, No. 3.

National Floor Safety Institute (NFSI). (2016). Quick Facts. Accessed from: https://www.nfsi.org/nfsi-research/quick-facts/

Phelps v. Stein Mart, 2011 U.S. Dist. Lexis 41121.

Occupational Safety & Health Administration (OSHA). (2005). Standard interpretation 29CFR 1910.22. Accessed from:https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_id=24511&p_table=INTERPRETATIONS.

Occupational Safety & Health Administration (OSHA). (2015). Walking/Working Surfaces. Accessed from: https://www.osha.gov/SLTC/walkingworkingsurfaces/index.html.

Powers CM, Kulig K, Flynn J, Brault JR. (1999). Repeatability and bias of two walkway safety tribometers. J. Testing & Eval. 27(6), pp.368–374.

Powers CM, Blanchette MG, Brault JR, Flynn J, Siegmund GP. (2010). Validation of walkway tribometers: establishing a reference standard. J. Forensic Sci., 55(2), pp.366-370.

Redfern, M. S., Cham, R., Gielo-Perczak, K., Gronqvist, R., Hirvonen, M., Lanshmmar, H., Marpet, M., Pai, Y.-C. and Powers, C. 2001. Biomechanics of slips, Ergonomics, 44, pp.1138-1166.

Sebald J. (2009). System oriented concept for testing and assessment of the slip resistance of safety, protective and occupational footwear. Berlin: Pro Business GmbH.

Slip Doctors. (2017). Slip doctors slip resistant products: slip meters. Accessed from: http://www.slipdoctors.com/products-slipmeters.asp. Images reproduced with permission by the publisher or copyright owner.

Strandberg, L. (1985). The effect of conditions underfoot on falling and overexertion accidents. Ergonomics 28, 131–147.

The National Volunteer Fire Council (NVFC). (2012) Understanding and implementing standards: NFPA 1500, 1720, and 1851. p.7.

APPENDIX A

IRB Approval Letter

EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board Office
4N-70 Brody Medical Sciences Building· Mail Stop 682
600 Moye Boulevard · Greenville, NC 27834
Office **252-744-2914** · Fax **252-744-2284** · **www.ecu.edu/irb**

From:	Social/Behavioral IRB
To:	Kevin Johnson
CC:	Michael Behm
Date:	3/29/2017
Re:	UMCIRB 17-000548 Floor Slipperiness of Dining Halls

I am pleased to inform you that your research submission has been certified as exempt on 3/29/2017. This study is eligible for Exempt Certification under category #Exempt #2.It is your responsibility to ensure that this research is conducted in the manner reported in your application and/or protocol, as well as being consistent with the ethical principles of the Belmont Report and your profession.

This research study does not require any additional interaction with the UMCIRB unless there are proposed changes to this study. Any change, prior to implementing that change, must be submitted to the UMCIRB for review and approval. The UMCIRB will determine if the change impacts the eligibility of the research for exempt status. If more substantive review is required, you will be notified within five business days.

The UMCIRB office will hold your exemption application for a period of five years from the date of this letter. If you wish to continue this protocol beyond this period, you will need to submit an Exemption Certification request at least 30 days before the end of the five year period. The Chairperson (or designee) does not have a potential for conflict of interest on this study.

APPENDIX B

Dining Hall Areas

Dining Hall 1 sink.

Dining Hall 1 sink area measured.

Dining Hall 1 fryer.

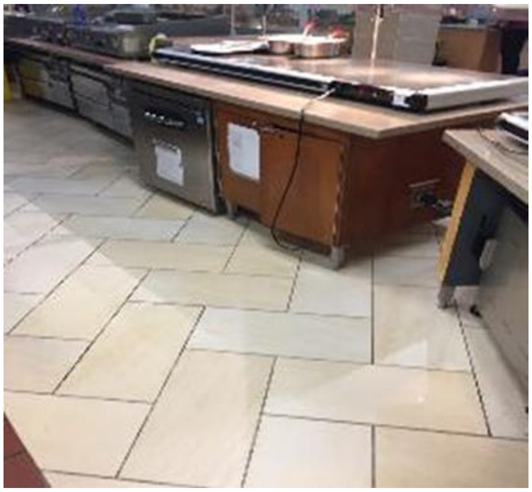
Dining Hall 1 fryer area measured tiles.

Dining Hall 1 oven.

Dining Hall 1 oven area measured tiles.

Dining Hall 1 walk through.

Dining Hall 1 walk through area measured tiles.



Dining Hall 1 front counter.

Dining Hall 1 front counter area measured tiles.

Dining Hall 2 sink.

Dining Hall 2 sink area measured tiles.

Dining Hall 2 fryer.

Dining Hall 2 fryer measured tiles.

Dining Hall 2 oven.

Dining Hall 2 oven area measured tiles.

Dining Hall 2 walk through.

Dining Hall 2 walk through area measured tiles.

Dining Hall 2 front counter.

Dining Hall 2 front counter area measured floor.

Dining Hall 3 sink area.

Dining Hall 3 sink area measured tiles.

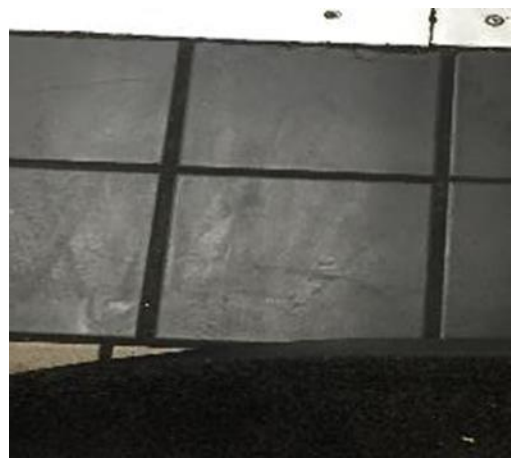
Dining Hall 3 fryer.

Dining Hall 3 fryer area measured tiles.

Dining Hall 3 oven.

Dining Hall 3 area measured tiles.

Dining Hall 3 walk through.



Dining Hall 3 walk through area measured tiles.

Dining Hall 3 front counter.

Dining Hall 3 front counter area measured tiles.

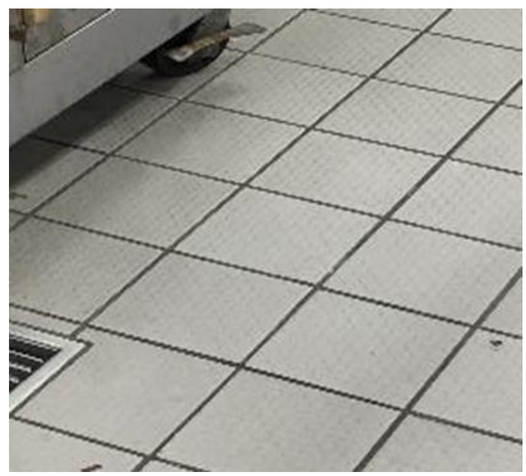
Dining Hall 4 sink.

Dining Hall 4 sing area measured tiles.

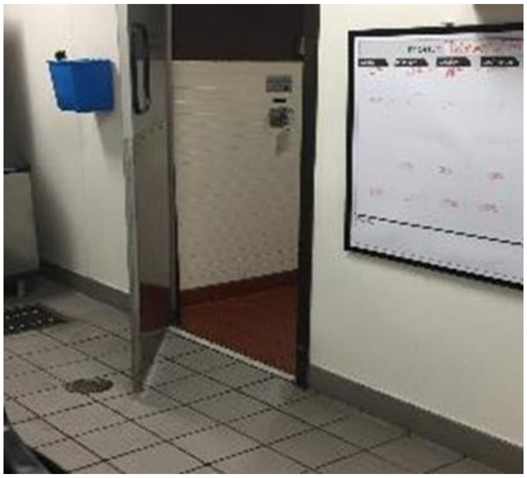
Dining Hall 4 fryer.

Dining Hall 4 fryer area measured tiles.

Dining Hall 4 oven.



Dining Hall 4 oven measured tiles.



Dining Hall 4 walk through.

Dining Hall 4 walk through area measured tiles.

Dining Hall 4 front counter.

Dining Hall 4 front counter area measured tiles.

APPENDIX C

Communication from Researcher Kevin Johnson to Researcher of Initial Restaurant Studies Dr. Wen Chang in Assistance in Developing Subjective Survey.

Kevin,

We had 1 as not slippery, 2 as a little slippery, 3 as more slippery and 4 as very slippery.

Wen

From: Johnson, Kevin Patrick [mailto:johnsonkev09@students.ecu.edu]
Sent: Tuesday, February 28, 2017 6:50 PM
To: Chang, Wen <WEN.CHANG@LibertyMutual.com>
Cc: Behm, Michael <BEHMM@ecu.edu>
Subject: Graduate Student Research - Slips, Trips, and Falls

Dr. Chang,

I'm a graduate student in the MS, Occupational Safety program at East Carolina University conducting a similar study as your objective vs. subjective analysis of slip meter readings in fast-food restaurants in Taiwan and the US.

I am in the process of developing my survey to distribute to the employees and was wondering if you could tell me what the four classifications were for your #1-4 employee perception ranking system for each kitchen area?

Please get back to me when you get the chance. I look forward to hearing from you soon and hope you have a great night.

Thanks,

Kevin Johnson
Graduate Assistant
MS, Occupational Safety
College of Engineering & Technology
East Carolina University

APPENDIX D

Brungraber Mark IIIB Tribometer Validation, Calibration, and Certification

TRIBOMETER CERTIFICATION

“Slip-Test Inc. certifies that the Slip -Test Mark IIIB walkway tribometer model has undergone certification procedures described in and in accordance with Practice F2508, as documented by the attached Certification Test Method, Validation Report, Interlaboratory Study Data, and Precision Statement.”

Reference: ASTM F2508-13 section 16.3.1.

John Leffler, PE

January 19, 2015 (Revision B: Precision Statement updated)

F2508 Validation / Calibration / Certification Test Method - 1/13/14 - Mark IIIB

1. Notes regarding use of Certification Test Method for Interlaboratory Study (ILS):

a. Each combination of tribometer, test foot & operator must remain together for all testing this defines each "laboratory". No operator may use multiple tribometers.

b. Each laboratory during testing will also require a recorder (to write down readings) and an observer (to ensure that this protocol is being followed). Recorders and observers can be interchanged if necessary.

c. One testing data sheet will be used by each laboratory to record the 48 slip resistance values to be measured.

2. Testfoot preparation (Neolite, obtained from Smithers-Rapra):

a. Ensure that testfoot identification number is recorded on testing data sheet.

b. Nominal testfoot dimensions are Neolite width and length of 2.95 +/- 0.05 inches, and thickness (Neolite + plate) of 0.30 +/- 0.03 inches. Testfeet older than 3 years shall not be used. When not in use, store Neolite testfeet in normal home/office ambient conditions.

For ILS: All testfeet must be 0.300 +/- 0.015 inches thick (Neolite + plate), and all testfeet must be from the same Smithers batch of Neolite.

c. Testfoot sanding:

i. Ensure that testfoot is completely dry.

ii. Utilizing surface plate or flat tile (e.g. equivalent to RS-A) and 180-grit 3M wet/dry sandpaper, place testfoot surface on sandpaper.

iii. Hold testfoot as shown in Figure 1. While ensuring that moderate and even downward force is applied, sand the testfoot four strokes
in one direction parallel with the groove orientation of the Neolite.

iv. Hold testfoot as shown in Figure 2. Ensuring that moderate and even downward force is applied, sand the testfoot four strokes in one direction perpendicular to the groove orientation of the Neolite.

v. Using clean compressed air, blow out the grooves in the testfoot. Inspect the testfoot surface and ensure that it has an even appearance, and re-sand per steps 2a(i-iv) if necessary.

3. Starting height verification:

a. Set the mast angle at zero on the graduated scale.

b. Using the aluminum "go/no-go" thickness gauge supplied with the tribometer (5/32" – 7/32"), check the gap between the bottom of the testfoot and a flat surface. This is done by seeing that the thinner end of the gauge can be slipped between the testfoot pivot and the surface and that the thicker end of the gauge will not fit in the same space. If the thinner end of the gauge does not fit, the gap is too small and the three feet on the bottom of the tribometer must each be shimmed using an equal amount of washers. If the thicker end of the gauge will fit then the gap is too large and it must be reduced by removing shims from under the feet.

c. Check that the articulated strut pivots freely at each of its two ends, and that it just contacts its stop when placed on a level surface.

4. Reference surface preparation

a. Prior to validation, calibration, or Interlaboratory Study, clean the reference surfaces using the procedure in section 8.2 of ASTM F2508-13. Once cleaned, avoid contacting the reference surface with fingers or other contaminants.

i. Between ILS test sessions, use the provided 50/50 alcohol-distilled water mixture and white towels to clean the entire top of the subject reference surface prior to beginning the next session of testing. Use spare non-white towels for spill cleanup.

5. Tribometer testing operation – wet

a. Place the tribometer on the surface to be tested, with the three rubber feet entirely within the perimeter of the reference tile surface, and with the testfoot nominally centered on the tile. Ensure the recorder knows which surface is being tested.

i. For calibration and for ILS, test the reference surfaces in the following order: RS-B, RS-C, RS-D, RS-A.

b. Place one 10 pound rubberized hand barbell on each end of the tribometer baseplate as ballast. Lift the top handle so that the strut carriage becomes supported by the trigger.

c. Using distilled water, apply enough water to provide an unbroken film (i.e. a puddle) under the testfoot. During all tests, it is necessary to ensure this unbroken film (puddle) is under the testfoot prior to triggering.

i. When testing RS-A only, utilize the provided distilled water/Triton solution.

ii. When testing an initially-dry RS-D tile, to reduce the tendency of the water to bead up due to surface tension, apply a puddle of water and allow to stand on the RS-D surface for at least 5 minutes prior to testing.

d. If the testfoot has just been sanded: set the mast to an angle expected to result in a slip (RS-A: 0.25, RS-B: 0.35, RS-C: 0.55, RS-D: 0.85), trigger the tribometer and see if it slips

– if it does not, increase the mast angle until it is well into the range of the testfoot slipping. Repeat triggering the tribometer into an unbroken puddle of water four additional times, and then proceed with test measurements below.

e. Set the mast at an angle expected to not result in a slip. Ensure that the mast lock knob is tight before each triggering, and that the front tab on the testfoot is pushed back against the testfoot pivot. Prepare to trigger by pausing for one second to reduce transitional vibrations. Trigger the tribometer. A testfoot slip has occurred when the testfoot rapidly slips all the way to its limits of travel – i.e. when the top handle contacts the rubber bumper. If a slip does not occur, increase the mast angle incrementally, reapply water (or Triton solution for RS-A only) as needed to ensure an unbroken film of liquid, and retest, continuing until slip does occur. If it is apparent that the point of slip is being approached, reduce the incremental changes in mast angle to 0.01 on the tribometer's scale.

f. Record the value at which slip occurred to two decimal places (e.g. 0.43).

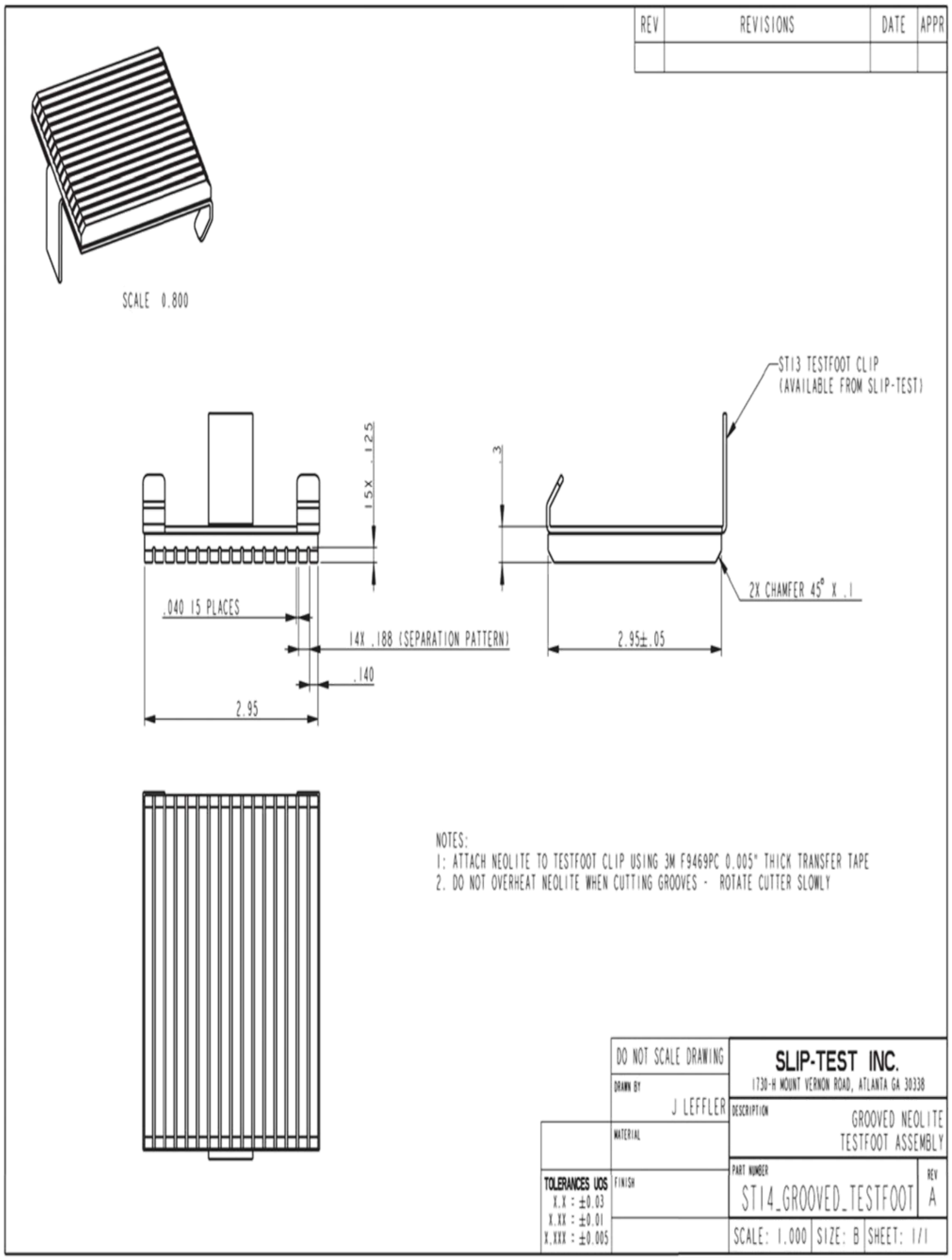
g. REPETITION:

i. For ILS, repeat steps 5a-f for a total of 3 slips in each of four perpendicular directions (~90º apart) on each reference surface, for a total of 12 slips per surface. Conduct all of the 3 slips in a particular direction sequentially.

ii. For F2508 calibration, repeat steps 5a-f for a total of 4 slips in each of four perpendicular directions (~90º apart) on each reference surface, for a total of 16 slips per surface. Conduct all of the 4 slips in a particular direction sequentially.

iii. For F2508 validation, repeat steps 5a-f for a total of 10 slips in each of four perpendicular directions (~90º apart) on each reference surface, for a total of 40 slips per surface. Conduct all of the 10 slips in a particular direction sequentially. Between testing each reference surface, re-sand testfoot per step 2 above.

b. Repeat steps 5a-g for the remaining reference surfaces.



ASTM F2508 VALIDATION REPORT

Operator: John Leffler

Test address: 8785 Glen Ferry Drive, Alpharetta GA 30022

Test date: January 24, 2014

Test surfaces: F2508ADJ reference surfaces acquired from ASTM in April 2011

Test conditions: 71.6ºF, 45% RH

Tribometer: Slip-Test Mark IIIB #47

Testfoot: Neolite, 15 grooves, polymer manufacturer's shipping date 1/15/2013, 2.95" x 2.95" x 0.290" thick (with plate). Prepared per attached test method. Labeled: 011513C.

TEST RESULTS

This tribometer passes the F2508 requirement for correct ranking of the references surfaces.

This tribometer passes the F2508 requirement for statistical differentiation of the reference surfaces.

This Validation was conducted in accordance with ASTM F2508-13.

Slip-Test, Inc.

F2508 Validation data

TEST #	RS-A GRANITE	RS-B PORCELAIN	RS-C VCT	RS-D CERAMIC		RS-A - RS-B	RS-B - RS-C	RS-C - RS-D
1	0.18	0.26	0.36	0.64		-0.08	-0.1	-0.28
2	0.16	0.25	0.35	0.62		-0.09	-0.1	-0.27
3	0.16	0.24	0.37	0.62		-0.08	-0.13	-0.25
4	0.16	0.24	0.35	0.61		-0.08	-0.11	-0.26
5	0.16	0.24	0.34	0.62		-0.08	-0.1	-0.28
6	0.16	0.24	0.34	0.61		-0.08	-0.1	-0.27
7	0.16	0.24	0.34	0.62		-0.08	-0.1	-0.28
8	0.16	0.24	0.35	0.62		-0.08	-0.11	-0.27
9	0.16	0.24	0.36	0.61		-0.08	-0.12	-0.25
10	0.17	0.24	0.35	0.62		-0.07	-0.11	-0.27
11	0.17	0.25	0.34	0.64		-0.08	-0.09	-0.3
12	0.17	0.24	0.35	0.63		-0.07	-0.11	-0.28
13	0.16	0.24	0.33	0.63		-0.08	-0.09	-0.3
14	0.16	0.23	0.32	0.63		-0.07	-0.09	-0.31
15	0.16	0.23	0.33	0.63		-0.07	-0.1	-0.3
16	0.16	0.23	0.33	0.62		-0.07	-0.1	-0.29
17	0.15	0.23	0.32	0.62		-0.08	-0.09	-0.3
18	0.16	0.23	0.31	0.62		-0.07	-0.08	-0.31
19	0.16	0.23	0.32	0.63		-0.07	-0.09	-0.31
20	0.16	0.23	0.31	0.62		-0.07	-0.08	-0.31
21	0.16	0.28	0.34	0.68		-0.12	-0.06	-0.34
22	0.15	0.26	0.34	0.68		-0.11	-0.08	-0.34
23	0.15	0.26	0.34	0.68		-0.11	-0.08	-0.34
24	0.16	0.25	0.33	0.69		-0.09	-0.08	-0.36
25	0.14	0.25	0.33	0.67		-0.11	-0.08	-0.34
26	0.15	0.25	0.33	0.70		-0.1	-0.08	-0.37
27	0.15	0.25	0.32	0.68		-0.1	-0.07	-0.36
28	0.16	0.25	0.33	0.68		-0.09	-0.08	-0.35
29	0.16	0.25	0.33	0.68		-0.09	-0.08	-0.35
30	0.16	0.25	0.33	0.66		-0.09	-0.08	-0.33
31	0.16	0.24	0.35	0.65		-0.08	-0.11	-0.3
32	0.17	0.24	0.33	0.65		-0.07	-0.09	-0.32
33	0.16	0.23	0.34	0.62		-0.07	-0.11	-0.28
34	0.16	0.23	0.33	0.61		-0.07	-0.1	-0.28
35	0.16	0.23	0.32	0.61		-0.07	-0.09	-0.29
36	0.17	0.23	0.33	0.61		-0.06	-0.1	-0.28
37	0.16	0.23	0.32	0.63		-0.07	-0.09	-0.31
38	0.15	0.23	0.32	0.62		-0.08	-0.09	-0.3
39	0.15	0.23	0.32	0.61		-0.08	-0.09	-0.29
40	0.15	0.23	0.32	0.61		-0.08	-0.09	-0.29
average	0.15925	0.241	0.33425	0.637	**dm:**	-0.08175	-0.09325	-0.30275
std deviation	0.007298577	0.011502508	0.01393897	0.02747493		0.013566078	0.014030644	0.03137756
std error	0.001154006	0.001818706	0.002203945	0.004344168				
95 %ile high	0.161511853	0.244564664	0.338569731	0.645514569	**t:**	-38.11215095	-42.03404909	-61.0231998
95 %ile low	0.156988147	0.237435336	0.329930269	0.628485431				
		Tribometer:	Mark IIIB #47		Temp:	71.6		
		Testfoot:	011513C		RH:	45%		

RECISION AND BIAS STATEMENT

SLIP-TEST MARK IIIB TRIBOMETER

Revision B - Updated January 19, 2015

The precision of the attached “F2508 Validation / Calibration / Certification Test Method” dated 1/13/2014 is based on an InterLaboratory Study (hereafter “ILS”) of one set of ASTM F2508 Adjunct reference tiles RS-A, RS-B, RS-C, and RS-D. The tiles were purchased from ASTM in April 2011. The Certification Test Method conforms to ASTM F2508-13 Standard Practice for Validation, Calibration, and Certification of Walkway Tribometers Using Reference Surfaces1. The ILS was conducted on January 15, 2014 in Lake Buena Vista, Florida. The eight different operators used eight different Slip-Test Mark III “B” series tribometers, each equipped with one of eight different testfeet – each unique combination of operator, tribometer, and testfoot comprised a “laboratory”. The ILS Coordinator was John Leffler, PE, lead engineering consultant to Slip-Test.

The Mark IIIB series of tribometers are conceptually and functionally identical to the original Slip-Test Brungraber Mark III tribometers but differ significantly in materials and manufacturing. As such, this precision statement is applicable only to Slip-Test Mark IIIB tribometers2.

Each of the eight operators tested the four different F2508 Adjunct reference tiles in four nominally perpendicular directions, and recorded three test results in each direction. Ambient test conditions were 72.6ºF and 48% RH. As prescribed for “Certification” within ASTM F2508, ASTM E691 Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method3 was utilized for analysis of the ILS data. The data and calculations are attached at the end of this Statement.

TERMINOLOGY

A glossary of terminology follows the Precision and Bias statements below.

ILS NOTES

The testfoot starting height requirements of Certification Test Method step 3 were verified through the use of a digital caliper and metal straightedge in addition to the specified go/no-go gauge, and the different testfoot starting heights of the 8 tribometers were found to be within 0.015” of each other.

As has been noted by others involved in tribometer testing on other F2508 reference tiles, the tiles tended to shed water to varying extents. At times, it was necessary to apply a lot of distilled water to the reference tile to ensure that a continuous unbroken film (puddle) of water remained under the testfoot before each test was triggered. Variability in the achievable thickness of the water puddle was more pronounced with RS-C (VCT) and RS-D (ceramic tile). This may have contributed to the generally higher reproducibility standard deviation of the results for RS-C and RS-D, as compared to RS-A and RS-B.

During testing, one droplet of fugitive lubricant/water residue fell from the fine- adjustment quick release nut of one tribometer, onto RS- D. The droplet fell to the side of the tile, outside the area of the tile being tested, and was noticed immediately by the lab personnel. The droplet was promptly soaked up with a paper towel, and though no visible residue remained, RS-D was re – scrubbed with SLS solution (and rinsed) per ASTM F2508 sections 8.2.1.2 through 8.2.1.4. It was then sprayed with 50% alcohol / 50% water mixture and wiped with a clean white terrycloth towel, prior to resuming testing.

Referring to the glossary definition below (from ASTM E177) for “reproducibility conditions”, for the subject ILS it was determined that utilizing a common location was acceptable; most entities that own tribometers do not have the sophisticated climate control (temperature/humidity) systems in their laboratory facilities that would be necessary to equalize this aspect of the ILS test conditions. Additionally, several of the tribometer operators were employed by the same entity and (at work) had the same supervisor – but this ILS was supervised by the ILS Coordinator.

PRECISION RESULTS

[Revision B update: results formerly were split by test direction] All data and calculations are attached following this Precision & Bias statement. The calculation worksheet references formulas by number from ASTM E691-11.

		RS-A	***RS-B***	***RS-C***	***RS-D***
average of lab averages	$\bar{\bar{X}}$	0.136042	0.244167	0.408854	0.677083
repeatability standard deviation	s_r	0.008704	0.011323	0.016620	0.027890
reproducibility standard deviation	s_R	0.011783	0.019433	0.03146	0.042007
repeatability limit	r	0.024371	0.031706	0.046537	0.078091
reproducibility limit	R	0.032992	0.054413	0.088087	0.11762

In accordance with E691, the above repeatability limits and reproducibility limits have an approximately 95% probability of being correct.

BIAS STATEMENT

At this time of this ILS, there was no walkway tile available that provided a “known” accepted reference value for traction; any such determination would be subject to the operational influences of the particular apparatus and method used to measure that traction.

GLOSSARY

The following definitions from ASTM E177 Standard Practice for Use of the Terms Precision and Bias in ASTM Test Methods 4 are applicable. See E177 for additional discussion of these terms, which are numbered here as in that standard..

3.1.3 Bias, n—the difference between the expectation of the test results and an accepted reference value.

3.1.10 Precision, n—the closeness of agreement between independent test results obtained under stipulated conditions.

3.1.11 Repeatability, n—precision under repeatability conditions.

3.1.12 Repeatability conditions, n—conditions where independent test results are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment within short intervals of time.

3.1.13 Repeatability limit (r), n—the value below which the absolute difference between two individual test results obtained under repeatability conditions may be expected to occur with a probability of approximately 0.95 (95%)

3.1.13.1 Discussion—The repeatability limit is 2.8 (~1.96 2) times the repeatability standard deviation. This multiplier is independent of the size of the interlaboratory study.

3.1.14 Repeatability standard deviation (sr), n—the standard deviation of test results obtained under repeatability conditions.

3.1.15 Reproducibility, n—precision under reproducibility conditions.

3.1.16 Reproducibility conditions, n—conditions where test results are obtained with the same method on identical test items in different laboratories with different operators using different equipment.

3.1.16.1 {excerpt} Discussion—A different laboratory of necessity means a different operator, different equipment, and different location and under different supervisory control.

3.1.17 Reproducibility limit (R), n—the value below which the absolute difference between two test results obtained under reproducibility conditions may be expected to occur with a probability of approximately 0.95 (95%).

3.1.17.1 Discussion—The reproducibility limit is 2.8 (~1.96 2) times the reproducibility standard deviation. The multiplier is independent of the size of the interlaboratory study (that is, of the number of laboratories participating).

3.1.18 Reproducibility standard deviation (sR), n—the standard deviation of test results obtained under reproducibility conditions.

Prepared by ILS Coordinator: John Leffler, PE

REFERENCES

1 ASTM F2508-13, Standard Practice for Validation, Calibration, and Certification of Walkway Tribometers Using Reference Surfaces, ASTM International, West Conshohocken PA, 2013

2 Slip-Test Mark IIIB tribometers can be identified as serial numbers 40 and 43-on.

3 ASTM E691-11 Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method, ASTM International, West Conshohocken PA, 2011

4 Reprinted, with permission, from ASTM E177-13 Standard Practice for Use of the Terms Precision and Bias in ASTM Test Methods, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be obtained from ASTM International, www.astm.org

	DATA				eq 1	x bar (cell avg)			eq 2	s (cell std deviation)			eq 6	sr (repeatability std dev)			eq 4	d (cell deviation)		
LAB #	***RS-A***	***RS-B***	***RS-C***	***RS-D***	***RS-A***	***RS-B***	***RS-C***	***RS-D***	***RS-A***	***RS-B***	***RS-C***	***RS-D***	***RS-A***	***RS-B***	***RS-C***	***RS-D***	***RS-A***	***RS-B***	***RS-C***	***RS-D***
1	0.15	0.24	0.38	0.67	0.140000	0.225833	0.406667	0.658333	0.004264	0.007930	0.019695	0.010299	0.008704	0.011323	0.016620	0.027890	0.003958	-0.018333	-0.002188	-0.018750
1	0.14	0.22	0.39	0.65																
1	0.13	0.22	0.39	0.65																
1	0.14	0.23	0.39	0.68																
1	0.14	0.22	0.39	0.66																
1	0.14	0.22	0.39	0.67																
1	0.14	0.23	0.42	0.65																
1	0.14	0.22	0.43	0.65									**eq 10**	**r (repeatability limit)**						
1	0.14	0.22	0.42	0.66									0.024371	0.031706	0.046537	0.078091				
1	0.14	0.24	0.43	0.65																
1	0.14	0.23	0.43	0.65																
1	0.14	0.22	0.42	0.66									**eq 11**	**R (reproducibility limit)**						
2	0.15	0.25	0.41	0.66	0.139167	0.245000	0.430833	0.673333	0.005149	0.007977	0.015050	0.024246	0.032992	0.054413	0.088087	0.11762	0.003125	0.000833	0.021979	-0.00375
2	0.14	0.25	0.41	0.65																
2	0.14	0.24	0.41	0.66									**eq 7**	**sR (reproducibility std dev)**						
2	0.14	0.26	0.43	0.70									0.011783	0.019433	0.03146	0.042007				
2	0.14	0.25	0.43	0.70																
2	0.14	0.24	0.42	0.69																
2	0.14	0.25	0.44	0.70																
2	0.14	0.25	0.45	0.70																
2	0.14	0.23	0.45	0.68																
2	0.14	0.24	0.44	0.66																
2	0.13	0.24	0.44	0.64																
2	0.13	0.24	0.44	0.64																
3	0.14	0.25	0.43	0.65	0.125	0.234167	0.440833	0.675833	0.006742	0.0079296	0.010836	0.0167649					-0.011042	-0.010000	0.031979	-0.00125
3	0.13	0.24	0.44	0.67																
3	0.12	0.24	0.42	0.67																
3	0.13	0.24	0.44	0.68																
3	0.13	0.23	0.44	0.68																
3	0.12	0.23	0.44	0.65																
3	0.13	0.24	0.45	0.70																
3	0.12	0.23	0.43	0.69																
3	0.12	0.22	0.44	0.70																
3	0.12	0.23	0.45	0.66																
3	0.12	0.23	0.45	0.68																
3	0.12	0.23	0.46	0.68																
4	0.16	0.24	0.37	0.63	0.1325	0.239167	0.385000	0.694167	0.0105529	0.0066856	0.009045	0.0524765					-0.003542	-0.005000	-0.023854	0.017083
4	0.14	0.24	0.38	0.62																
4	0.13	0.24	0.38	0.61																
4	0.13	0.25	0.39	0.68																
4	0.13	0.24	0.38	0.67																
4	0.12	0.23	0.38	0.69																
4	0.14	0.25	0.40	0.75																
4	0.13	0.23	0.39	0.73																
4	0.13	0.24	0.40	0.73																
4	0.13	0.24	0.39	0.76																
4	0.13	0.24	0.38	0.74																
4	0.12	0.23	0.38	0.72																
5	0.14	0.27	0.38	0.68	0.1325	0.2475	0.364167	0.7125	0.0086603	0.0128806	0.009003	0.0338781					-0.003542	0.003333	-0.044688	0.035417
5	0.15	0.26	0.37	0.67																
5	0.14	0.25	0.36	0.66																
5	0.14	0.25	0.37	0.70																
5	0.13	0.25	0.35	0.71																
5	0.12	0.23	0.37	0.70																
5	0.13	0.26	0.35	0.71																
5	0.13	0.25	0.36	0.73																
5	0.13	0.23	0.36	0.76																
5	0.12	0.25	0.37	0.77																
5	0.13	0.23	0.37	0.74																
5	0.13	0.24	0.36	0.72																
6	0.15	0.25	0.37	0.61	0.128333	0.2325	0.400000	0.615833	0.0119342	0.0086603	0.020000	0.0178164					-0.007708	-0.011667	-0.008854	-0.06125
6	0.15	0.24	0.41	0.61																
6	0.13	0.24	0.36	0.61																
6	0.12	0.24	0.40	0.62																
6	0.13	0.23	0.39	0.62																
6	0.11	0.22	0.39	0.60																
6	0.12	0.23	0.41	0.66																

6	0.12	0.23	0.41	0.64																
6	0.12	0.23	0.43	0.61																
6	0.13	0.23	0.42	0.61																
6	0.13	0.23	0.40	0.60																
6	0.13	0.22	0.41	0.60																
7	0.17	0.28	0.41	0.73	0.151667	0.278333	0.440000	0.7175	0.0119342	0.0158592	0.022962	0.0252713					0.015625	0.034167	0.031146	0.040417
7	0.14	0.26	0.44	0.73																
7	0.15	0.28	0.42	0.72																
7	0.16	0.31	0.44	0.71																
7	0.17	0.29	0.44	0.75																
7	0.16	0.27	0.44	0.76																
7	0.16	0.30	0.43	0.74																
7	0.15	0.28	0.42	0.71																
7	0.14	0.26	0.42	0.70																
7	0.14	0.28	0.48	0.68																
7	0.14	0.26	0.48	0.69																
7	0.14	0.27	0.46	0.69																
8	0.15	0.26	0.38	0.67	0.139167	0.250833	0.403333	0.669167	0.0066856	0.0172986	0.019695	0.0197523					0.003125	0.006667	-0.005521	-0.007917
8	0.15	0.25	0.38	0.67																
8	0.14	0.23	0.38	0.64																
8	0.14	0.29	0.40	0.68																
8	0.13	0.27	0.39	0.68																
8	0.14	0.26	0.39	0.68																

APPENDIX E

Subjective Study Perception Survey

Agreement to Participate in Research

Responsible Investigator: Kevin Johnson
Title of Protocol: "Assessing floor slipperiness in a college campus's dining halls using objective and subjective measures."

1. You have been asked to participate in the research study that aims at investigating workers' perception of the floor slipperiness in select areas of the dining hall.
2. You will be asked to take the attached survey.
3. Completing the survey involves no risk to you.
4. You and the other employees of Aramark Corporation will benefit if this research is used by Aramark Corporation and/or the East Carolina University to find ways to enhance the safety and quality of your work areas.
5. Although the results of this study may be published, no information that could identify you will be included.
6. Questions or complaints about this research may be addressed to research Faculty Advisor Dr. Mike Behm, behmm@ecu.edu or 252-328-9674.
7. Your consent is being given voluntarily. You may refuse to participate in the survey. If you decide to participate in the survey, you are free to withdraw at any time without any negative effect on you relations with Aramark Corporation, East Carolina University, or with any other participating institutions or agencies.

Thank you for participating in this survey.

Sincerely,

Kevin Johnson

Kevin Johnson
Graduate Assistant
MS, Occupational Safety
College of Engineering & Technology
East Carolina University

FOR INVESTIGATOR USE, PLEASE SKIP TO "QUESTIONNAIRE" BELOW

Survey No. ______ Date: ___________

Location: _____________________ Time: _____________

Questionnaire

Please answer all of the following questions to the best of your abilities.

1. How many years and months have you been employed at this facility?

____ years ______months

2. What is your age?

3. What is your gender?

1 = Male
2 = Female

4. What is your race/ethnicity?
1 = White
2 = Hispanic or Latino
3 = Black or African American
4 = Native American or American Indian
5 = Asian / Pacific Islander
6 = Multi-Racial

5. How many hours per week (average) do you work at this facility?

Please rate the slipperiness of the floor at each area, in your general opinion, from extremely slippery to not slippery at all.

	Extremely Slippery	More Slippery	A Little Slippery	Not Slippery at All
Fryer/Back Vat	1	2	3	4
Oven	1	2	3	4
Sink	1	2	3	4
Front Counter	1	2	3	4
Walk-through Area	1	2	3	4

Thank you for your cooperation in completing this survey.

APPENDIX F

Communication of Publisher Owned Figure Usage

Figure 1 and Figure 2

Academic Books Permissions <mpkbookspermissions@tandf.co.uk>
Wed 08/16, 11:05 AM

9780415298285 | Measuring Slipperiness | Edn. 1 | Hardback | Figure 1 & 2

Further to your recent email permission is granted for use of the requested material only in your forthcoming thesis, subject to the following conditions:

1. The material to be quoted/produced was published without credit to another source. If another source is acknowledged, please apply directly to that source for permission clearance.
2. Permission is for non-exclusive, English Language rights and covers use in your thesis only. Any further use shall be the subject of a separate application for permission.
3. Full acknowledgement must be given to the original source, with full details of figure/page numbers, title, author(s), publisher and year of publication.

Best Regards

Sarah

UK Book Permissions

Johnson, Kevin Patrick
Fri 07/07, 01:02 PM
mpkbookspermissions@tandf.co.uk;

Hello,

My name is Kevin Johnson and I am a graduate student pursuing my degree in Master of Science, Occupational Safety at East Carolina University in Greenville, NC. I am currently working on my graduate thesis research titled "Assessing Floor Slipperiness in Campus Dining Halls Using Objective and Subjective Measures" and am seeking permission to use two figures from the copyright text "Measuring Slipperiness: Human Locomotion and Surface Factors" ISBN: 9780415298285 - CAT# TF1578. The specific figures are Figure 1 on page 5 and Figure 2 on page 6 of the text.

Figure 5

Katie Thayer <katie@cscforce.com>
Fri 07/07, 12:51 PM
Good Afternoon,

The owner of the company says you have permission to use the Horizontal Slip Meter image from our website for your purpose.

Katie Thayer
C.S.C. Force Measurement, Inc
84 Ramah Circle North, Agawam, MA 01001
Toll Free: 800-866-3672 x801 Fax: 413-789-3598
International/Local: +1-413-789-3086 x801
www.cscforce.com

Johnson, Kevin Patrick
Fri 07/07, 09:51 AM
katie@cscforce.com;

Hello,

My name is Kevin Johnson and I am a graduate student pursuing my degree in Master of Science, Occupational Safety at East Carolina University in Greenville, NC. I am currently working on my graduate thesis research titled "Assessing Floor Slipperiness in Campus Dining Halls Using Objective and Subjective Measures" and am seeking permission to use the image from your website of the "C.S.C. Force Measurement Horizontal Pull Slipmeter (HPS)" from the URL: http://www.cscforce-express.com/C.S.C.-Force-Measurement-Horizontal-Pull-Slipmeter-HPS.html.

Figure 3, Figure 4, Figure 6, Figure 7, and Figure 8

Greg Cohen <greg@slipdoctors.com>
Fri 07/07, 09:56 AM

Of course!

Greg Cohen
President
SlipDoctors Corporate
2101 Midway Rd. Suite 350
Carrollton, TX 75006

Sent: Friday, July 7, 2017 8:55 AM
To: greg@slipdoctors.com; howard@slipdoctors.com
Subject: Slip Doctors Information [#1569]
johnsonkev09@students.ecu.edu

Hello,

My name is Kevin Johnson and I am a graduate student pursuing my degree in Master of Science, Occupational Safety at East Carolina University in Greenville, NC. I am currently working on my graduate thesis research titled "Assessing Floor Slipperiness in Campus Dining Halls Using Objective and Subjective Measures" and am seeking permission to use the images from your website of the “Horizontal Dynamometer Drag Sled Pull-Meter,” "BOT-3000E SKU: S-MTR-3000E," "English XL SKU: S-MTR-ENGXL," "Slip-Test Mark IIIB," and the "American Slip Meter 825A SKU: S-MTR-ASM." The URL these images appear on is: http://www.slipdoctors.com/products-slipmeters.asp.

Thanks,

Kevin Johnson