Development of Standard Data for Donning and Doffing Personal Protective Equipment

by

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Abstract

Personal Protective Equipment (PPE) is specialized clothing or equipment worn to minimize exposure to a variety of occupational hazards. It has been estimated that 20 million U.S. workers wear some form of PPE. How much time it takes for employees to don and doff PPE and whether they should be compensated for this time has been frequently litigated in the last decade. Surprisingly, few studies have been performed to determine empirical donning and doffing times for PPE where the detailed method is documented for the given times. Three studies were conducted as part of this dissertation. In one study, a detailed method was developed for donning a single-use personal fire escape mask (aka smoke hood). A time study of the method was conducted to derive a donning time standard. In another study, donning and doffing multiple layers of different combinations of work gloves was conducted. In a third study, donning and doffing methods and times for common PPE used in industry such as ear plugs, aprons, safety glasses, etc. were developed. A computer model was refined to enable researchers or practitioners to easily determine standard times for donning and doffing. The studies demonstrate that Time Study is an effective means of determining don and doff times for PPE.

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List of Abbreviations

ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
BLS	Bureau of Labor Statistics
CDC	Centers for Disease Control and Prevention
CPSC	Consumer Product Safety Commission
GTA	Graduate Teaching Assistant
INSY	Industrial and Systems Engineering
IRB	Institutional Review Board
ISEA	International Safety Equipment Association
MOST	Maynard Operation Sequence Technique
NIOSH	National Institute of Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PDTS	Pre-Determined Time Systems
PPE	Personal Protective Equipment
RPED	Respiratory Protective Escape Device
STAFDA	Specialty Tools & Fasteners Distributors Association

Chapter 1. Introduction

It has been estimated that 20 million U.S. workers wear some form of Personal Protective Equipment (PPE) to protect them from workplace hazards. (National Institute for Occupational Safety and Health, "Personal Protective Equipment", web page last updated August 13, 2012). A presentation given at the 2015 Specialty Tools & Fasteners Distributors Association (STAFDA) Convention reported that PPE is a $7.3 billion U.S. market for industry, construction and "other" (utilities, mining, and transportation) employers consisting of hand protection (30%), apparel (21%), footwear (17%), fall protection (5%), above-the-neck (16%), and respiratory (10%).[1] According to Global Market Insights, the global market for PPE will be $67.6 billion USD by 2023; in 2015 it was $38 billion USD.[2] One of the types of PPE studied in the work reported in this dissertation is work gloves. Using Bureau of Labor Standards (BLS) incidence and employment rates[3], there were 12.7 lost-time hand injuries per 10,000 employees in 2014 (approximately 150,000 people) in the U.S. The median days away from work for these hand injuries were five. OSHA has reported that 70% of workers experiencing hand injuries were not wearing gloves and the other 30% were wearing gloves, but they were either inadequate, damaged, or the wrong type of glove.[4]

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[1] Roberts, Robin, "State of the Industry", 2015 STAFDA Convention, Keynote Address, Nov. 9, 2015.
[2] Global Market Insights, Inc., "Personal Protective Equipment (PPE) Market Size Worth $67.6 billion by 2023", Apr 20, 2016.
[3] Bureau of Labor Standards, "2014 Nonfatal Occupational Injuries and Illnesses: Cases with days away from work", Case and Demographics, November 2015.
[4] OSHA, Regulations (Preambles to Final Rules), Personal Protective Equipment for General Industry, Section 2-II. Workplace Hazards Involved, 59 FR 16334, April 6, 1994.

Another type of PPE studied is corded ear plugs. According to the National Institute of Occupational Safety and Health (NIOSH), approximately 22 million U.S. workers are exposed to hazardous noise levels at work and approximately $242 million is spent annually on worker's compensation for hearing loss.[5] The Leavitt Group reported in a 2015 article on a survey of safety professionals that "…98% indicated they had observed workers not wearing safety equipment when they should have been. Even worse, 30% indicated this had occurred on numerous occasions."[6]

Wearing PPE and wearing it properly (compliance) is important to keep workers safe when other controls are not feasible. In a survey conducted by Kimberly-Clark Professional, more than half of the 110 "safety professionals surveyed attributed noncompliance to workers thinking that safety equipment was not needed."[7] Other reasons cited for noncompliance were "uncomfortable, too hot, blamed for decreased productivity or an inability to perform tasks, unavailable near the work task, ill-fitting, unattractive looking." The time it takes to don and doff PPE is related to decreased productivity if the worker is not allowed time or enough time to don/doff PPE. Over the past decade, many lawsuits have arisen relating to employees not being compensated for time spent donning and doffing PPE, even though the PPE is required by the employer to be worn on the job. Litigation issues will be discussed as they relate to the studies completed as part of this dissertation, especially in Chapter Five.

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[5] NIOSH, "Noise and Hearing Loss Prevention", Workplace Safety & Health Topics, page updated January 25, 2016.
[6] Leavitt Group, "Keeping Employees Safe with Personal Protective Equipment", News & Publications, December 29, 2015.
[7] Kimberly-Clark Professional, "Alarming Number of Workers Fail to Wear Required Protective Equipment", Roswell, Ga., October 9, 2012.

The researcher has experience with multiple companies in work measurement and in no case was engineer time spent in developing methods and standards for donning and doffing PPE because it was done “off the line” and did not significantly affect production capacity. Accurate engineered methods and standard data for this activity can be used as a resource for such companies and other entities. This research includes experiments resulting in empirical and validated standard times for donning and doffing various types of PPE.

Industrial and Systems Engineers (ISEs) typically receive education and training in how to develop repeatable methods and associated time standards as part of their undergraduate education. Labor time standards are used in industry for determining product costs, staffing requirements (which affect plant layout and size), production capacity, productivity, and other critical measures. Engineer time is costly and priority must be given to study the operations in a manufacturing plant or other organization that consume the most labor time. For most engineers providing technical support to industries, studying donning and doffing of PPE for the purpose of developing efficient methods and associated standards would probably not be high on their priority list. However, since the use of PPE is so pervasive in industry, if donning and doffing engineered and reliable standards were readily available in a usable format, engineers could simply use the data as they see appropriate.

Most undergraduate ISE programs have at least one class in methods and work measurement to teach their students this material. At Auburn University, the class is INSY 3021, Methods and Work Measurement, a three semester hour class that is taught each spring to sophomores. It is one of the first “applied” classes in the major. Many students use the material in their first co-op or internship position as it is very common

for industries to have students perform time studies as part of their assignment. This author had access to various types of PPE and also was the instructor numerous times for the INSY 3021 class. Teaching the students how to develop repeatable methods and associated labor standards through donning and doffing of PPE provided an opportunity to teach the required material while also developing useful PPE standards. The students were trained and then supervised in a set of controlled experiments conducted during scheduled lab times to develop the donning and doffing times reported in this dissertation.

The experiments were conducted over three years from 2013-2015 using over 330 students, primarily working in teams of four to five. The students were first introduced to the concept of labor standards and why they are important to an organization. They were given some brief training in conducting time studies and performed an individual lab where they wrote a method for donning and doffing an article of clothing (jacket, vest, etc.). The methods were checked for accuracy and completeness by either the instructor or graduate teaching assistant (GTA). Once the methods were refined, the students completed 30 trials for don and 30 trials for doff and then calculated an average time. For details, Appendix A contains a copy of the lab instructions and an exemplar student submission of the completed assignment.

Section 1.1 Performance Rating Training and Qualification of Students

Classical Time Study involves not only stopwatch use to capture the actual times of an operation but also requires that operators be "rated" based on the pace at which they are observed to be working. Engineers must be trained in how to rate performance (aka pace rating), which is used to adjust the time standard since, during observed trials, operators may not be performing at 100% pace or "standard performance". "*Standard*

performance is defined as the level of performance attained by a thoroughly experienced operator working under customary conditions at a pace neither too fast nor too slow, but representative of one that can be maintained throughout the day." [8]

One lab period (2.5 hours) was devoted to teaching the students how to pace rate. Appendix B contains the lab instructions for this activity as well as an exemplar student team submission. The lab was built using benchmark examples that are familiar to most industrial engineers, and well known in the literature (first suggested by Presgrave in 1957)[9], walking 100 feet in 0.38 minutes (22.8 seconds) and dealing a 52 deck of cards in 0.50 minutes (30 seconds).

After this lab was completed, a qualification test was devised to assess students' ability to pace rate accurately. Two different dealers (Graduate Teaching Assistants) were trained to deal a deck of cards at 100% pace (30 seconds). The dealers' hands were recorded using the video feature of an Apple iPhone 4S camera. The recording work method used a two-step process as follows:

Step 1: The dealer sat in front of the table with both the hands on top of the table and with the non-dominant hand holding the deck of cards and the dominant hand on top of the deck. At this point the video is turned ON.

Step 2 (Dealer 1): The dealer starts to deal the cards one at a time, into four orderly piles, beginning at the opposite side of the table, then to their right, then directly in front of the dealer and finally to their left (a diamond pattern), repeating this pattern until the deck is exhausted. This was performed in a 30 second time frame.

[8] Freivalds, Andris, Neibel's Methods, Standards, and Work Design, Thirteenth Edition, Chapter 11, p. 450.
[9] Freivalds, Andris, Neibel's Methods, Standards, and Work Design, Thirteenth Edition, Chapter 11, p. 452.

Step 2 (Dealer 2): The dealer starts to deal the cards one at a time, into four orderly piles, beginning directly in front of the dealer, then to his left, then to the opposite side of the table and finally to his right (a diamond pattern), repeating this pattern until the deck is exhausted. This was performed in a 30 second time frame.

Following the 100% performance cycle video, ten additional clips were extracted from the base video using Apple iMovie. The pace for the 10 clips created ranged from 50% to 150%, in 10% increments. This same process was repeated for the second dealer to create 10 additional clips of the same performance. While dealing the cards, two conditions were maintained: 1) The cards must remain on the table and 2) they must come to rest in orderly and easily distinguished piles, though they do not have to be perfectly stacked. All the videos were imported into a PowerPoint file and were converted to a Slideshow. To insure that the actual run time was not available for students to view, the media scrollbar was removed from the videos.

The 11 clips from Dealer 1 and 11 clips from Dealer 2 were randomized on the PowerPoint file by generating 22 random numbers between 1 and 22 using the Excel RandLotto function (RandLotto(1,22,1). The order of the names and corresponding paces for each dealer are shown in Table 1-1. The second column represents the dealer (D1 or D2) and the pace. For example, "D1-60" represents the clip for dealer 1 (D1) dealing at 60% pace rate. The third column shows the corresponding name. The clips were placed in random order so that students would not have any indication of pace by the order of clips on the slide show.

Random Number	Dealer and Pace	Name
14	D2-70	Bottle
6	D1-100	Pink
11	D1-150	Carrot
15	D2-80	Antler
20	D2-130	Sprinkle
13	D2-60	Sofa
19	D2-120	Limbo
18	D2-110	Halo
17	D2-100	Dallas
8	D1-120	Crank
4	D1-80	Apple
21	D2-140	Walrus
7	D1-110	Mug
22	D2-150	Mist
3	D1-70	Juniper
5	D1-90	Marshmallow
1	D1-50	Tulip
10	D1-140	Kitten
16	D2-90	Penny
12	D2-50	Sailboat
2	D1-60	Star
9	D1-130	Folly

Table 1-1. Names and Paces for Card Dealers

Each of the 22 clips was then assigned a random “name” that had no meaning associated with a pace. Each name was a common word. The purpose of the naming was so that we could assign 5 random paces to each student for the qualification test. By using random names, there was no way for a student to guess which paces they were assigned. The names were assigned in Table 1-2:

Dealer 1			Dealer 2		
Clip	Pace	Name	Clip	Pace	Name
1	50	Tulip	12	50	Sailboat
2	60	Star	13	60	Sofa
3	70	Juniper	14	70	Bottle
4	80	Apple	15	80	Antler
5	90	Marshmallow	16	90	Penny
6	100	Pink	17	100	Dallas
7	110	Mug	18	110	Halo
8	120	Crank	19	120	Limbo
9	130	Folly	20	130	Sprinkle
10	140	Kitten	21	140	Walrus
11	150	Carrot	22	150	Mist

Table 1-2. Dealer Pace Name Assignment

Five random numbers were generated in Excel for each student in the class using the function RandLotto(1,22,5). These five numbers represented the clips (paces) that would be viewed by each student. The five numbers were translated into five words. For example, the first student in the class was assigned the 5 random numbers 9, 11, 17, 18, 12. The student was given the word list Folly, Carrot, Dallas, Halo, and Sailboat. They were instructed to go to the clip for each word given. They were also instructed to watch the entire deal and then to assign a pace rating for that deal. Students were monitored by the instructor or GTA to insure they were not using a timing device to aid in rating.

For a student to be qualified, they had to rate within +-10% of the actual rate for 4 out of 5 of the clips and no more than +-20% on the 5th (exclusionary criteria). If they did not qualify the 1st time, they were allowed to try again two more times (for a lower grade on the lab assignment). A separate list of 200, 5 random words were generated for the 2nd and 3rd trials of students. These were assigned in order to students by the GTAs as needed. Appendix C contains a copy of the lab assignment and an example student submission. Approximately 99% of the students qualified as raters after 3 attempts. The

1% that did not qualify were disqualified to performance rate on subsequent experiments. Following the qualification test, PPE studied included thermal gloves, corded ear plugs, disposable aprons, safety glasses, hard hats, work jackets, boots, dust masks, headsets, respiratory masks, and smoke hoods. These specific PPE were chosen since they are commonly used in industries where many of the students will work (such as automobile assembly plants) and because the author had access to multiple types and pieces of the selected PPE.

Section 1.2 Research and Dissertation Organization

The seven chapters of this dissertation are organized in a manuscript publication format. Chapter One contains a general introduction to the research. Chapter Two contains a comprehensive literature review of the subject of the dissertation (times for donning and doffing PPE). Chapters Three, Four, and Five contain research papers that have been prepared as stand-alone publications. They have been reformatted to match the formatting required by this dissertation. Chapter Three, "Developing Empirical Donning Times for Smoke Hoods", has been presented at and published in the Athens Institute for Education and Research Conference Paper Series, Athens, Greece, IND2015-1637. Chapter Four, "Determining Empirical Donning and Doffing Times for Complex Combinations of Personal Protective Equipment (PPE)", has been accepted for publication and presented in July 2016 at the Applied Human Factors and Ergonomics International Conference (www.ahfe.org), Orlando, FL. Chapter Five, "An Interactive Model of PPE Donning and Doffing Times", will be submitted for publication. Chapter Six contains overall conclusions while Chapter Seven suggests future research that can be conducted to extend this work. The appendices contain detailed experiment descriptions and representative examples of results.

Chapter 2. A Review of the Literature on Donning and Doffing Methods and Times for PPE

The latest estimate by the National Institute of Occupational Safety and Health (NIOSH) is that 20 million workers don and doff PPE every day. Industry estimates PPE is a $7.3 billion industry in the US as previously stated. However, there are very few published studies of methods and times for donning and doffing PPE. One reason may be that for each worker, the time spent donning and doffing PPE is a very small percentage of his or her workday and it is not worth the time of an industrial engineer or other time study specialist to spend time studying this operation. As previously documented, some companies do not pay for the don and doff times anyway. Regardless, there is very little in the literature regarding don and doff time studies.

One of the studies performed as part of this dissertation focused on the donning of a fire escape mask [1], which is a device designed for single adult use in an emergency evacuation from fire conditions. Such devices are generally covered by standards from the American National Standards Institute (ANSI) or the American Society for Testing and Materials (ASTM). The consensus standards [2,3] specify that a "donning test" must be passed prior to approval of the device for public use requiring that a user can correctly don the device in 30 seconds or less after viewing the donning instructions for 120 seconds.

Don times for smoke hoods have been stated in a few other sources. Professor Galea [4] states a time of around 10 seconds. While Vant [5] agrees with this timeframe, Frankoski [6] states a time of 15 seconds. McFadden and Smith [7] reported a time of

17.41 seconds. A 2007 study by the Consumer Product Safety Commission [8] reported that out of ten timed trials, only one trial (10%) met the 30 second consensus standard and also met the correct donning criteria.

Another study done as part of this work was conducted on donning and doffing of layers of work gloves. No other studies were found that developed empirical don and doff times for gloves, nor were any studies found that addressed the time to don and doff multiple layers of work gloves. Wearing multiple layers of work gloves may provide simultaneous protection from cold temperatures, wet conditions, sharp cutting tools, blood or body fluid exposure, or other hazards. According to the U.S. Centers for Disease Control and Prevention, there are over one million emergency department visits by US workers per year for hand injuries [9]. According to OSHA [10], of the workers who experienced hand injuries, 70% were not wearing gloves and the remaining 30% were wearing gloves that were inadequate, damaged, or the wrong type.

Several combinations of glove layering were studied; one of these was Thermal + Rubber + Protective (Steel Mesh). This combination was specifically discussed in a 2013 publication of the North Carolina Department of Labor [11] where it is recommended that “cotton gloves can be worn under rubber gloves to keep the hands warm” and metal mesh gloves are also recommended to prevent cuts and lacerations. The Fair Labor Standards Act of 1938 and the Portal-to-Portal Act of 1947 entitle employees to compensation for work activities that are integral and indispensable to their principal work activities. Employees and employers have disagreed as to what constitutes compensable work so that numerous lawsuits have arisen concerning this issue [12]. In 1956, the US Supreme Court ruled in *Steiner v. Mitchell*, 350 U.S. 247, 255 (1956) that employees at a battery plant were entitled to be compensated for the time it took to

change their clothes and shower after their shift. In the same year, the Court found in *Mitchel v. King Packing Co.*, that employees in a beef packing plant had to be paid for knife sharpening time, 350 U.S. 260, 262-263 (1956).

In 2005, the Supreme Court consolidated two cases involving donning and doffing of PPE at meat and poultry processing plants, *Tum v. Barber Foods, Inc.*, 360 F.3d 274 (1st Cir. 2004) and *Alvarez v. IBP*, 339 F.3d 894 (9th Cir. 2003). The ruling in these cases was that the don and doff times were compensable if that activity is "integral and indispensable" to the employee's principal work activity. Despite this ruling and other compatible rulings by lower courts, employees in some companies continued to file lawsuits over the last decade because they were not being compensated for donning and doffing PPE. In the most recent decision decided March 22, 2016, the Supreme Court upheld a $5.8 million judgment against Tyson Foods Inc. [13] in a pay dispute with more than 3,000 workers at a pork-processing plant in Iowa. The workers sued to be paid for the time spent donning and doffing PPE. Interestingly, Tyson wanted the court to broadly rule out statistical evidence in the case concerning the time it took to don and doff, but the Supreme Court allowed it.

In June 2006, The U.S. Army Research, Development and Engineering Command published results of a study of PPE used for explosive ordnance disposal [14]. Time studies were performed and results were published on the don and doff times for four types of suits. Most of the other recent studies found concern donning and doffing of PPE in healthcare and there have been several publications concerning PPE specifically for healthcare workers managing patients with Ebola. Published in October 2015, a review was conducted to inform the World Health Organization's guideline on personal protective equipment with a focus on workers directly caring for patients with Ebola or

Marburg virus diseases [15]. This study found 30 studies relating to the topic and the researchers said "Reporting of personal protective equipment components and infection prevention and control protocols was generally poor." The researchers also said that in most of the reports studied, the quantity (such as double-gloving), quality or specific characteristics of the PPE was not given. They said there was insufficient evidence to draw conclusions regarding the effectiveness of PPE and that the lack of adequate training on donning and doffing was an "important factor for virus transmission." The Centers for Disease Control and Prevention (CDC) published a guidance on August 27, 2015 [16] for healthcare workers caring for Ebola patients. This document establishes a procedure for donning and doffing PPE including a list of PPE to be used, a donning and doffing room, and the use of a trained observer. However, no detailed methods nor donning and doffing times are given. For example, in Section 9, "Recommended Sequences for Donning PPE", step 5 reads "Put on first pair of gloves." How to put on the gloves is not stated.

This dissertation fills a gap in the literature on an effective way to study donning and doffing PPE to determine and document the correct method and to determine standard times.

Chapter 3. Developing Empirical Donning Times for Smoke Hoods

The manufacturer of the KIKAR XHZLC 60 Fire Escape Mask (see Figure 3-1) states on the package (ready-to-use configuration) “This respirator is intended for applications in governmental locations, hotels, offices buildings, forests, airports, department stores, banks, ships, post offices, power industry, telecommunications, subways, recreation centers, refineries and chemical industry, etc. as an essential breathing-protective device for personal safety in fire accidents” [1]. Hence, smoke hoods are designed for adult single use, immediate emergency evacuation from fire conditions, without reentry. Protection is provided for the head, eyes, and respiratory system against smoke, irritants, radiant heat, and toxic gases such as HCL, SO_2, HCN, and CO, for a short period, usually 15 to 60 minutes [17]. The hood studied in this experiment was rated to last 60 minutes.

ASTM E2952-14 Standard Specification for Air-Purifying Respiratory Protective Smoke Escape Devices (RPED) [2] and ANSI/ISEA 110-2009 the American Nation Standard for Air-Purifying Respiratory Protective Smoke Hood Escape Devices [3] describe the *Donning Test* that must be passed prior to approving a smoke hood for commercial (public) use. The test requires two (one male & one female) subjects who have not been trained in RPED use and who have not previously donned an RPED. Neither subject can have obvious mental or physical disabilities that pertain to donning an RPED. Subjects have 120 seconds to view the donning instructions supplied by the manufacturer or printed on the RPED, then they immediately don it without further

instruction. For the test to be passed, the RPED must be correctly donned (verified by evaluator) in 30 seconds or less.

Figure 3-1. KIKAR XHZLC 60 Fire Escape Mask

Others suggest the times to don smoke hoods are considerably lower than the ≤30 seconds specified in the ASTM & ANSI standards. The University of Greenwich, Fire Safety Engineering Group (FSEG) offers a number of 'Fire Safety Tips' including some for smoke hood selection and use. Professor Galea [4] states that the smoke hood should "Be easy to put on and have clear instructions for proper use. Owners should aim to be able to don the smoke hood correctly in around 10 seconds (as measured from the time of opening packaging to putting it on correctly)." Vant [5] also reports a similar timeframe when he states that a majority of subjects can don a smoke hood within 10 seconds, and this is essentially attributed to subject motivation, design for ease of use, and the effectiveness of related safety training briefings. Further, in a 1995 Los Angeles Times article written by Kathleen Doheny, titled "Do Smoke Hoods Improve Safety?" Geraldine Frankoski espouses that "It takes 15 seconds to put on." [6]

However, some studies have indicated that subjects have difficulty donning smoke hoods in the recommended timeframe. The Consumer Product Safety Commission (CPSC) released a detailed study in 2007 which included donning smoke hoods [8]. Two subjects, a male and a female, each donned five different smoke hoods following the ANSI/ISEA standard. Out of the ten trials, only one trial successfully met the 30 second and correct donning criteria.

Methods Engineering and *Work Measurement* [18, 19, 20, 21, 22, and 23] are two closely related sub-fields of *Industrial Engineering* that have for the past century established statistically based techniques such as *Time Study* to empirically develop time standards (with statistical confidence and accuracy) for quantifying how much time it should take to perform a virtually unlimited number of processes, jobs, tasks, etc., including donning and doffing times associated with Personal Protective Equipment (PPE), in this case smoke hoods.

The purpose of the study was to use work measurement and methods engineering techniques to determine the times necessary to don smoke hoods according to manufacturer instructions.

Section 3.1 Method for Conducting Experiments

Sixteen (N=16) college students aged 19-23 ($\bar{x}$ = 20.0 years) were recruited to participate in a time study approved by the Auburn University Institutional Review Board (IRB). After being briefed on the purpose of the study, and watching a short (< 1 minute) video three times on how the smoke hood was to be properly donned, (none had experience donning a smoke hood) subjects performed five (5) successive trials of donning the KIKAR XHZLC 60 Fire Escape Mask.

Section 3.2 Manufacturer Donning Instructions

The manufacture of the KIKAR XHZLC 60 Fire Escape Mask provides the following verbatim "Operation Instructions" on the exterior of the protective storage box.

a) Open the box and take out the vacuum packing bag;

b) Tear off the vacuum packing bag, take out the Respirator and pull out the two plugs respectively;

c) Put on the helmet and tighten the string;

d) Decide your way out and escape quickly;

In addition to the written instructions located on the side panels of the box, the manufacturer provides four (4) pictograms, labeled 1, 2, 3, 4 on the top panel of the box. Written instructions (small font) are co-located by each of the pictograms (Figure 3-2). The verbiage, labelled again as "Operation Instructions" reads exactly;

1. Open the lid of a box, Take out the vacuum packing bag.

2. Tear the vacuum packing bag, Pull off two jars squeeze in inside and outside.

3. Put on head cover, The head brings tensioning along.

4. Choose route, Flee for one's life decisively.

Figure 3-2. Donning Pictograms

Section 3.3 Description of Experiments

In Trial (1) of the five trials, each subject stood in front of a table with a vacuum packed smoke hood located inside a sealed box resting on the table. Subjects were instructed beforehand (verbally and by video) to:

1. Reach out and pull the box towards them, rotate the box so the opening flap faced them, open the box (breaking the outer seal by pulling up on the tab), remove the smoke hood (sealed in a vacuum-packed bag), keeping the bagged smoke hood in their hand, and put aside (move to the side) the box.
2. Open the vacuum-packed bag by ripping (bag was notched), remove the smoke-hood from the bag, keeping the smoke hood in their hand, and put aside the bag on the table.
3. Carefully unroll the smoke hood, remove the two plugs connected by a string in the filter (and put aside the plugs), orient the smoke hood to be donned over the head, pull the smoke hood on over the head, ensure their

mouth and nose are in the internal half mask, ensure a proper seal around neck, push hair up into hood (if applicable), grasp mask (by the external filter) while tensioning the strap to the desired tension, make any final adjustments, and cover the filter inlet hole with the palm of their hand to ensure an appropriate seal (mask will slightly collapse against face when large breath is inhaled).

In Trials (2) through (5), elements a and b (open box, tear bag) were conducted only during trial (1) as the seals were broken on the container and the vacuum-packed inner bag. Trials (2) thru (5) started with the mask (restored to its initial condition by loosening the strap, reinserting the inner and outer plugs back into the filter, carefully rolling and folding back to its initial shape and size) inside the ripped bag [to represent a starting breakpoint for element (c)].

A brief rest period (1 minute) was given between trials to allow for the mask to be restored to its original condition, and data recording. Breakpoints for the time study were identified at the start and end of each of the three elements. Teams consisted of a subject who donned the equipment each time, a timer, a video recorder, and at least two participants who independently performance rated each element every trial. Data were tested for normality and outliers before being analyzed.

The sole task of two team members (students) was to independently performance rate each element of every trial. These students were previously trained and ‘certified’ in performance rating during a previous (unrelated) laboratory curriculum activity. Ratings were recorded independently between trials during the rest period. The results from these two raters were checked for agreement and averaged for the computation of the time standard.

Subjects (N=16; 15 Males, 1 Female) who donned the smoke hoods were asked to provide basic demographic data such as prior smoke hood use, their age and gender, and items that may potentially impact the way they don a smoke hood such as; eyeglass use, wearing earrings, hair/beards [24] hanging down below the bottom of the earlobe, neck circumference, or if clothing was worn high on the neck (such as necktie, scarf, turtleneck sweater, etc.).

Section 3.4 Results

Table 3-1 summarizes the results obtained from the study. The Standard Time was determined by adding the times for Elements (a), (b), and the average of trials 2 through 5 for Element (c) [the average Trial (1) time of 33.65 seconds was identified as an outlier*]. This resulted in a Standard Time of 39.1 seconds. Data were verified to be normal, and three outliers were detected (all on the high side) in Element (a), (b) and Element (c) during Trial (2) and removed from the dataset.

Trial	1			2	3	4	5
Element	a	b	c	c	c	c	c
Mean	*3.98	*10.72	33.65	*24.24	25.02	24.61	23.69
STDEV	1.07	4.99	10.21	5.88	6.81	6.85	6.50
CV	0.27	0.47	0.30	0.24	0.27	0.28	0.27
N	15	15	16	15	16	16	16
Hi	5.8	19.7	49.6	36.6	40.6	41.7	38.3
Lo	2.7	4.4	14.3	15.5	11.8	13.2	14.0

Table 3-1. Smoke Hood Results Summary Table (time in seconds)

Independent performance ratings (in increments of '5', i.e., 85, 90, 100, 105) were compared against each other to check for mutual agreement. Since performance rating is subjective many authoritative sources suggest that a concurrence within 10 is indicative of fair consistency between raters. In all there were 105 elements that were independently rated by two performance raters. Of these, 32 (30.5%) were identical ratings, 31 (29.5%) were within 5%, 32 (30.5%) were within 10%, and 10 ratings (9.5%) exceeded 10%.

No subject reported having previously donned a fire escape (smoke) hood. Regarding items that may potentially impact the way subjects don a smoke hood; One (1) subject reported eyeglass use, one (1) subject reported wearing small stud earrings, two (2) subjects reported hair length below the earlobe of 2.3" and 2.5" (the female subject had her hair tied up in a pony-tail at arrival). Subjects' neck circumference ranged between 12.5" and 16.5" ($\bar{x}$ = 14.9") and no clothing was reported (nor observed) to be worn high on the neck (such as necktie, scarf, turtleneck sweater, etc.) that might potentially interfere with (or delay) obtaining a tight seal around the neck.

Five trials for Element (c) were conducted to ascertain if learning was occurring. the mean donning times for Element (c) in Trials (1) through (5) were 33.65, 24.24, 25.02, 24.61, and 23.69 seconds respectively. A pronounced learning effect occurred between the first and second smoke hood donning trials.

Maynard Operation Sequence Technique (MOST) [23], developed by Kjell B. Zandin in 1980, was used to validate the time study. The training video and experiments were observed by one of the researchers, an experienced MOST analyst. MOST uses the concept that work occurs when you have movement of objects by force. Three basic sequence models are used for manual work, one for general moves (where the object

being moved can freely move in space), one for controlled moves (where the object being moved is restricted in one or more dimensions) and one for "tool use" moves. Donning of the smoke hoods primarily consists of a series of controlled moves. Once a sequence model is chosen for the move, index values are assigned to each letter in the model based on standard table data developed by Zandin. The MOST analysis (shown in Figure 3-3) is done using a standardized form that details the steps taken in the process and shows the index values chosen for each of the sequence models. For each sequence model, the index values are added and then multiplied by the frequency of the move. Total TMU (Time Measurement Units: 1 TMU=0.036 seconds) is obtained by multiplying by 10. MOST is based on 100% pace, so no performance rating is done. Element (a) consists of MOST steps 1-3. Element (b) has steps 4-6. Element (c) has steps 7-17. The MOST analysis for smoke hoods produces a standard time in seconds for elements a, b, and c of 3.60, 7.20, and 25.56. These are compared to the average times obtained in the time study of 3.98, 10.72, and 24.39 (mean for all trials 2-5).

MOST Calculation		Date: 5/8/2015			
		Engineer: LuAnn Sims			
Operation:		Study No.:			
No.	Method Description	No.	Sequence Model	Fr.	TMU
1	Grasp the box and turn it on the table.	3	$A_1 B_0 G_1 A_1 B_0 P_1 A_0$	1	40
2	Grasp the box's opener and pull open.	6	$A_1 B_0 G_3 A_1 B_0 P_1 A_0$	1	60
3	Grasp the package and hold and place the box on the table.	10	$A_0 B_0 G_0 A_1 B_0 P_0 A_0$	1	10
4	Grasp the bag and tear open.				
5	Re-grasp the bag and spread it open.				
6	Grasp the folded hood and aside the bag.				
7	Grasp the hood and unfold twice.				
8	Grasp one red plug and unplug it.				
9	Grasp 2nd red plug and unplug it.				
10	Aside the plugs as a unit.				
11	Place the hood over your head and pull down to ears.				
12	Regrasp the hood and pull it down to neck.				
13	Grasp filter and position over nose and mouth.				
14	Grasp one strap and pull to adjust.				
15	Check position of hood using both hands.	1	$A_1 B_0 G_1 M_1 X_0 I_0 A_0$	1	30
16	Re-grasp strap and tighten.	2	$A_1 B_0 G_1 M_1 X_0 I_0 A_0$	1	30
17	Grasp filter and hold while doing breath test for 2 secs.	4	$A_1 B_0 G_3 M_3 X_0 I_0 A_0$	1	70
		5	$A_1 B_0 G_3 M_3 X_0 I_0 A_0$	1	70
		7	$A_1 B_0 G_1 M_3 X_0 I_0 A_0$	2	100
		8	$A_1 B_0 G_1 M_3 X_0 I_0 A_0$	1	50
		9	$A_1 B_0 G_3 M_3 X_0 I_0 A_0$	1	70
		11	$A_1 B_0 G_1 M_3 X_0 I_0 A_0$	1	60
		12	$A_1 B_0 G_1 M_3 X_0 I_0 A_0$	1	60
		13	$A_1 B_0 G_3 M_1 X_0 I_3 A_0$	1	80
		14	$A_1 B_0 G_3 M_3 X_0 I_0 A_0$	1	70
		15	$A_1 B_0 G_1 M_1 X_0 I_3 A_0$	1	60
		16	$A_1 B_0 G_3 M_3 X_0 I_0 A_0$	1	70
		17	$A_1 B_0 G_1 M_0 X_6 I_0 A_0$	1	80
			$A_0 B_0 G_0 A_0 B_0 P_0 F_0 A_0 B_0 P_0 A_0$		
	Time in Seconds: 36.4		TMU:		1010

Figure 3-3. MOST Analysis of Smoke Hood Donning

There are very few documented times pertaining to donning a smoke-hood (fire escape hood) in the literature. McFadden and Smith [7] reported “the average smoke hood donning time as 17.41 seconds.” Though the time is quantified, no supporting information is provided to ascertain the statistical rigor associated with establishing this time. The time obtained in the present study of 39.1 seconds, is twice that reported by McFadden and Smith [7]. The learning effect was most noticeable between trials (1) and

(2). This was expected since the subjects were unable to practice (handle) the device before the first trial. Trials (2) through (5) of Element (c) were remarkably consistent with the mean being 24.39, and the STDEV (standard deviation) is 0.56. This suggests that viewing a demonstration video three times and donning the hood one time for practice has the potential to provide a meaningful impact on subsequent donning times.

The following conclusions can be reached from the study:

1) Classical time study can be used to empirically establish statistically sound donning times for personal protective equipment such as smoke escape hoods.
2) For this particular hood, a pronounced learning effect occurred between the first and second smoke hood donning trials, emphasizing the need for effective safety briefings/practice.
3) If reported donning times for smoke hoods are to be of sufficient value for inclusion in evacuation models and consensus standards such as ANSI/ISEA, it is incumbent on researchers to perform donning/doffing time studies in accordance with accepted practice and report sufficient details in the literature.

Chapter 4. Determining Empirical Donning and Doffing Times for Complex Combinations of Personal Protective Equipment (PPE)

In many occupations, workers must wear various types of PPE to protect multiple body parts or to protect one body part from multiple hazards. Wearing multiple layers of work gloves may provide simultaneous protection from cold temperatures, wet conditions, sharp cutting tools, blood or body fluid exposure, or other hazards. A literature review did not uncover any reports of studies conducted to determine times for donning and doffing multiple layers of work gloves. Each layer of glove that is worn has an associated time for donning and doffing, but the previous pair(s) of gloves that are donned and the pair(s) of gloves underneath the pair being doffed may affect the don and doff times. Statistically based techniques such as *Time Study* can be used to empirically develop standards for donning and doffing times, including those for multiple layers of work gloves. These techniques are well established within *Industrial Engineering* and two closely related sub-fields *Methods Engineering* and *Work Measurement*. This study describes the methodology and results of several experiments conducted to develop the methods and times for donning and doffing multiple layers of work gloves in four different combinations.

Section 4.1 Time Study Experiments

Engineering students were trained on how to develop methods and conduct time studies including how to perform pace rating. The students were randomly placed into teams of 4-5 students and randomly assigned one of four glove layering methods, listed here in order from innermost to outermost layer: 1) Thermal (Cotton) + Rubber +

Protective (Steel Mesh) (TRP); 2) Thermal +Rubber + Protective + Rubber (TRPR); 3) Thermal + Thermal + Rubber (TTR); and 4) Thermal + Rubber + Rubber (TRR). These combinations were chosen because they represent glove layering methods observed in industry by the researchers. One of the combinations (TRP) has been specifically referred to in documents related to litigation regarding the compensability of donning and doffing required PPE.[10] Each team was instructed to identify a donner/doffer, a timer, and the rest of the team members were assigned to be pace raters; therefore, each team had two-three pace ratings for each trial. These individually observed pace ratings were averaged to apply to the timed trial.

Information often missing in the literature when instructions are given and/or standard times are reported is the description of the method used to perform the operation that is studied. When detailed methods are missing, it is not possible to determine if the standard times are accurate or to compare standard times from different researchers. For example, in the Centers for Disease Control (CDC) directions for nurses to don gloves when working with confirmed Ebola cases, the instructions read: "Put on first pair of gloves."[11] How to "put on" the gloves is not detailed. The importance of a detailed doffing process for PPE is addressed in a 2014 article in the Annals of Internal Medicine: "Despite its lethal nature, Ebola transmission can be interrupted with simple interventions and by focusing on basics. Improvement in basic health care infrastructure and providing an adequate supply of PPE along with a ritualized process for donning and doffing PPE

[10] Federal Litigation Update: Compensability of Pre-Shift and Post-Shift Duties, ABA 2009 Labor and Employment Law CLE Conference.
[11] Guidance on Personal Protective Equipment (PPE) To Be Used By Healthcare Workers during Management of Patients with Confirmed Ebola or Persons under Investigation (PUIs) for Ebola who are Clinically Unstable or Have Bleeding, Vomiting, or Diarrhea in U.S. Hospitals, Including Procedures for Donning and Doffing PPE, CDC guidance, August 27, 2015, http://www.cdc.gov/vhf/ebola/healthcare-us/ppe/guidance.html.

are desperately needed to prevent further unnecessary infection and loss of life among the heroic health care workers who are on the frontlines of this war. Protection of health care workers in Ebola outbreaks does not happen by accident—it is achieved through the provision of adequate PPE and, more important, a focus on systems processes that enforce the safe use and removal of PPE."[12]

In this study, students were given detailed training in how to write work methods and were assigned several different donning/doffing time study experiments prior to this one. Methods Engineering teaches that when work methods are written, actions of the body parts (usually the right and left hands) are detailed. The students conducting these experiments were also instructed to "Minimize wasted motion. Minimize mistakes. Minimize awkward hand positions. Make sure that you clearly describe the start and stop positions for donning and doffing, defining the position of the person, the person's body, and the gloves. The donner/doffer should be able to perform the method repetitiously and identically at '100%' before the time study begins."[13] The number of practice trials conducted by each team was not prescribed and varied by team.

A representative sample of the work methods produced by this study before the time studies were conducted is quite different from the CDC instruction referenced above. The example contained here is for donning and doffing the TRP layers of gloves.

[12] Fischer WA, Hynes NA, Perl TM.: Protecting Health Care Workers From Ebola: Personal Protective Equipment Is Critical but Is Not Enough. Ann Intern Med. 2014;161:753-754. doi:10.7326/M14-1953
[13] Sims, LuAnn, "Lab Instructions for INSY 3021, Layers of Work Gloves", Department of Industrial and Systems Engineering, Auburn University, Spring 2013.

Section 4.2 Donning Thermal+Rubber+Protective (TRP) Layered Gloves

1. Begin: With all gloves lying flat on table. Left glove facing your left and right glove facing your right. Thumbs towards each other. Thermal gloves closest to you: followed by rubber gloves then protective gloves (Figure 4-1).
2. With right hand grasp bottom cuff of left hand glove and lift upwards (Figure 4-2).
3. 3A. Insert left hand into glove; slide hand towards fingertips while simultaneously pulling glove towards your wrist with your right hand. Continue sliding hand inside glove until fingertips of left hand reach the end of the fingertips of left glove (Figure 4-3).

   3B. Right hand must non-simo regrasp and pull glove one time. Release cuff with right hand.
4. With left hand grasp bottom cuff of right hand glove and lift upwards
5. 5A. Insert right hand into glove; slide hands towards fingertips while simultaneously pulling glove towards your body with your left hand. Continue sliding hand inside glove until fingertips of right hand reach the ends of the fingertips of right glove.

   5B. Left hand must non-simo [sic, non-simultaneous] regrasp and pull glove two times. Release cuff with left hand. Thermal gloves are now donned (Figure 4-4).
6. Grasp bottom left rubber glove cuff with right hand and top left rubber glove cuff with left hand. Open up the cuff by pulling apart (Figure 4-5).

7. Release glove cuff with left hand and insert left hand into glove. While sliding left hand in glove pull glove towards your body with right hand. Continue until finger tips reach the end of the glove (Figure 4-6).
8. Grasp bottom right rubber glove cuff with left hand and top right rubber glove cuff with right hand. Open up the cuff by pulling apart.
9. Release glove cuff with right hand and insert right hand into glove. While sliding right hand in glove pull glove towards your wrist with left hand. Continue until finger tips reach the end of the glove. Rubber gloves are donned.
10. With right hand grasp bottom cuff of left hand protective glove and lift upwards.
11. Insert left hand into left glove. While sliding left hand inside glove, pull glove towards your wrist with right hand. Continue until finger tips of left hand reach the end of the left glove fingertips. Release cuff with right hand.
12. 12A.Hold left hand horizontally in front of body with palm facing downwards.

    12B.Grasp button clasp tab with right hand and pull over to top of hand (Figure 4-7). Push down on button tab until clasp snaps and is secure (Figure 4-8). Release clasp with right hand.
13. With left hand grasp bottom cuff of right hand protective glove and lift upwards.
14. Insert right hand into right glove. While sliding right hand into protective glove pull glove towards your body with left hand. Continue until fingertips of right hand reach the ends of the fingertips of right glove. Release cuff with left hand.
15. 15A.Hold right hand palm down horizontally in front of body.

    15B.Grasp button clasp tab with left hand and pull over to top of hand. Push down on button tab until clasp snaps and is secure. Release clasp with left hand. End: All gloves are now donned.

Section 4.3 Doffing Protective-Rubber-Thermal Layered Gloves

1. Begin: All layers of gloves donned.
2. With right hand grasp left hand protective glove buckle with thumb and index finger and pull upwards to unbuckle and release strap with right hand.
3. Grab finger tips of left hand glove with right hand and pull away from body until glove completely slides off hand (Figure 4-9).
4. Lie glove flat on table.
5. With left hand grasp right hand protective buckle with thumb and index finger and pull upwards to unbuckle and release strap with left hand.
6. Grab finger tips of right hand glove with left hand and pull away from body until glove completely slides off hand.
7. Lie glove flat on table: Protective gloves are now doffed.
8. Grab finger tips of left hand rubber glove with right hand and pull away from body until glove completely slides off hand.
9. Lie glove flat on table.
10. Grab finger tips of right hand rubber glove with left hand and pull away from body until glove completely slides off hand.
11. Lie glove flat on table: Rubber gloves are now doffed.
12. Grab finger tips of left hand thermal glove with right hand and pull away from body until glove completely slides off hand.
13. Lie glove flat on table.
14. Grab finger tips of right hand thermal glove with left hand and pull away from body until glove completely slides off hand.

15. Lie glove flat on table (Thermal gloves are now doffed). End: All gloves are now doffed and lying on table (Figures 4-1 through 4-10).

Fig. 4-1. Start position.

Fig. 4-2. Begin don of left thermal glove.

Fig. 4-3. Complete don of left thermal glove.

Fig. 4-4. Complete don of thermal gloves.

Fig. 4-5. Begin don of left rubber glove.

Fig. 4-6. Don left rubber glove.

Fig. 4-7. Begin fasten of left protective glove.

Fig. 4-8. Fasten left protective glove.

Fig. 4-9. Begin doff of left protective glove.

Fig. 4-10. Stop position.

Section 4.4 Results

The experiments were conducted over a two semester period with approximately 120 engineering students per semester conducting the time studies. All of the students were different from one semester to the next. The layering method experiments were repeated with different teams from 5-8 times each. The number of trials for each experiment was supposed to be 30 as directed by the lab assignment. The number of trials for each experiment actually varied from 15-50 but averaged 28. Some teams reported that they did not have enough time to conduct 30 trials. The data were collected and aggregated for both years. A check for normality was conducted, and then the mean, standard deviation, and statistical outliers were identified. The resulting data representing the recommended standard time (based on the means) for donning and doffing layers of glove combinations is shown in Table 4-1. The ratio of doff time to don time for different combinations of glove layering is also shown in Table 4-1.

One experiment was also done for the TRP layering method to compare donning and doffing times of multiple layers of gloves to the times for donning and doffing single layers. If all three gloves are donned and doffed separately, the total don and doff times are 26.8 and 12.2 seconds respectively. For this experiment, donning multiple layers of gloves increases the time by 57% and doffing increases the time by 42%.

Seven experiments were conducted where the times were recorded for donning each layer in addition to the total times for the don. These experiments show that the don time of the second layer was similar for different gloves: an average of 10.82 secs. for a second thermal glove (TTR) and an average of 10.57 secs. for a second rubber glove (TRP, TRPR, and TRR). However, donning the third layer had much more variability, with average times of 8.70, 12.80, and 23.68 for TTR, TRR, and TRP/TRPR respectively. Additional data from this study directly compared the time to don a thermal glove as the first layer vs. donning a second thermal glove over the first thermal glove. These times were 6.19 secs. vs. 10.82 secs., an increased time of 75% for the same type glove.

Layering Method	Don	Doff	Ratio Doff/Don (%)
TRP	42.2	16.2	38.3
TRPR	66.2	23.6	35.6
TRR	35.7	18.7	52.3
TTR	34.9	24.1	68.9

Table 4-1. Time Study Results in Seconds for Glove Layering

Section 4.5 Sample Validation using a Predetermined Time System (MOST)

MOST (Maynard Operation Sequence Technique) [23] was developed by Kjell B. Zandin in 1980. One of the researchers is an experienced MOST analyst who conducted a MOST study of one of the glove layering methods, TRP, for both donning and doffing as a validation of the time studies. MOST uses the concept of sequence models for manual work. Two sequence models were used in this study, General Move and Controlled Move. A General Move occurs when an object moves freely through space. In this study, this only happens at the beginning of the don, when the first glove is picked up. The rest of the moves were Controlled Moves, where the object that moves is

constrained in some way during the move. In this case, the hand is constrained by the glove (and vice versa). The MOST analyses (shown in Figures 4-11 and 4-12) were done using a standardized form where the steps are shown on the left hand side (the same steps as shown above for the methods preceding the time study) and the sequence models on the right hand side. Index values were chosen from a table depending on the move characteristics. A higher index value results in more time being given for a motion. When the index values are summed and multiplied by 10, the subsequent time is in TMU (1/100,000) of an hour or 0.036 seconds. MOST is based on 100% pace, eliminating the need to pace rate an operator. The MOST analyses for this study result in a recommended donning standard for TRP of 42.5 seconds (compared to 42.2 average for all time studies) and a doffing standard for TRP of 17.3 (compared to 16.2 average for all time studies).

MOST Calculation				Date: 3/1/2016	
				Engineer: LuAnn Sims	
Operation:				Study No.: Don TRP Glove	
No.	**Method Description**	**No.**	**Sequence Model**	**Fr.**	**TMU**
1	With all gloves lying flat on table. Left glove facing your left and right glove facing your right. Thumbs towards each other. Thermal gloves closest to you: followed by rubber gloves then protective gloves (Figure 1).	9	$A_1 B_0 G_1 A_0 B_0 P_0 A_0$	1	20
2	With right hand grasp bottom cuff of left hand glove and lift upwards (Figure 2).	4	$A_1 B_0 G_1 A_0 B_0 P_0 A_0$	1	20
3	3A. Insert left hand into glove; slide hand towards fingertips while simultaneously pulling glove towards your wrist with your right hand. Continue sliding hand inside glove until fingertips of left hand reach the end of the fingertips of left glove (Figure 3). 3B. Right hand must non-simo regrasp and pull glove one time. Release cuff with right hand.				
4	With left hand grasp bottom cuff of right hand glove and lift upwards	3A	$A_1 B_0 G_0 M_3 X_0 I_6 A_0$	1	100
5	5A. Insert right hand into glove; slide hands towards fingertips while simultaneously pulling glove towards your wrist with your left hand. Continue sliding hand inside glove until fingertips of right hand reach the ends of the fingertips of right glove. 5B. Left hand must non-simo regrasp and pull glove two times. Release cuff with left hand. Thermal gloves are now donned (Figure 4).	3B	$A_1 B_0 G_1 M_3 X_0 I_0 A_1$	1	60
6	Grasp bottom left rubber glove cuff with right hand and top left rubber glove cuff simo with left hand. Open up the cuff by pulling apart (Figure 5).	5A	$A_1 B_0 G_0 M_3 X_0 I_6 A_0$	1	100
7	Release glove cuff with left hand and insert left hand into glove. While sliding left hand in glove pull glove towards your wrist with right hand. Continue until finger tips reach the end of the glove (Figure 6).	5B	$A_1 B_0 G_1 M_3 X_0 I_0 A_1$	2	120
8	Grasp bottom right rubber glove cuff with left hand and top right rubber glove cuff with right hand. Open up the cuff by pulling apart.	6	$A_1 B_0 G_1 M_1 X_0 I_0 A_0$	1	30
9	Release glove cuff with right hand and insert right hand into glove. While sliding right hand in glove pull glove towards your wrist with left hand. Continue until finger tips reach the end of the glove. Rubber gloves are now donned.	7	$A_1 B_0 G_0 M_3 X_0 I_6 A_0$	1	100
10	With right hand grasp bottom cuff of left hand protective glove and lift upwards.	8	$A_1 B_0 G_1 M_1 X_0 I_0 A_0$	1	30
11	Insert left hand into left glove. While sliding left hand inside glove, pull glove towards your wrist with right hand. Continue until finger tips of left hand reach the end of the left glove finger tips. Release cuff with right hand.	9	$A_1 B_0 G_0 M_3 X_0 I_6 A_0$	1	100
12	12A. Hold left hand horizontally in front of body with palm facing downwards. 12B. Grasp button clasp tab with right hand and pull over to top of hand (Figure 7). Push down on button tab until clasp snaps and is secure (Figure 8). Release clasp with right hand.	10	$A_1 B_0 G_1 M_1 X_0 I_0 A_0$	1	30
13	With left hand grasp bottom cuff of right hand protective glove and lift upwards.	11	$A_1 B_0 G_0 M_3 X_0 I_6 A_0$	1	100
14	Insert right hand into right glove. While sliding right hand into protective glove pull glove towards your wrist with left hand. Continue until fingertips of right hand reach the ends of the fingertips of right glove. Release cuff with left hand.	12A	$A_1 B_0 G_0 M_0 X_0 I_0 A_0$	1	10
15	15A. Hold right hand palm down horizontally in front of body. 15B. Grasp button clasp tab with left hand and pull over to top of hand. Push down on button tab until clasp snaps and is secure. Release clasp with left hand.	12B	$A_1 B_0 G_1 M_3 X_0 I_6 A_0$	1	110
	End: All gloves are now donned.	13	$A_1 B_0 G_1 M_1 X_0 I_0 A_0$	1	30
		14	$A_1 B_0 G_0 M_3 X_0 I_6 A_0$	1	100
		15A	$A_1 B_0 G_0 M_0 X_0 I_0 A_0$	1	10
		15B	$A_1 B_0 G_1 M_3 X_0 I_6 A_0$	1	110
	Time in Seconds:	42.48		TMU	1180

Figure 4-11. MOST Analysis Don TRP

MOST Calculation				Date: 3/1/2016	
				Engineer: LuAnn Sims	
Operation:				Study No.: Doff Protective Glove-Rubber-Th	
No.	Method Description	No.	Sequence Model	Fr.	TMU
1	Begin: All layers of gloves donned.	4	$A_0 B_0 G_0 A_1 B_0 P_3 A_0$	1	40
2	With right hand grasp left hand protective glove buckle with thumb and index finger and pull upwards to unbuckle and release strap with right hand.	7	$A_0 B_0 G_0 A_1 B_0 P_3 A_0$	1	40
3	Grab finger tips of left hand glove with right hand and pull away from wrist until glove completely slides off hand (Figure 9).	9	$A_0 B_0 G_0 A_1 B_0 P_3 A_0$	1	40
4	Lie glove flat on table.	11	$A_0 B_0 G_0 A_1 B_0 P_3 A_0$	1	40
5	With left hand grasp right hand protective buckle with thumb and index finger and pull upwards to unbuckle and release strap with left hand.	13	$A_0 B_0 G_0 A_1 B_0 P_3 A_0$	1	40
6	Grab finger tips of right hand glove with left hand and pull away from wrist until glove completely slides off hand.	15	$A_0 B_0 G_0 A_1 B_0 P_3 A_0$	1	40
7	Lie glove flat on table: Protective gloves are now doffed.				
8	Grab finger tips of left hand rubber glove with right hand and pull away from wrist until glove completely slides off hand.	2	$A_1 B_0 G_1 M_1 X_0 I_0 A_0$	1	30
9	Lie glove flat on table.	3	$A_1 B_0 G_1 M_1 X_0 I_0 A_0$	1	30
10	Grab finger tips of right hand rubber glove with left hand and pull away from wrist until glove completely slides off hand.	5	$A_1 B_0 G_1 M_1 X_0 I_0 A_0$	1	30
11	Lie glove flat on table: Rubber gloves are now doffed.	6	$A_1 B_0 G_1 M_1 X_0 I_0 A_0$	1	30
12	Grab finger tips of left hand thermal glove with right hand and pull away from wrist until glove completely slides off hand.	8	$A_1 B_0 G_1 M_1 X_0 I_0 A_0$	1	30
13	Lie glove flat on table.	10	$A_1 B_0 G_1 M_1 X_0 I_0 A_0$	1	30
14	Grab finger tips of right hand thermal glove with left hand and pull away from wrist until glove completely slides off hand.	12	$A_1 B_0 G_1 M_1 X_0 I_0 A_0$	1	30
15	Lie glove flat on table (Thermal gloves are now doffed).	14	$A_1 B_0 G_1 M_1 X_0 I_0 A_0$	1	30
	End: All gloves are now doffed and lying on table.				
	Time in Seconds:	17.28		TMU:	480

Figure 4-12. MOST Analysis Doff TRP

This study shows that Time Study can be used to develop don and doff times for layers of work gloves. Several different sizes of each type of glove were made available to the teams. The teams were instructed to self-select a donner/doffer that had a “reasonable” fit to the first thermal layer in each layering sequence. Subsequent layers had to fit over previous layers without undue effort as well. As an aside, fit of gloves is a factor in the time it takes to don and doff, and some research was done in this set of experiments to define “fit” of gloves to hands. Further research may be done in this area, but for the purposes of this experiment, teams self-selected for proper glove fit without specific definition.

The instructions given to the teams specified that all layers were to be donned on each hand. However, it is common in industry for the layers on one hand to be different than on the other hand depending on whether the worker is right or left handed and what type of tool (such as a knife) will be used with each hand. Therefore, the don and doff

times we found can be viewed as a worst-case scenario. We also know that gloves can become wet when worn for certain jobs. Only dry gloves and hands were used in these experiments; adjustments to don/doff times might have to be made for wet conditions. It is also very important to note that these experiments did not take into account doffing gloves in cases where the worker must be protected against contamination such as in the case of health care workers exposed to Ebola. Future work may include developing detailed methods and times for donning and doffing gloves and other PPE under different conditions.

The following conclusions can be reached from the study:

1) Classical time study can be used to empirically establish statistically sound donning and doffing times for personal protective equipment such as work gloves. MOST can be used effectively as validation for the time study experiments when the detailed methods performed in the time study are known.
2) There is evidence from this study that in general, doffing time is less than donning time for work gloves. Further research may result in the ability to provide useful models for the relationship between donning and doffing times so that researchers or practitioners may estimate the time for one if they know the other without performing separate time studies.
3) Donning and doffing layers of work gloves increases the time more than simply adding up times for donning and doffing one glove at a time by a significant amount, up to 75% for donning and 42% for doffing. Additional research may be done to model interaction effects of multiple PPE combinations.

Chapter 5. An Interactive Model of PPE Donning and Doffing Times

Various aspects of employment law in United States have historically been, and continue to be, subject to litigation in the court system, including cases eventually being argued before the Supreme Court. One such issue that has seen numerous occurrences of litigation in the past decade relates to the Fair Labor Standards Act (FLSA) of 1938. Essentially, the FLSA contains the workplace rules that most employees and employers are fairly familiar with, addressing such issues as the establishment of the forty (40) hour workweek, paid overtime at a rate of 1.5 X hourly pay (when applicable), the establishment of a National minimum wage, and work permits for children, etc. A related piece of legislation known as the Portal-To-Portal Act (PTPA) of 1947 states that certain employment activities (performed by the employee) may be non-compensable under the FLSA. Relevant to the present research the PTPA states that; 1) Time spent on 'incidental activities' before and/or after the employees' principle activities, and 2) Time spent 'Traveling To/From' the actual place of work where the employees' principle activities are performed; may individually or both be non-compensable, depending on the specifics of each unique circumstance.

As eluded to earlier, a large number of lawsuits have arisen over the past decade relating to the PTPA non-compensable activities, and in larger scope the FLSA in general. Employees in numerous industries such as poultry processing, meat-slaughtering and packing, police and corrections officers, neo-natal nurses, commercial bakeries, industrial welders, and clean-room employees, among others have retained plaintiff attorneys to represent themselves (and others) primarily in class action matters. In a

general sense, employees feel that the time spent to procure (including waiting), open packaging, remove item(s), dispose of packaging material, don (put on) and adjust the specific item(s), wash and sanitize (if necessary or required), and eventually remove and dispose of the item(s), should all be compensable time as they believe these activities are part of the 'job' and primarily benefit the employer. These employees also assert that this total amount of don/doff & wash/sanitize time in aggregate [pre-shift, (break, post-break), lunch, post-lunch, (break, post-break), post-shift] is substantive enough to merit compensation, more often than not at the overtime rate. Some employers tend to view these tasks in isolation, each taking a very small amount of time, and *De Minimis* in aggregate. With each party believing their perceptions are correct, the court system has seen numerous filings in such matters.

Section 5.1 Recent Decisions

The most recent major decision relating to donning/doffing matters was delivered by Justice Kennedy for the US Supreme Court in TYSON FOODS, INC., PETITIONER, v. PEG BOUAPHAKEO, ET AL., INDIVIDUALLY AND ON BEHALF OF ALL OTHERS SIMILARLY SITUATED, Supreme Court of the United States [13] argued on November 10, 2015 and decided March 22, 2016. A thorough reading of the decision is needed to understand particular issues associated with the matter. As it specifically relates to this study, Plaintiff's Expert, Dr. Ken Mericle, conducted a study by videoing 744 observations to analyze how long various donning and doffing activities took. He subsequently averaged the time taken in the observations to produce an estimate of 18 minutes/day for the cut and re-trim departments, and 21.3 minutes/day for the kill department. Tyson desired to reverse the judgment arguing "the class should not have been certified because the primary method of proving injury assumed each employee

spent the same time donning and doffing protective gear, even though differences in the composition of that gear may have meant that, in fact, employees took different amounts of time to don and doff." The opinion further states, "Just as individual managers inherently make discretionary decisions differently, so too do individual employees inherently spend different amounts of time donning and doffing." This defense assertion is not unique to this matter, and is often used to counter scientific studies.

As such, it is prudent to develop and disseminate a tool (model) that can objectively calculate in an unbiased manner how much time should be allocated to donning and doffing common combinations of PPE and sanitation typically found in many of the litigated cases. Using this information, employers can build this amount of time into an allowance for their employees, or choose to compensate them at an overtime rate of pay for all time exceeding forty (40) hours per week. Such a model should be statistically sound and robust enough to withstand external scrutiny.

Section 5.2 Methodology

A study was designed to collect the required data for model enhancement and validation, and conducted at a poultry processing facility located in the United States. The fundamental approach in determining the time for employees to don/doff both personal protective equipment (PPE) and sanitization items was to acquire some representative items of PPE and have employees (subjects) demonstrate how it is donned and doffed, while conducting a time study of the process. This group was chosen for a number of reasons: 1) For the most part, these subjects are highly experienced in the donning and doffing procedure as they perform it numerous times per workday. Use of a naïve sample could require some amount of learning (practice) until they demonstrated consistent results; 2) the subjects were readily available and willing to participate and no

subject refused to participate or was in any way observed to be uncooperative during the observations; and 3) representative of the plaintiffs in similar actions. None of the employees (subjects) that participated were members of any litigation matter at the time of the study.

Employees (subjects) were recruited to participate in the study. Subjects would leave their normal assignment, wash-up, and report to a facility conference room, as requested. Subjects provided some basic demographic information such as name, job title, and the amount of time employed at the facility. They were asked to remove any PPE or sanitation items they wore to the room, and lay them out in an orderly fashion on a table directly in front of them. Subjects were provided (out of company stock) with any sanitation items or PPE that they normally wore, but did not bring with them. Though items such as smocks, aprons, and gloves were reused by other participants, personal items such as earplugs, beard-nets & hair-nets, were disposed of after each use for sanitary purposes.

Prior to actually performing any timing of the donning or doffing, the researcher would explain in detail what was about to happen, demonstrate the sequence (usually with earplugs and/or gloves) and start/stop the watch a number of times in order to familiarize the subjects with the sequence and the sound (chirping) that the stopwatch produces. A number of the participants were of Hispanic background and spoke little or none of the English language. In these cases, a translator was provided to the researcher by the facility to ensure these participants were able to communicate with the researcher.

Subjects were asked to don (to put on or dress in) [25] the PPE and sanitation items in their usual order (personal preference) and asked to indicate that they were complete with any individual piece (or pieces such as pairs of gloves) by verbally stating

that they were ‘done’ or indicating such to the researcher with a ‘thumbs-up’ or other mutually agreed upon signal. Subjects were carefully instructed that though they were being timed, this was not a race, and that they should proceed at their usual (typical) pace. If an error occurred (various reasons) the trial was stopped, the reason explained (acknowledgement obtained), and the trial repeated.

The specific procedure used in the donning trials required that the item be picked up from a standard surface (a table located directly in front of the employee) and returned to the same location at the completion of doffing (to remove or take off, to throw off, to get rid of) [25] the item. By establishing this control, the time to grasp and move the PPE or sanitation item to the location of use is standardized for each participant. Therefore, return times, from the time when the subject indicated completion of the item to the time that they were physically picking up the next item (return arm movement), must be accounted for and added into the model. Likewise, for doffing, this time is the time spent from when the item is laid down on the table, until the participant touches the next item to be removed. This time was added as a function of the number of specific reaches used during any specific donning or doffing combination.

All reaches for these trials were classified “within reach”, which is defined as “Actions are confined to an area within the arc of the outstretched arm pivoted about the shoulder. With body assistance--a short bending or turning of the body from the waist—this ‘within reach’ area is extended somewhat.” [23] The use of the A_1 time from the BasicMOST® predetermined time system is an appropriate value to be inserted for this return time. Since the actual time using this approximation is 0.59999999 centi-minutes (cmin), the use of two (2) cmin per return is conservative.

Individual items (or pairs when applicable) were donned, timed, and recorded, prior to proceeding to the next item(s). If the researcher felt a comment was required, it was entered directly on the form. Comments might arise from any number of possibilities, but most were entered to explain why a certain time would appear to be excessively short or long, due to some external issue associated with the procedure. The snapback method of time study was used [18]. In the snapback method, the researcher resets the clock to zero at each break point of the operation. A break point is an easily identifiable point in time that the researcher chooses as the end of an element (and usually the beginning of the next element).

After sequentially donning (and timing) each individual PPE and sanitation item, the subject was instructed that they would be following the reverse sequence during the doffing phase, and acknowledgement was obtained. Next, the researcher asked the subject to don and doff the same equipment (in exactly the same order) without stopping while being recorded by a digital recorder. Again, the participant was specifically instructed that they should proceed at their 'typical' pace. This recording was primarily for the benefit of the researcher, should it be necessary later to clarify any visible item of use (such as smocks v. apron, one glove v. two, etc.). It also provided the researcher with an uninterrupted video recording against which to compare (validate) the results of the model. At the conclusion of the doffing portion of the taped trial, the subject was instructed that they could begin to don their PPE and sanitation items (required to proceed back to work) while the researcher asked them to verbally answer a few additional questions. Upon completion they were asked if they had any questions, and thanked for their participation, prior to being released back to their normal work area. The researcher would ensure that all paperwork for the previous participant was in order,

and take a moment or so to rearrange the table (stock PPE), dispose of any used PPE or other items, and prepare for the next subject. This process was repeated for the remaining subjects.

Section 5.3 Data Entry and Analysis

Data from the individual collection sheets were entered into a Microsoft Excel spreadsheet and subsequently verified for accuracy. For any observed PPE or sanitation item, specific entries were made for participant ID (assigned by the researcher), date, number of this specific item used for don (one or two gloves, etc.), don time, mean don time (don time/number of items), number of this specific item used for doff, doff time, and mean doff time (doff time/number of items). Suspected outliers were annotated for identification. Notes were entered directly into the spreadsheet if found on the data collection form.

Section 5.4 Tests for Outliers

After entering data into a spreadsheet, a statistical test was performed to determine if there were any potential outliers. Commonly accepted tests for this purpose are found in a number of statistical texts [26, 27, and 28]. The 1.5*IQR test was chosen for this study. To perform the test, the column of data times was copied into an additional column, rank ordered, and analyzed to determine the first (Q1) and third (Q3) quartiles of the data set. The interquartile range (IQR) is calculated and multiplied by 150%. This resulting product is then subtracted from Q1 and added to Q3 to obtain the range of inclusive data. Data that exceeds these values (high or low) are classified as suspected outliers and treated accordingly in subsequent data analysis. Of the 936 times measured during the study, 22 data points, or 2.4% were deemed as outliers. Twenty (20) of the twenty-two (22) data points have researcher comments explaining the excessive times.

Section 5.5 Results

A Microsoft Excel spreadsheet model was refined for this study. The model developed in previous studies utilizes a database containing over 2000 individual donning/doffing times associated with pieces of PPE/sanitation equipment items routinely used in poultry processing applications. Figure 5-1 summarizes the standard data obtained from the study. The "Raw" column in Figure 5-1 represents the average time obtained from the time study, while the "Filtered" column represents the average time after outliers were removed as explained in Section 5.4. Figures 5-2 through 5-14 illustrate the various types of PPE studied. Figures 5-15 through 5-28 show the output of Excel's statistical tests for the data from each type of PPE studied. This output is obtained when the "Analysis ToolPak" add-in is used in Excel with "Descriptive Statistics."

		Raw		Filtered	
Item	**n**	**Don**	**Doff**	**Don**	**Doff**
Apron-Blue	145	25.5	13.6	24.2	12.1
Apron-Disposable	55	54.4	7.9	52.9	7.4
Arm Guard	81	5.8	4.0	4.9	3.9
Boots-High	33	12.4	7.8	11.6	6.9
Boots-Mid	76	28.8	18.1	25.8	15.8
Boots-Yellow Low	61	24.1	12.2	20.8	11.0
Bump Cap	35	6.4	4.2	6.1	4.1
Ear Muffs	28	5.1	3.6	4.4	3.2
Ear Plugs-Foam	64	17.3	7.6	16.6	5.9
Ear Plugs-Non Foam	123	14.9	7.5	13.7	6.1
Eyeglasses-Safety	34	8.9	4.9	8.3	4.7
Glove-Blue	80	13.3	5.6	12.7	4.9
Glove-Cloth	177	10.2	5.3	8.9	4.9
Glove-Kevlar	56	9.2	5.9	8.5	5.8
Glove-Metal Mesh	16	21.3	6.5	21.3	6.5
Glove-Rubber	194	11.1	5.7	10.0	5.3
Mask-Dust	4	13.5	5.3	8.4	5.3
Net-Beard	101	12.8	5.6	12.8	4.9
Net-Hair	202	15.1	6.0	14.6	5.6
Rain Suit-Jacket	30	43.4	16.2	42.1	15.2
Rain Suit-Pants	30	56.2	36.7	56.2	29.4
Sleeves	74	17.8	5.5	15.0	4.8
Sleeves-Disposable	70	13.0	4.4	12.3	4.1
Smock-Cloth	160	35.8	14.6	34.2	13.8
Smock-Cloth Button	81	38.4	12.6	37.5	12.3
Smock-Paper	11	44.7	16.5	44.7	16.6
Smock-Paper Tie	6	36.1	17.2	36.1	17.2

Figure 5-1. Summary of Standard Data in Centiminutes

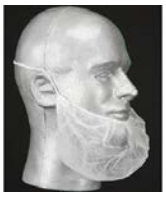

Figure 5-2. Beard-Net

Figure 5-3. Hair-Net

Figure 5-4. Bump Cap

Figure 5-5. Rubber Gloves

Figure 5-6. Cloth Gloves

Figure 5-7. Plastic Sleeves

Figure 5-8. Safety Glasses

Figure 5-9. Metal Mesh Gloves

Figure 5-10. Cloth Smock

Figure 5-11. Apron (tie-up)

Figure 5-12. Ear Plugs

Figure 5-13. Rain Suit

Figure 5-14. “Whizard” Glove (anti-cut)

	Apron-Blue				Apron-Disposable			
	Raw		Filtered		Raw		Filtered	
	Don	Doff	Don	Doff	Don	Doff	Don	Doff
Mean	25.45793	13.58276	24.21898	12.11278	54.36182	7.903636	52.92075	7.382692
Standard Error	0.621699	0.541844	0.474528	0.274085	1.589815	0.433652	1.253987	0.334873
Median	23.8	11.9	23.5	11.8	51.3	7.3	51.3	7.15
Mode	30.2	11	30.2	11	44.6	6.7	44.6	6.7
Standard Deviation	7.486244	6.524668	5.554205	3.160898	11.79038	3.216046	9.129166	2.414801
Sample Variance	56.04384	42.5713	30.8492	9.991275	139.0131	10.34295	83.34168	5.831263
Kurtosis	1.822256	15.19837	-0.2308	0.135505	3.610404	1.61407	-0.46839	-0.98548
Skewness	1.308624	3.318191	0.581769	0.649416	1.556556	1.098496	0.617753	0.145951
Range	36.2	47.7	24.5	15	62.4	14.6	33.7	8.8
Minimum	14.8	6.2	14.8	6.2	38.7	3.2	38.7	3.2
Maximum	51	53.9	39.3	21.2	101.1	17.8	72.4	12
Sum	3691.4	1969.5	3318	1611	2989.9	434.7	2804.8	383.9
Count	145	145	137	133	55	55	53	52
Confidence Level (95.0%)	1.228834	1.070996	0.938408	0.542166	3.187387	0.869419	2.51631	0.672285

Figure 5-15. Apron-Blue and Apron-Disposable Statistical Analysis

	Arm Guard				Boots-High			
	Raw		Filtered		Raw		Filtered	
	Don	Doff	Don	Doff	Don	Doff	Don	Doff
Mean	5.790123	4.039506	4.923288	3.912821	12.4303	7.8	11.59688	6.866667
Standard Error	0.398355	0.118474	0.184508	0.097391	1.157596	0.657777	0.828895	0.432085
Median	4.9	3.9	4.8	3.8	10.9	6.7	10.9	6.55
Mode	3.2	3.8	3.2	3.8	9	6.5	9	3.9
Standard Deviation	3.585199	1.066264	1.576434	0.860136	6.649882	3.778641	4.688936	2.366626
Sample Variance	12.85365	1.13692	2.485145	0.739833	44.22093	14.27813	21.98612	5.60092
Kurtosis	20.50869	1.842547	0.802876	-0.26057	7.093086	2.089756	-0.28479	-0.20481
Skewness	3.821681	1.055287	0.869745	0.26372	2.186166	1.362967	0.693686	0.170273
Range	26.3	5.4	7.2	4	34.5	16.5	17	10.3
Minimum	2.2	2.2	2.2	2.2	4.6	2	4.6	2
Maximum	28.5	7.6	9.4	6.2	39.1	18.5	21.6	12.3
Sum	469	327.2	359.4	305.2	410.2	257.4	371.1	206
Count	81	81	73	78	33	33	32	30
Confidence Level (95.0%)	0.792753	0.23577	0.367809	0.193931	2.357946	1.339848	1.690542	0.883713

Figure 5-16. Arm Guard and Boots-High Statistical Analysis

	Boots-Mid				Boots-Yellow Low			
	Raw		Filtered		Raw		Filtered	
	Don	Doff	Don	Doff	Don	Doff	Don	Doff
Mean	28.83816	18.13289	25.81944	15.8274	24.11148	12.22459	20.79464	10.95263
Standard Error	2.175792	1.78267	1.667268	1.18204	1.861837	0.856782	1.284987	0.624209
Median	24	14.75	23.2	14	20.9	10.4	19.85	10.1
Mode	11.3	5.3	11.3	5.3	16	8.7	15.4	8.7
Standard Deviation	18.96811	15.54096	14.14724	10.09936	14.54141	6.691678	9.615961	4.712677
Sample Variance	359.7893	241.5214	200.1444	101.997	211.4527	44.77855	92.4667	22.20932
Kurtosis	2.259438	9.281239	0.30681	-0.17638	1.551691	2.076452	-0.12334	-0.76561
Skewness	1.489853	2.543607	0.920828	0.816569	1.367498	1.292292	0.656708	0.266902
Range	92.8	93.5	60	38.1	61.9	32	38.8	17.8
Minimum	4	3.1	4	3.1	4.8	2.4	4.8	2.4
Maximum	96.8	96.6	64	41.2	66.7	34.4	43.6	20.2
Sum	2191.7	1378.1	1859	1155.4	1470.8	745.7	1164.5	624.3
Count	76	76	72	73	61	61	56	57
Confidence Level (95.0%)	4.3344	3.551261	3.324438	2.356354	3.724229	1.713818	2.575171	1.250441

Figure 5-17. Boots-Mid and Boots-Yellow Low Statistical Analysis

	Bump Cap				Ear Muffs			
	Raw		Filtered		Raw		Filtered	
	Don	Doff	Don	Doff	Don	Doff	Don	Doff
Mean	6.351429	4.225714	6.091176	4.070588	5.060714	3.557143	4.448	3.224
Standard Error	0.449451	0.255473	0.377376	0.209044	0.424711	0.254766	0.284846	0.194789
Median	5.9	4.1	5.8	4.05	4.3	3.15	4.1	3
Mode	6.3	5.2	2.9	4.1	4.1	3	2.7	3
Standard Deviation	2.658988	1.511396	2.200464	1.218924	2.247359	1.348093	1.424231	0.973944
Sample Variance	7.070218	2.284319	4.842041	1.485775	5.050622	1.817354	2.028433	0.948567
Kurtosis	2.298918	3.054996	-0.38329	-0.43127	0.901178	0.332463	-0.07615	0.698732
Skewness	1.132672	1.295753	0.34798	0.349075	1.174807	0.935285	0.452638	0.663208
Range	12.8	7.3	8.8	4.6	8.6	5.2	6	3.9
Minimum	2.4	2.2	2.4	2.2	1.8	1.6	1.8	1.6
Maximum	15.2	9.5	11.2	6.8	10.4	6.8	7.8	5.5
Sum	222.3	147.9	207.1	138.4	141.7	99.6	111.2	80.6
Count	35	35	34	34	28	28	25	25
Confidence Level (95.0%)	0.913394	0.519183	0.767778	0.425303	0.871435	0.522736	0.587894	0.402024

Figure 5-18. Bump Cap and Ear Muffs Statistical Analysis

	Ear Plugs-Foam				Ear Plugs-Non Foam			
	Raw		Filtered		Raw		Filtered	
	Don	Doff	Don	Doff	Don	Doff	Don	Doff
Mean	17.31719	7.60625	16.63548	5.868966	14.87967	7.543089	13.70085	6.083478
Standard Error	0.951785	0.777061	0.848634	0.284413	0.791369	0.591748	0.55912	0.245903
Median	16.9	6.1	16.5	5.4	12.1	5.4	11.85	5.3
Mode	10.6	6.3	10.6	6.3	10.2	4.1	9.4	4.1
Standard Deviation	7.614284	6.216488	6.682154	2.166022	8.776711	6.5628	6.073601	2.637015
Sample Variance	57.97732	38.64472	44.65118	4.691652	77.03065	43.07034	36.88863	6.953847
Kurtosis	0.696748	8.581598	-0.06805	0.116678	13.26736	16.70133	0.344871	0.755473
Skewness	0.844992	2.862517	0.513627	0.582392	2.783662	3.655712	0.992815	1.151985
Range	36.5	32.4	31.4	9	66.8	47.3	26.4	11.6
Minimum	3.8	2	3.8	2	4.3	2	4.3	2
Maximum	40.3	34.4	35.2	11	71.1	49.3	30.7	13.6
Sum	1108.3	486.8	1031.4	340.4	1830.2	927.8	1616.7	699.6
Count	64	64	62	58	123	123	118	115
Confidence Level (95.0%)	1.901992	1.552832	1.696949	0.569526	1.566595	1.171424	1.107308	0.487132

Figure 5-19. Ear Plugs-Foam and Ear Plugs-Non Foam Statistical Analysis

	Eyeglasses, Safety				Glove-Blue			
	Raw		Filtered		Raw		Filtered	
	Don	Doff	Don	Doff	Don	Doff	Don	Doff
Mean	8.858824	4.908824	8.303125	4.721212	13.3475	5.565	12.72368	4.937333
Standard Error	0.583723	0.294736	0.464755	0.234309	0.474908	0.380727	0.37612	0.26439
Median	8.2	4.45	7.5	4.4	12.9	4.45	12.7	4.3
Mode	5.9	4.1	5.9	4.1	11.4	4.2	11.4	4.2
Standard Deviation	3.403663	1.718591	2.629054	1.346003	4.247709	3.405323	3.278938	2.289682
Sample Variance	11.58492	2.953556	6.911925	1.811723	18.04303	11.59623	10.75143	5.242641
Kurtosis	1.086702	3.897038	0.309539	-0.05358	2.222123	4.918099	-0.30321	0.250333
Skewness	1.282439	1.625866	0.996621	0.707443	1.109468	1.946406	0.159258	0.949529
Range	12.7	8.6	9.9	5.4	23.2	18.9	14.7	9.9
Minimum	5.2	2.5	5.2	2.5	6	1.4	6	1.4
Maximum	17.9	11.1	15.1	7.9	29.2	20.3	20.7	11.3
Sum	301.2	166.9	265.7	155.8	1067.8	445.2	967	370.3
Count	34	34	32	33	80	80	76	75
Confidence Level (95.0%)	1.187594	0.599645	0.947875	0.477272	0.945281	0.757818	0.749269	0.526808

Figure 5-20. Eyeglasses, Safety and Glove-Blue Statistical Analysis

	Glove-Cloth				Glove-Kevlar			
	Raw		Filtered		Raw		Filtered	
	Don	Doff	Don	Doff	Don	Doff	Don	Doff
Mean	10.22542	5.253672	8.925625	4.885294	9.176786	5.921429	8.492453	5.805455
Standard Error	0.375552	0.214619	0.215592	0.167658	0.507432	0.346623	0.339051	0.33264
Median	9.1	4.4	8.55	4.35	8.55	5.3	8.2	5.2
Mode	10.5	3.6	10.5	3.6	7.3	3.8	7.3	3.8
Standard Deviation	4.996394	2.855318	2.727042	2.185987	3.797271	2.593889	2.468326	2.466923
Sample Variance	24.96395	8.152842	7.436761	4.77854	14.41927	6.72826	6.092634	6.08571
Kurtosis	5.742775	3.798669	-0.47571	-0.12679	4.591039	-0.02282	-0.5241	-0.04149
Skewness	2.061375	1.661217	0.403841	0.800374	1.869892	0.762882	0.447963	0.718139
Range	30.3	16.7	10.9	9	19.3	11.6	9.6	10.8
Minimum	4.1	1.7	4.1	1.7	4.2	0.7	4.2	0.7
Maximum	34.4	18.4	15	10.7	23.5	12.3	13.8	11.5
Sum	1809.9	929.9	1428.1	830.5	513.9	331.6	450.1	319.3
Count	177	177	160	170	56	56	53	55
Confidence Level (95.0%)	0.741165	0.423558	0.425793	0.330973	1.016916	0.694648	0.680355	0.666903

Figure 5-21. Glove-Cloth and Glove-Kevlar Statistical Analysis

	Glove-Metal Mesh				Glove-Rubber			
	Raw		Filtered		Raw		Filtered	
	Don	Doff	Don	Doff	Don	Doff	Don	Doff
Mean	21.25625	6.51875	21.25625	6.51875	11.14278	5.690206	10.00276	5.320745
Standard Error	3.353592	0.897832	3.353592	0.897832	0.412671	0.229845	0.234203	0.176724
Median	20.55	5.75	20.55	5.75	9.85	5.1	9.6	4.95
Mode	#N/A	#N/A	#N/A	#N/A	9.8	6	7.5	6
Standard Deviation	13.41437	3.591326	13.41437	3.591326	5.747843	3.201369	3.15088	2.423116
Sample Variance	179.9453	12.89763	179.9453	12.89763	33.03769	10.24876	9.928048	5.871492
Kurtosis	-0.18806	-0.03321	-0.18806	-0.03321	14.96447	5.689808	-0.15979	-0.21561
Skewness	0.598101	0.754034	0.598101	0.754034	3.134124	1.852476	0.544362	0.626889
Range	47.1	12.5	47.1	12.5	43.7	21.6	14.5	10.6
Minimum	3.9	1.9	3.9	1.9	3.8	1.4	3.8	1.4
Maximum	51	14.4	51	14.4	47.5	23	18.3	12
Sum	340.1	104.3	340.1	104.3	2161.7	1103.9	1810.5	1000.3
Count	16	16	16	16	194	194	181	188
Confidence Level (95.0%)	7.148013	1.913683	7.148013	1.913683	0.813924	0.45333	0.462137	0.348629

Figure 5-22. Glove-Metal Mesh and Glove-Rubber Statistical Analysis

	Mask-Dust				Net-Beard			
	Raw		Filtered		Raw		Filtered	
	Don	Doff	Don	Doff	Don	Doff	Don	Doff
Mean	13.45	5.3	8.366667	5.3	12.78218	5.620792	12.78218	4.935417
Standard Error	5.102042	1.387444	0.617342	1.387444	0.448269	0.353075	0.448269	0.159336
Median	8.95	5.2	8.6	5.2	12.8	4.7	12.8	4.7
Mode	#N/A	#N/A	#N/A	#N/A	10.7	4.9	10.7	4.9
Standard Deviation	10.20408	2.774887	1.069268	2.774887	4.50505	3.548361	4.50505	1.561172
Sample Variance	104.1233	7.7	1.143333	7.7	20.29548	12.59086	20.29548	2.437259
Kurtosis	3.859295	-0.04144	#DIV/0!	-0.04144	-0.22018	15.33879	-0.22018	0.270122
Skewness	1.95572	0.191888	-0.93522	0.191888	0.435174	3.592751	0.435174	0.903414
Range	21.5	6.6	2.1	6.6	20.2	23.7	20.2	7
Minimum	7.2	2.1	7.2	2.1	4.8	2.4	4.8	2.4
Maximum	28.7	8.7	9.3	8.7	25	26.1	25	9.4
Sum	53.8	21.2	25.1	21.2	1291	567.7	1291	473.8
Count	4	4	3	4	101	101	101	96
Confidence Level (95.0%)	16.23697	4.415465	2.656208	4.415465	0.889353	0.700491	0.889353	0.316323

Figure 5-23. Mask-Dust and Net-Beard Statistical Analysis

	Net-Hair				Rain Suit-Jacket			
	Raw		Filtered		Raw		Filtered	
	Don	Doff	Don	Doff	Don	Doff	Don	Doff
Mean	15.0599	6.002475	14.62374	5.551832	43.38	16.15	42.11724	15.20357
Standard Error	0.485352	0.202841	0.442491	0.159461	2.270862	1.047732	1.953638	0.869539
Median	13.4	5.2	13.25	5.1	43.35	14.55	43.3	14.45
Mode	12.3	3.5	12.3	3.5	#N/A	#N/A	#N/A	#N/A
Standard Deviation	6.898152	2.882913	6.226396	2.203797	12.43802	5.738662	10.52066	4.601166
Sample Variance	47.5845	8.311188	38.76801	4.85672	154.7044	32.93224	110.6843	21.17073
Kurtosis	1.085945	2.034242	0.236561	-0.04989	1.232009	0.641085	-0.51544	0.338439
Skewness	1.101144	1.387512	0.850224	0.841859	0.848282	0.980744	0.226339	0.705938
Range	36.7	16.2	29.5	9.5	55.4	24.2	41.9	18.9
Minimum	4	2.1	4	2.1	24.6	7.1	24.6	7.1
Maximum	40.7	18.3	33.5	11.6	80	31.3	66.5	26
Sum	3042.1	1212.5	2895.5	1060.4	1301.4	484.5	1221.4	425.7
Count	202	202	198	191	30	30	29	28
Confidence Level (95.0%)	0.957035	0.399969	0.872627	0.314542	4.644434	2.142852	4.001846	1.784146

Figure 5-24. Net-Hair and Rain Suit-Jacket Statistical Analysis

	Rain Suit-Pants				Sleeves			
	Raw		Filtered		Raw		Filtered	
	Don	Doff	Don	Doff	Don	Doff	Don	Doff
Mean	56.17333	36.71667	56.17333	29.39643	17.78649	5.490541	15.01642	4.774648
Standard Error	3.437434	6.120593	3.437434	2.603795	1.272372	0.513293	0.656318	0.216156
Median	50.7	24.4	50.7	23.9	14.4	4.45	13.8	4.4
Mode	50.7	16.1	50.7	16.1	13.5	3.1	13.5	3.1
Standard Deviation	18.8276	33.52387	18.8276	13.77799	10.94536	4.415513	5.372195	1.821359
Sample Variance	354.4786	1123.85	354.4786	189.8329	119.8009	19.49676	28.86048	3.317348
Kurtosis	-0.03957	15.07655	-0.03957	0.574312	9.343411	32.11268	0.258917	-0.33152
Skewness	0.624595	3.552665	0.624595	1.047564	2.693756	5.027557	0.813938	0.582667
Range	76.7	177.4	76.7	55.9	63.8	34.5	22.8	8.1
Minimum	25.4	11.6	25.4	11.6	6.4	1.5	6.4	1.5
Maximum	102.1	189	102.1	67.5	70.2	36	29.2	9.6
Sum	1685.2	1101.5	1685.2	823.1	1316.2	406.3	1006.1	339
Count	30	30	30	28	74	74	67	71
Confidence Level (95.0%)	7.030342	12.51802	7.030342	5.342546	2.535834	1.022991	1.310381	0.431109

Figure 5-25. Rain Suit-Pants and Sleeves Statistical Analysis

	Sleeves-Disposable				Smock-Cloth			
	Raw		Filtered		Raw		Filtered	
	Don	Doff	Don	Doff	Don	Doff	Don	Doff
Mean	13.02714	4.38	12.30909	4.120588	35.81813	14.59688	34.24013	13.775
Standard Error	0.578045	0.25728	0.484832	0.177703	0.805332	0.412551	0.591405	0.305824
Median	12.3	4.1	11.35	4.05	34.15	13.35	33.9	13.2
Mode	10.7	4.1	10.7	4.1	39.6	11.9	39.6	11.9
Standard Deviation	4.836274	2.152558	3.93879	1.465377	10.18673	5.218405	7.291329	3.770454
Sample Variance	23.38954	4.633507	15.51407	2.147331	103.7694	27.23175	53.16348	14.21632
Kurtosis	0.557965	11.79901	0.025824	-0.42717	5.345457	4.057963	-0.08336	0.406902
Skewness	0.987632	2.632579	0.69614	0.42016	1.723652	1.717957	0.329527	0.807713
Range	22.3	14.4	17.4	5.9	70.3	33.2	38.7	18.2
Minimum	4.7	1.6	4.7	1.6	15.7	6.4	15.7	6.4
Maximum	27	16	22.1	7.5	86	39.6	54.4	24.6
Sum	911.9	306.6	812.4	280.2	5730.9	2335.5	5204.5	2093.8
Count	70	70	66	68	160	160	152	152
Confidence Level (95.0%)	1.153169	0.513259	0.968276	0.354697	1.590527	0.814787	1.168497	0.604247

Figure 5-26. Sleeves-Disposable and Smock-Cloth Statistical Analysis

	Smock-Cloth Button				Smock-Paper			
	Raw		Filtered		Raw		Filtered	
	Don	Doff	Don	Doff	Don	Doff	Don	Doff
Mean	38.43333	12.57654	37.50886	12.31772	44.73636	16.59091	44.73636	16.59091
Standard Error	1.20543	0.449826	1.034167	0.421889	4.120862	1.775718	4.120862	1.775718
Median	35.3	12.6	35.3	12.5	42.2	14.8	42.2	14.8
Mode	32.9	13.1	32.8	13.1	#N/A	#N/A	#N/A	#N/A
Standard Deviation	10.84887	4.048434	9.191875	3.749829	13.66735	5.88939	13.66735	5.88939
Sample Variance	117.698	16.38982	84.49056	14.06122	186.7965	34.68491	186.7965	34.68491
Kurtosis	2.468915	-0.18502	-0.07874	-0.5219	-0.53873	0.712062	-0.53873	0.712062
Skewness	1.297753	0.433759	0.681931	0.239256	0.552344	0.906939	0.552344	0.906939
Range	61.3	17.6	39.2	16.1	42.2	20.6	42.2	20.6
Minimum	20.4	5.4	20.4	5.4	25.1	8.6	25.1	8.6
Maximum	81.7	23	59.6	21.5	67.3	29.2	67.3	29.2
Sum	3113.1	1018.7	2963.2	973.1	492.1	182.5	492.1	182.5
Count	81	81	79	79	11	11	11	11
Confidence Level (95.0%)	2.398882	0.895182	2.058868	0.839916	9.181853	3.956546	9.181853	3.956546

Figure 5-27. Smock-Cloth Button and Smock-Paper Statistical Analysis

	Smock-Paper Tie			
	Raw		Filtered	
	Don	Doff	Don	Doff
Mean	36.06667	17.2	36.06667	17.2
Standard Error	3.596171	1.298204	3.596171	1.298204
Median	37.15	17.3	37.15	17.3
Mode	#N/A	18.9	#N/A	18.9
Standard Deviation	8.808783	3.179937	8.808783	3.179937
Sample Variance	77.59467	10.112	77.59467	10.112
Kurtosis	0.056786	-1.40179	0.056786	-1.40179
Skewness	-0.45911	0.305472	-0.45911	0.305472
Range	25.1	8.2	25.1	8.2
Minimum	22.4	13.6	22.4	13.6
Maximum	47.5	21.8	47.5	21.8
Sum	216.4	103.2	216.4	103.2
Count	6	6	6	6
Confidence Level (95.0%)	9.244251	3.337139	9.244251	3.337139

Figure 5-28. Smock-Paper Tie Statistical Analysis

The model allows a user to enter any desired combination of PPE and sanitation items that data have been collected on, and reports how much time should be required for the desired donning & doffing combinations. The model takes values [mean, lower confidence limit (LCL) & upper confidence limit (UCL)] from each of the worksheets containing data on various items and uses them in the statistical calculations. The user can select “Raw Data” or “Filtered Data” where the “Filtered Data” has the outliers removed from the “Raw Data” before the statistics are calculated. In Figure 5-29, a representative selection page for the model is shown. On this page, multiple items of PPE have been selected and “Filtered Data” has also been selected. A calculation section of the model is shown in Figure 5-30 for don times of the selections made on the user screen in Figure 5-29. The calculation section for doff times for the same user screen is shown in Figure 5-31. The example does not represent a typical group of PPE that would be worn by a single employee, but rather is shown to demonstrate how the model is used.

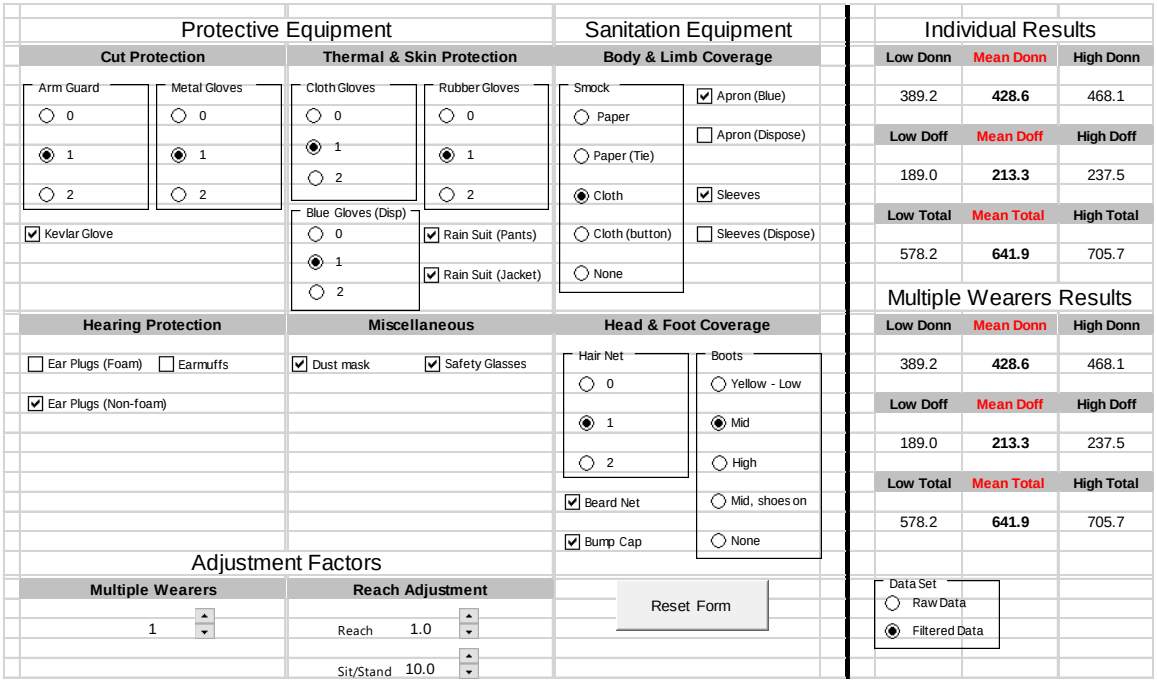

Figure 5-29. User Page of Excel Model to Select PPE

Don								
			Filtered Low	Filtered	Filtered High	Raw Low	Raw	Raw High
Rubber Gloves	1		9.54	10.00	10.46	10.33	11.14	11.96
Cloth Gloves	1		8.50	8.93	9.35	9.48	10.23	10.97
Metal Mesh Golves	1		14.11	21.26	28.40	14.11	21.26	28.40
Kevlar Glove	TRUE		7.81	8.49	9.17	8.16	9.18	10.19
Ear Plugs (Non-foam)	TRUE		12.59	13.70	14.81	13.31	14.88	16.45
Safety Glasses	TRUE		7.36	8.30	9.25	7.67	8.86	10.05
Apron (Disposable)	TRUE		50.40	52.92	55.44	51.17	54.36	57.55
Dust mask	TRUE		5.71	8.37	11.02	-2.79	13.45	29.69
Ear plugs	TRUE		14.94	16.64	18.33	15.42	17.32	19.22
Ear muffs	TRUE		3.86	4.45	5.04	4.19	5.06	5.93
Arm Guard	1		4.56	4.92	5.29	5.00	5.79	6.58
Boots	2		44.99	51.64	58.29	49.01	57.68	66.35
Blue Gloves	1		11.97	12.72	13.47	12.40	13.35	14.29
Apron (Blue)	TRUE		23.28	24.22	25.16	24.23	25.46	26.69
Beard net	TRUE		11.89	12.78	13.67	11.89	12.78	13.67
Hair net	1		13.75	14.62	15.50	14.10	15.06	16.02
Sleeves	TRUE		57.44	60.07	62.69	66.07	71.15	76.22
Bump Cap	TRUE		5.32	6.09	6.86	5.44	6.35	7.26
Rain Suit (Pants)	TRUE		49.14	56.17	63.20	49.14	56.17	63.20
Rain Suit (Jacket)	TRUE		38.12	42.12	46.12	38.74	43.38	48.02
Sleeves (Disposable)	TRUE		22.68	24.62	26.55	23.75	26.05	28.36
Smock	3		33.07	34.24	35.41	34.23	35.82	37.41

Figure 5-30. Excel Model – Don Data

Doff								
			Filtered Low	Filtered	Filtered High	Raw Low	Raw	Raw High
Rubber Gloves	1		4.97	5.32	5.67	5.24	5.69	6.14
Cloth Gloves	1		4.55	4.89	5.22	4.83	5.25	5.68
Metal Mesh Golves	1		4.61	6.52	8.43	4.61	6.52	8.43
Kevlar Glove	TRUE		5.14	5.81	6.47	5.23	5.92	6.62
Ear Plugs (Non-foam)	TRUE		5.60	6.08	6.57	6.37	7.54	8.71
Safety Glasses	TRUE		4.24	4.72	5.20	4.31	4.91	5.51
Apron (Disposable)	TRUE		6.71	7.38	8.05	7.03	7.90	8.77
Dust mask	TRUE		0.88	5.30	9.72	0.88	5.30	9.72
Ear plugs	TRUE		5.30	5.87	6.44	6.05	7.61	9.16
Ear muffs	TRUE		2.82	3.22	3.63	3.03	3.56	4.08
Arm Guard	1		3.72	3.91	4.11	3.80	4.04	4.28
Boots	2		26.94	31.65	36.37	29.16	36.27	43.37
Blue Gloves	1		4.41	4.94	5.46	4.81	5.57	6.32
Apron (Blue)	TRUE		11.57	12.11	12.65	12.51	13.58	14.65
Beard net	TRUE		4.62	4.94	5.25	4.92	5.62	6.32
Hair net	1		5.24	5.55	5.87	5.60	6.00	6.40
Sleeves	TRUE		18.24	19.10	19.96	19.92	21.96	24.01
Bump Cap	TRUE		3.65	4.07	4.50	3.71	4.23	4.74
Rain Suit (Pants)	TRUE		24.05	29.40	34.74	24.20	36.72	49.23
Rain Suit (Jacket)	TRUE		13.42	15.20	16.99	14.01	16.15	18.29
Sleeves (Disposable)	TRUE		7.53	8.24	8.95	7.73	8.76	9.79
Smock	3		13.17	13.78	14.38	13.78	14.60	15.41

Figure 5-31. Excel Model – Doff Data

Section 5.6 Validation

In order to validate the model output, the times obtained from the time study of fifty-nine (59) subjects donning and doffing 936 pieces of PPE and sanitation equipment were compared to those housed in the database for similar equipment. As seen in Table 5-1, the model conservatively overestimates the time (cmin) it actually took (observed) for the subjects to don and doff the items by an average of six percent (6%), 3% for don and 9% for doff.

	Don			Doff		
PPE	**Timed Data**	**Model**	**% Diff**	**Timed Data**	**Model**	**% Diff**
Earplugs	14.2	14.7	3%	7.2	7.1	-1%
Hair net	11.3	15.6	28%	5.3	6.6	20%
Beard net	12.5	13.8	9%	5.5	5.9	7%
Smock	32.8	35.2	7%	13.6	14.8	8%
Bump Cap	7.1	7.1	0%	4.9	5.1	4%
Chain Glove	12.9	22.3	42%	6.2	7.5	17%
Kevlar Glove	11.3	9.5	-19%	5.3	6.8	22%
Apron	25.9	25.2	-3%	12.1	13.1	8%
Cloth Glove	9.8	9.9	1%	5.4	5.9	8%
Rubber Glove	15.1	11.0	-37%	6.7	6.3	-6%
Mean Diff			**3%**			**9%**

Table 5-1. PPE Donning/Doffing Validation Results

The model is of great utility in determining how long it should take to don and doff various combinations of PPE and sanitary gear. A user can simply click on the appropriate items being considered, the model retrieves the values that are needed from the data spreadsheets, and returns an interval that contains the estimated time to accomplish the don & doff sequence. Of the three values reported, the mean is most appropriately used to represent the correct time. Use of the upper confidence limit is highly conservative, while using the lower confidence limit would be very liberal.

Section 5.7 Model Case Study

A poultry processing facility in the US desired to know how much time its employees should be spending daily on donning/doffing PPE and sanitation items associated with their jobs. The facility contained numerous departments, encompassing one hundred forty-one (141) unique job descriptions (excluding maintenance), employing one thousand (1,000) individuals over two shifts. The first step in determining the don & doff time for any of the 141 discrete jobs was to work with management to develop a list

of the PPE and sanitation items required for each job. It is important to note the term "required". There can exist a significant difference in what PPE, sanitation equipment, and even personal clothing items an employee chooses to wear, and those items deemed required by the employer for various reasons, such as safety issues mandated by the Occupational Safety and Health Administration (OSHA), food safety concerns such as Hazard Analysis and Critical Control Points (HAACP), Good Manufacturing Practice (GMP) and contractual concerns (potential union issues), among others. When determining what items to add to the model, only those items identified as required in the PPE/Sanitation Equipment Matrix (Figure 5-32) were added.

					Gloves												
Dept.	No. Empl.	Smock	Boots	Bump Cap	Rubber	Cotton	Cutting	Steel	Arm Guard	Sleeves	Apron	Glasses	Ear Plugs	Hair Net	Dust Mask	Safety Vest	Cover-alls
Giblets																	
Heart Puller	3	X	X	Orange	X	X				X	X	X	X	X			
Liver	2	X	X	Orange	X	X				X	X	X	X	X			
Heart	1	X	X	Orange	X	X				X	X	X	X	X			
Gizzard	1	X	X	Orange	X	X				X	X	X	X	X			
Gizzard Scaler	1	X	X	Orange	X	X				X	X	X	X	X			
Gizzard Packer	1	X	X	Orange	X	X				X	X	X	X	X			
Heart/Liver/Lung Chiller	1	X	X	Orange	X	X				X	X	X	X	X			
Floor Person	1	X	X	Red	X	X				X	X	X	X	X			
Line Leader	1	X	X	Orange	X	X				X	X	X	X	X			
Ice	1	X	X	Orange	X	X				X	X	X	X	X			
Neck Chiller	1	X	X	Orange	X	X				X	X	X	X	X			
Grading & Rehang																	
Rehanger	22	X	X	Orange	X	X				X	X	X	X	X			
Saw Operator	2	X	X	Orange	X	X		X	X	X	X	X	X	X			
Line Leader	1	X	X	Orange	X	X				X	X	X	X	X			
Floor person	2	X	X	Red	X	X					X	X	X	X			
Jack Driver	1	X	X	Orange	X	X						X	X	X			
Reconditioner	1	X	X	Orange	X	X				X	X	X	X	X			
PEDCO Sizer	2	X	X	Orange	X	X						X	X	X			
Thigh Debone																	
Hanger	4	X	X	Green	X	X				X	X		X	X			
Cutter	16	X	X	Green	X	X	X	X		X	X		X	X			
Trimmer	16	X	X	Green	X	X	X	X		X	X		X	X			
Line Leader	4	X	X	Green	X	X				X	X		X	X			
Scaler	2	X	X	Green	X	X				X	X		X	X			
Strapper	1	X	X	Green		X							X	X			
Packer	3	X	X	Green	X	X				X	X		X	X			
Grader	3	X	X	Green	X	X				X	X		X	X			
Singulator	1	X	X	Green	X	X				X	X		X	X			
CVP Operator	1	X	X	Green		X							X	X			
Floor Person	2	X	X	Red	X	X							X	X			
Box Maker	1	X	X	Green		X							X	X			
Box Room																	
Box Room Employees	5	X	X	Grey									x	x			

Figure 5-32. PPE/Sanitation Equipment Matrix

The individual required items of PPE and sanitation equipment were entered into the model, outputting the estimated time to don & doff this specific combination. These times were entered into a spreadsheet, multiplied by the number of employees in that job title (all shifts), and summed across all 141 jobs. This grand sum is divided by the total number of employees (1000 in this case), resulting in the time it takes the average employee to don & doff (a single time). This time is multiplied by three (3) to represent the three times per day that the employees don & doff their equipment. An adjustment is

made to allow for only a single don and doff of the hair net, as it remains on the employee's head during all break periods.

The output of this procedure results in the average employee spending slightly less than 4 minutes (3.97) per shift donning and doffing the required equipment. An additional use of the model may be the determination of which specific jobs, and the associated number of affected employees, might exceed a particular threshold of interest to the company. Say the company wanted to know what percentage (or exact number) of employees exceeding ten (10) total minutes per workday donning and doffing. The model could easily provide answers to such questions.

It should also be noted that no accommodation has been used in the model to account for simultaneous operations. Meaning, the vast majority of the PPE and sanitation equipment could be donned/doffed while walking to and from the job without significantly impacting either the walking time or the don/doff time.

Section 5.8 Self-Reporting

When asked, "How long does it typically take you to put on (don) the PPE and sanitation items that you just were timed on?", the mean answer was 211.7 seconds. For the "How long does it typically take you to take off (doff) the PPE and sanitation items that you just were timed on?" question, the mean answer was 139.4 seconds.

The time donning and doffing PPE and sanitary gear (single time) was self-reported by the subjects as being 351.1 seconds or 5.85 minutes. It is also interesting to determine whether or not individuals underestimated, nearly correctly estimated, or overestimated how much time it takes to don and doff these PPE and sanitation items. To determine this, the specific combinations of items in which each subject was tested

(timed from the video) was compared to their self-reported estimate about how long it took them to don and doff the same items.

Self-Reported Time Estimation (n=59)				
Estimation	Under Estimate	Correctly Estimate*	Over Estimate	Average % Off
Don	15.3%	8.5%	76.2%	231%
Doff	8.5%	5.1%	86.4%	360%

*Subjects were deemed to provide a 'Correct Estimate' if they reported a value within +/- 15% of the actual time it took to don and doff.

Table 5-2. Self-Reported Donning/Doffing Times

These results (shown in Table 5-2) suggest that the vast majority of subjects (81.3%) tend to over-estimate the time that it takes to don and doff PPE and sanitation equipment. Though it is interesting in itself to note this tendency to overestimate, the magnitude of the over estimation is of interest.

When donning items, individuals reported that it took 231% of the actual measured time to accomplish this task. In other words, if it actually took an individual 1-minute to correctly don the items, they reported on the average that it took approximately 2 minutes and 18 seconds. The actual observed mean time to don the items that they normally wear (sanitation and PPE) across all 59 observed employees, was slightly more than 1.5 minutes (153.0 cmin).

When doffing items, individuals reported that it took 360% of the actual measured time to accomplish this task. In other words, if it actually took an individual 1-minute to correctly doff the items, they reported on the average that it took approximately 3 minutes and 35 seconds. The actual observed mean time to doff the items that they

normally wear (sanitation and PPE) across all 59 observed employees, was approximately 39 seconds (64.8 cmin).

Having directly observed and timed fifty-nine (59) employees' (subjects') don and doff the actual sanitation gear and PPE they choose to normally wear in the course of their jobs, the mean time to don and doff all of the equipment, for those employees observed, was 2 minutes and 11 seconds. When asked how long it takes for them to don and doff the exact same combination of equipment, the subjects' answered an average of 5 minutes and 51 seconds. Taking the employees self-reported time of 351.1 seconds and dividing by the observed time of 130.7 seconds, results in a factor of roughly 2.7, or 270% over-estimation.

Section 5.9 Conclusions

The model (based on factual data) developed and validated for this study provides a superior, unbiased, easy to use, objective approach to provide any interested party with the ability to accurately determine how much time should be allocated to a donning or doffing (limited to the items contained in the model) sequence. The model output for the case study resulted in the average employee spending slightly less than 4 minutes (3.97) per shift donning and doffing the required equipment, significantly less time than the employees (subjects) tended to self-report.

Chapter 6. Conclusions

The studies conducted as part of the work for this dissertation lead to the following conclusions:

1) Methods Engineering can be used to determine the most efficient and effective method for donning and doffing PPE.
2) Classical time study can be used to empirically establish statistically sound donning and doffing times. MOST can be used by an experienced analyst to validate such time studies or in lieu of such studies.
3) For the smoke hood studied, a pronounced learning effect occurred between the first and second smoke hood don, emphasizing the need for effective training and practice, especially for potentially life-saving equipment.
4) Academic courses can be used as "labs" to conduct controlled time study experiments to produce detailed methods and associated donning and doffing times (which can be used by industry) as part of the instructional mission of a traditional land-grant university.
5) The data from the studies performed as part of this dissertation indicates that in general, doffing time is less that donning time for most types of PPE. Early indications are that a model can be developed for the don/doff relationship for each type of PPE.
6) Donning and doffing layers of work gloves increases the time more than simply summing times for donning and doffing one glove at a time by a significant amount, up to 75% for donning and 42% for doffing.

7) Using the data collected for the studies reported in this dissertation, the model developed provides an easy to use tool to determine donning and doffing times for many types of PPE used in the workplace. The case-study model calculated that employees studied spent less than four (4) minutes per shift donning and doffing required PPE, significantly less time than they self-reported.

Chapter 7. Future Work

The smoke hood study indicated that don training and/or practice significantly affects the don time. Subsequent studies may be conducted to measure the effect of video or other types of training on don times. Fit of gloves to hands is a factor in the time it takes to don and doff, and preliminary research was conducted in glove experiments to derive a definition of "fit" of gloves to hands. The data collected for this area can be analyzed and future experiments designed to characterize glove fit and develop a relationship between glove fit and don and doff times. In addition, studies could be conducted to determine the optimum relationship between the different layers of gloves in terms of size when multiple layers of gloves are worn. As reported in the "Conclusions" section, the interaction effect of donning and doffing multiple layers of gloves resulted in times greater than summing times for individually donned and doffed gloves. Additional research should be conducted to model interaction effects of other types of PPE combinations, such as hair-nets, safety glasses, ear plugs, and bump caps or helmets.

The experiments conducted revealed multiple methods for donning and doffing different types of PPE that all were effective and did not affect the donning and doffing times significantly. However, additional analysis should be done to develop a heuristic to determine when the "optimal" method is found and how to characterize it.

Performance (pace) rating was used in the time study experiments. However, several experiments produced evidence that under conditions such as practicing prior to the experiment and/or conducting a large number of trials, performance rating is not necessary and an accurate time standard can be developed using timed trials alone.

Additional work should be done in this area because training individuals to performance rate is time consuming and expensive.

As stated earlier, there is evidence that doffing time is less than donning time for most types of PPE, at least in clean, non-contaminated environments. Additional studies can be conducted to investigate whether or not a similar relationship exists in environments where PPE doffing methods are at least as critical (or perhaps even more critical) to worker safety as donning methods and associated times.

In industrial settings, gloves may become wet when worn by workers for certain jobs. The glove experiments that were conducted only used dry gloves. Additional experiments should be undertaken to determine the effect of wet gloves on donning and doffing times. These experiments did not address doffing methods when there is a possibility of worker contamination in health care situations such as caring for Ebola patients. Evidence was presented that a real threat exists in this area and it would be beneficial to create fool-proof doffing methods and times for such circumstances.

The studies conducted as part of this dissertation established start and stop locations for PPE, in general located on a 29-inch-high table in order (such as in Figure 4.1) with the worker standing in close proximity and facing the table. In industrial facilities, PPE may be located in a locker, cabinet, or bin. In certain circumstances, PPE may be donned and doffed from seated or other positions. For example, in a smoke-filled room, a person may be crouching while donning a smoke hood. Additional experiments could be conducted to study the effects of different worker positions and different PPE locations on donning and doffing times.

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Appendix A. Lab Instructions: Don and Doff an Article of Clothing

This lab is an individual lab assignment. You must do all of your own work except that your partner may take photographs and time you.

1) Individual: Choose an article of clothing such as a jacket, vest, etc. If you do not have a jacket or vest, ask your instructor or GTA for approval to substitute another article. Partners may not use the same article of clothing.
2) Individual: Design the method you will use to don and doff the clothing and document it in writing on a piece of paper. Ask your GTA to sign off on your method and for a partner.
3) Individual: Practice the method at least 5 times (5 dons and 5 doffs) or until you can perform the operation smoothly without error.
4) With a partner: You perform 30 trials (30 dons and 30 doffs) and your partner records the times for each.
5) Individual: Calculate the mean and standard deviation of the dons and doffs.
6) Individual: Submit your finished document to Canvas by the deadline. It should look something like the example below (notice formatting is professional). This example shows the doffing process only but your assignment is to show donning and doffing.

Rubric: Method (50 points), Time Study (30 points), Presentation (20 points).

Section A.1 Example Student Submission of Completed Assignment

DONNING

Begin:

1) Lay vest vertically [sic, horizontally] on table with collar on top and unzipped with zipper at the bottom. Stand above vest. (Figure A-1)
2) Pick up left side of vest near the top by zipper with left hand.
3) Stick right arm through the hole and pull vest all the way over right arm with your left hand.
4) Use left hand to grab the vest by zipper from around your back and over left shoulder. (Figure A-2)
5) Use right hand to grip zipper near the top and bend left arm to put it into the hole.
6) Use both hands and grab both bottom edges of zipper and bring edges together. (Figure A-3)
7) Grip zipper with right hand and use left hand to guide left teeth of zipper into right hole of zipper.
8) Once zippers are attached, hold the bottom of vest with left hand and pull the zipper up with the right hand.

DOFFING

Begin:

1) Vest zipped about half way up and arms at sides. (Figure A-4)
2) Use right hand to grab zipper and pull down to bottom of vest with enough force as to disconnect the zippers at the bottom of the vest.
3) Use left and right hands and grip inside flaps of the vest near the middle of the zippers.

4) Bring both arms back while bending elbows and rolling shoulders as to get vest off the upper body. (Figure A-5)
5) Use right hand to grip inside flap of right side of vest near middle of zipper and straighten right arm so vest falls past elbow.
6) Pull out right arm.
7) Grab inside flap of left side of vest with right arm.
8) Straighten left arm with right hand still gripping flap and pull left arm out of hole.
9) Pull right arm back towards right leg and grab left flap with left hand on middle of zipper.
10) Place vest face up with zippers facing you and grab bottom left and right corners and fold into vest. (Figure A-1)

Figure A-1. Start Position

Figure A-2. Don Left Shoulder

Figure A-3. Zip Vest

Figure A-4. Begin Doff

Figure A-5. Doff from Shoulders

Donning		Doffing	
Trial:	Time:	Trial:	Time:
1	12.55	1	9.11
2	13.75	2	9.66
3	8.90	3	11.63
4	15.08	4	8.58
5	11.08	5	9.18
6	12.71	6	9.75
7	14.35	7	5.23
8	13.63	8	9.25
9	9.09	9	9.29
10	12.80	10	9.19
11	15.41*	11	11.76
12	13.28	12	9.14
13	11.94	13	9.13
14	11.84	14	10.41
15	12.76	15	9.19
16	11.23	16	8.07
17	11.29	17	7.43
18	11.33	18	8.31
19	12.76	19	8.41
20	12.58	20	9.25
21	13.00	21	7.84
22	11.56	22	7.76
23	10.63	23	7.93
24	10.83	24	8.23
25	11.23	25	8.81
26	10.98	26	9.30
27	11.53	27	7.31
28	10.41	28	9.06
29	11.11	29	7.46
30	9.78	30	8.64
Mean:	11.98	Mean:	8.81
Standard deviation:	1.58	Standard deviation:	1.25

Table A-1. Timed Trials to Don and Doff a Vest

The observed time in trial 11 for don is a statistical outlier and is noted with an asterisk. However, the instructions were given for the lab assignment to not remove outliers from the data.

Appendix B. Lab Instructions: Performance (Pace) Rating

Portions of the information below excerpted from Niebel's Methods, Standards and Work Design, 12th ed.,by Andris Freivalds. Also, portions are excerpted from Piper and Davis (unpublished), "Laboratory Exercises for Ergonomics, Safety and Methods Engineering". Even though you will work in groups to collect the data, each student will turn in their own data sheet(s) for an individual grade for this lab.

Due: See Canvas

Topics: Pace Estimation, Performance Ratings, Normal Pace, Standard Task Times, Inter-rater Reliability.

Objectives:

· To gain experience estimating the pace of common tasks and of industrial jobs

· To practice performing simple tasks at normal pace and at faster or slower paces.

Introduction: Along with learning how to perform time studies, it is important to consider the pace at which people work. Certainly, we cannot expect everyone to perform the same task in the same amount of time. Thus, some adjustment to a given worker's work speed must be made so that we can come to an understanding of what an average worker's pace might be. We spend a great amount of effort using precise digital watches to time a task to the nearest tenth, hundredth, or thousandth of a minute. While it may seem unintuitive that we will now 'guess' as to how fast someone is working, it is a critical part of setting standards, and cannot be overemphasized. Remember, time study is both an art and a science. This exercise will definitely emphasize the artistic nature of the field. Industrial engineers are the only engineers trained to rate performance. The ability to learn and apply these techniques will give you a firm foundation upon which to build an industrial engineering career.

Rating Task 1. Walking a 50 foot long indoor level straight course. There are several locations on the 3rd floor of Shelby where this experiment can be performed. Use masking tape to mark your course. You may use the fact that most of the flooring is made up of 12" tiles. Be careful to note and account for if there is a partial tile on your course. Pick up and discard the masking tape after your experiment. Working in groups of 4-5, there will be in each group for each trial:

Role 1: Walker

Role 2: Time Recorder

Role 3: Raters (There are 2-3 for each trial depending on the size of the group)

Roles will change until every group member has had each of the 3 roles.

While the walking member performs the exercise, the other group members should stand along the middle portion of the track and observe the task to estimate the pace at which the subject is walking (using 5% increments), between 70% and 130%.

i. Before recording any data, the Time Recorder will announce whether the trial was a "good trial" or not. The trial is a "good trial" if the time is within 10% of the expected time. (For 100%, the expected time is between 0.171 and 0.209 minutes.)
ii. Raters will not record the rating unless there is a "good trial".
iii. The Time Recorder will keep the actual time and provide it to the group after each trial's pace estimates are recorded by the raters.

For safety and consistency, the walking subject should ensure that there is always a foot in contact with the ground (i.e. no running) and that stability is not compromised (i.e. do not go so fast as to lose your balance).

Each group member will perform their walking task in three trials while their fellow group members in rater roles estimate their pace as described above:

i. The subject will attempt to walk the course at 100% (normal) pace, which is 19 cmin. for a 50 ft. course. If the pace is within 10% of normal, the Time Recorder will instruct you to go on to step ii. Otherwise, repeat this step once more.

ii. The walker will be secretly assigned a random pace (60-140 % of normal) by the Time Recorder, and will attempt to walk at that pace. See instructions below for generating a random number between 60 and 140. If you are unable to generate random numbers, see your GTA. If you generate 1.00, generate another number until you have a number that is not 1.00. If the pace is within 10% of the target pace, the Time Recorder will inform you to move to step iii. Otherwise, repeat this step (with the same secret pace) a 2nd and a 3rd time, if necessary. After 3 attempts, move to step iii. Fellow group members will not know the target pace.

iii. The subject will walk the course at his/her maximum pace, making sure to adhere to the proper walking guidelines above. This trial will only be performed once per group member unless there is a disruption or a stumble.

<u>Rating Task 2. Each subject will deal a deck of 52 cards into 4 equal piles onto a table while seated.</u>

While the dealer distributes the cards, the other group members should observe the task to determine the pace at which the subject is working (using 5% increments).

i. Observers will not measure or be told the actual duration of the task until they have recorded their pace estimates on the data collection form.

ii. The Time Recorder will keep the actual time and provide it to the group after each trial's pace estimates are recorded.

The dealer should deal the cards one at a time, into four orderly piles, beginning at his/her left, then to the opposite side of the table, then to his/her right, and finally directly in front of the dealer (a diamond pattern), repeating this pattern until the deck is exhausted.

i. The cards must remain on the table

ii. The cards should come to rest in orderly and easily distinguished piles, though they do not have to be perfectly stacked.

Each group member will perform their card-dealing trials according to the following procedure (remember, other group members are recording pace estimate data as described above):

i. The subject will attempt to deal all 52 cards at 100% (normal) pace, which is 50 cmin. If the pace is within 10% of normal, the Time Recorder will instruct you to go on to step ii. Otherwise, repeat this step once more.

ii. The subject will be assigned a secret random pace (60-140 % of normal) by the Time Recorder, and will attempt to deal all 52 cards at that pace. If the pace is within 10% of the target pace, the Time Recorder will inform you to move to step iii. Otherwise, repeat this step a 2nd and a 3rd time, if necessary. After 3 attempts, move to step iii. Fellow group members will not know the target pace.

iii. The subject will deal all 52 cards at his/her maximum pace, adhering to the proper dealing guidelines above. This trial will only be performed once per group member unless there is a major interruption or a bad deal.

Deliverables: Submit one Excel file per student to Canvas. Use the template posted on Canvas to show your data; compare your ratings with the actual performances of the walkers/dealers quantitatively. Write an assessment paragraph or two in the Excel file as

to how you performed as a rater in this experiment, using the data as supporting evidence of your assessment.

How to generate a random number: I downloaded the free app "NumeroRama" and set the "From" to 0.60 and the "To" to 1.30 and the decimal points to 1. This will generate random numbers between .60 and 1.30 by tenths.

Example Student Submission of Completed Assignment

	Trial	Assigned %	Target Time	Actual Time	1	2	3	4
1	Normal	100%	11.40 sec	12.18 sec	T	105%	100%	W
1	Other	121%	9.42 sec	9.56 sec	T	115%	110%	W
1	Max	138%	N/A	8.29 sec	T	130%	145%	W
2	Normal	100%	11.40 sec	11.34 sec	W	T	95%	90%
2	Other	84%	13.60 sec	14.28 sec	W	T	70%	75%
2	Max	155%	N/A	7.35 sec	W	T	140%	130%
3	Normal	100%	11.4 sec	12.8 sec	95%	W	T	90%
3	Other	107%	10.6	11.9 sec	105%	W	T	93%
3	Max	154%	N/A	7.4 sec	120%	W	T	130%
4	Normal	100%	11.4 sec	12.6 sec	95%	98%	W	T
4	Other	116%	9.8 sec	10.2 sec	120%	110%	W	T
4	Max	139%	N/A	8.23 sec	127%	119%	W	T

Table B-1. Walking Experiment Trial Data

	Trial	Assigned %	Target Time	Actual Time	1	2	3	4
1	Normal	100%	30.00 sec	30.13 sec	C	92%	90%	D
1	Other	92%	27.30 sec	30.01 sec	T	80%	70%	D
1	Max	131%	N/A	22.83 sec	T	117%	110%	D
2	Normal	100%	30.00 sec	28.80 sec	95%	97%	D	T
2	Other	93%	32.10 sec	31.53 sec	95%	95%	D	T
2	Max	119%	N/A	25.20 sec	115%	108%	D	T
3	Normal	100%	30.00 sec	32.20 sec	105%	D	T	95%
3	Other	130%	21.00 sec	20.80 sec	130%	D	T	132%
3	Max	149%	N/A	20.20 sec	130%	D	T	125%
4	Normal	100%	30.00 sec	27.50 sec	D	T	95%	102%
4	Other	106%	28.20 sec	26.30 sec	D	T	110%	115%
4	Max	128%	N/A	23.50 sec	D	T	120%	130%

Table B-2. Card Dealing Experiment Trial Data

"Overall our group successfully predicted on a consistent level of percentages. My predictions did not have any outliers that made my data vary too much from the actual time given. With consistent data, only one actual time was more than a second from the target time on the walking experiment. Also, on the dealing experiment, only on trial 3 my prediction was more than 5 percent deviation."

Appendix C. Lab Instructions: Performance Rating Qualification

This is an individual lab and allows you to qualify as a performance rater using the benchmark task dealing a deck of cards. If you qualify, I will provide you with an email as evidence that you did so which you may use on your resume. Also, if you qualify, you will be able to performance rate future time studies that may be used in doctoral research in our department. So please do your best and take the assignment seriously. On Canvas, you will find an Excel file with a list of 5 "Words" by your name. Also, you will be given a copy of a file "Card Dealing" (see screen shot below) which will be used for the qualification. Open the "Card Dealing" file. Use "Go to slide" and select the slide that corresponds to your first word. View the video clip of the first slide and rate the speed from 50% to 150% in 10% increments, after watching the entire deal. There are 2 different dealers pictured in the video clips, and it is possible that you will have 2 deals that are done at the same rate (though not from the same dealer). Make a note of your rating. Use "Go to slide" and select the slide that corresponds to your second word. View the slide and rate the speed from 50% to 150% by 10% and make a note of your rating. Continue until you have completed your 5 words. You may NOT re-view clips. Create an Excel File, put your name in Cell A1, then create 2 columns. The first column will be your 5 words and the second column will be your 5 corresponding ratings. Format appropriately. Submit this Excel file to Canvas before you leave the lab. Delete the "Card Dealing" file from your computer.

Students will be given three attempts to receive qualification as a performance rater. If you qualify on the first attempt, you will receive 100 points for the lab. If you qualify on the second attempt, you will receive 90 points. If you qualify on the third

attempt, you will receive 80 points. After three attempts, you will receive 70 points. Qualification tests cannot be given on the same day; after the first test, your GTA will schedule individually with you for your subsequent test.

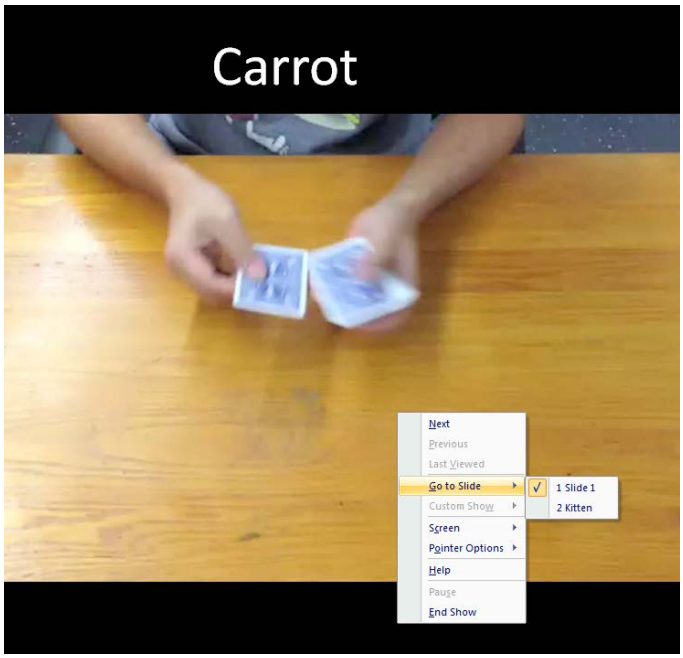

Figure C-1. Screenshot of “Carrot” Video

Words	Ratings
Folly	100
Sailboat	60
Antler	80
Sprinkle	120
Walrus	140

Table C-1. Student Submission of Completed Performance Rating Assignment