# Developing Empirical Donning Times for Smoke Hoods

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*Few studies exist that report donning times for personal fire escape masks (aka; smoke hoods). Methods Engineering and Work Measurement are sub-fields of Industrial Engineering that have established statistically based techniques to empirically develop standards for donning and doffing times, including those for PPE such as smoke hoods. Subjects were trained on the proper method to don a smoke hood and performed five trials in succession with a short rest period between trials. Performance raters independently rated each element for speed and consistency. Times were checked for outliers and normalized for standard development. For the studied hood, the donning time totaled 39.1 seconds. An independent validation using a predetermined time and motion system resulted in a donning time of 36.4 seconds. It is important for researchers to utilize statistically recognized techniques and include sufficient details when conducting and reporting time study research, particularly when it regards safety critical issues.*

**Keywords:** *Donning Times, Performance Rating, Smoke Hoods, Time Study, Work Measurement*

## Introduction

The manufacturer of the KIKAR XHZLC 60 Fire Escape Mask (Figure 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." Hence, smoke hoods are designed for adult single use, immediate emergency evacuation from fire conditions, without reentry, KIKAR (2015). Protection is provided for the head, eyes, and respiratory

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system against smoke, irritants, radiant heat, and toxic gases such as HCL, $SO_2$, HCN, and CO, for at least 60 minutes.

ASTM E2952-14 Standard Specification for Air-Purifying Respiratory Protective Smoke Escape Devices (RPED), ASTM (2014) and ANSI/ISEA 110-2009 the American National Standard for Air-Purifying Respiratory Protective Smoke Hood Escape Devices, ANSI/ISEA (2009) 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 a 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 an evaluator) in 30 seconds or less.

**Figure 1.** *KIKAR XHZLC 60 Fire Escape Mask (Package, Vacuum Sealed Bag, Mask)*


Others have suggested 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 Ed Galea, Galea (2014) 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 (1989) reports a similar timeframe when stating 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 states that "It takes 15 seconds to put on." Doheny (1995).

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, Khanna (2007). Two subjects, a male and a female, each donned five different smoke hoods following the ANSI/ISEA standard.

Of the ten reported trials, only one successfully met the 30 second requirement and correct donning criteria.

Methods Engineering and Work Measurement 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 time necessary to don a smoke hood (KIKAR XHZLC 60 Fire Escape Mask) according to the manufacturer's instructions.

## Method

Sixteen (N=16) college students, one from each lab group, aged 19-23 ($\bar{x}$ = 20.0, SD = 1.41) years were recruited to participate in a time study approved by the Auburn University (AL) 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 prior experience donning a smoke hood) subjects performed five (5) successive trials of donning the KIKAR XHZLC 60 Fire Escape Mask.

*Manufacturer Donning Instructions*

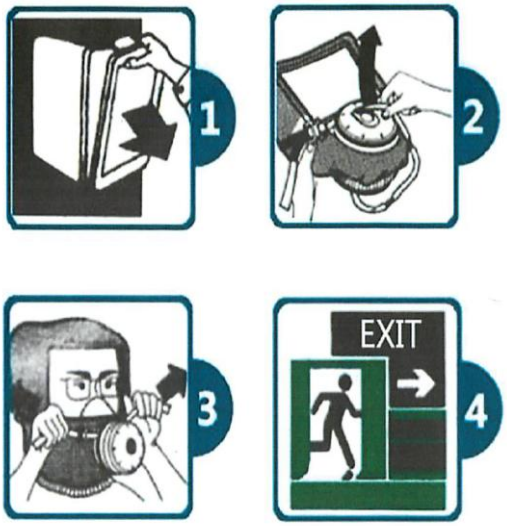
The manufacture provides the following **verbatim** "Operation Instructions" on the exterior of the protective storage box.

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 (very small font) are co-located by each of the pictograms (Figure 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 2.** *Manufacturer Donning Pictograms*




*Elements*

Trial (1) – Each subject stood in front of a table with a vacuum packed smoke hood (ready-to-use configuration) located inside a sealed box resting on the table. Subjects were instructed beforehand (verbally and by video) to:

a) 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 on the table.

b) 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.

c) Carefully unroll the smoke hood, remove the two plugs connected by a string (and put aside the filter plugs on the table), orient the smoke hood to be donned over the head, insert both hands into the neck seal to expand, 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 should slightly collapse against face when large breath is inhaled if proper seal was obtained).

Trials (2)→(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. Research teams consisted of a subject who donned the equipment each time, a timer, a video recorder, and at least two additional researchers who independently performance rated each element every trial. Data were tested for outliers before being analyzed.

*Performance Rating*

The sole task of two team (lab group) 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.

*Questionnaire*

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, Transport Canada (2011), 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.). Though individual subject dexterity could have a minor effect on the timing, no abstract (extraneous) motions were observed during the trials.

## Results

Table 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 2-5 for Element (c) [the average Trial (1) time of 33.65 seconds was identified as a statistical 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.

**Table 1.** *Results Summary Table (time in seconds)*

| **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 |

*Performance Ratings*

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, as a whole, authoritative sources such as, Niebel and Freivalds (2009), Myers and Stewart (2002), Aft (2000), Kanawaty (1992) suggest (imply) that an overall 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 or 30.5% (were identical ratings), 31 or 29.5% (were within 5%), 32 or 30.5% (were within 10%), and 10 ratings (9.5%) exceeded 10%.

*Questionnaire*

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"-16.5" ($\bar{x}$ = 14.9, SD = 1.02) 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.

*Learning Effect*

Five trials for Element (c) were conducted to ascertain if learning was occurring. The mean donning times for Element (c) in Trials (1) → (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.

*Validation*

Maynard Operation Sequence Technique (MOST), developed by Zandin (2001), 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 data table developed by Zandin. The MOST analysis (Figure 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 after multiplying by 10. MOST is based on 100% (normal) pace, so no performance rating is done. Element (a) consists of MOST steps 1-3. Element (b) consists of steps 4-6. Element (c) consists of steps 7-17. The MOST analysis for this particular smoke hood produced a standard time in seconds for elements a, b, and c of 3.60, 7.20, and 25.56, respectively. These are compared to the average times obtained in the time study of 3.98, 10.72, and 24.39 (mean for trials 2 → 5).

**Figure 3.** *MOST Analysis*

| MOST Calculation | | | Date: 5/8/2015<br>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 | | |
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| | | | | | |
| | Time in Seconds: 36.4 | | TMU: | | 1010 |

## Discussion

There are very few documented times pertaining to donning a smoke-hood (fire escape hood) in the literature. McFadden and Smith (1970) 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 & Smith (1970). The learning effect was most noticeable between trials (1) and (2). This was not unexpected being the subjects were unable to practice (handle) the device before the first trial. Trials 2 → 5 of Element (c) were remarkably consistent with the mean being 24.39, and the STDEV 0.56. This suggests that viewing a demonstration video numerous (three) times and donning the hood one time for

practice has the potential to provide a meaningful impact on subsequent donning time.

## Limitations

The following study limitations are acknowledged:

1) Only one smoke hood, a KIKAR XHZLC 60 Fire Escape Mask, was used in the study.
2) Subjects donned the smoke hood in the ready-to-use configuration supplied by the manufacturer, which include the protective 'outer box'.
3) No level of subject concern or fear was present during the laboratory testing.
4) The manufacturer's donning instructions were not consistent between the two different locations on the protective 'outer box'.

## Conclusions

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. 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.
2) For this particular hood, a pronounced learning effect occurred between the first and second donning trials emphasizing the need for effective safety briefings/practice.
3) The standard donning time of 39.1 seconds is **solely applicable** to the KIKAR XHZLC 60 Fire Escape Mask. It is reasonable to expect that smoke hoods with more simplistic designs, may quite possibly take less time for subjects to correctly don.

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## References

Aft, L. (2000) *Work Measurement and Methods Improvement*. John Wiley and Sons, Inc., New York, USA.

Doheny, K. (1995) *Do Smoke Hoods Improve Safety?* Available from: http://articles.latimes.com/print/1995-02-26/travel. [Accessed: 2014].

Galea, E. Available from: http://fseg.gre.ac.uk/fire/fire_safety_tips.html. [Accessed: 2014].

Kanawaty, G. (ed.) (1992) *Introduction to Work Study*. 4th (revised) Ed. International Labour Office (ILO), Geneva.

Khanna, R. (2007) *Evaluation of Consumer Personal Protective Equipment: EMERGENCY ESCAPE MASKS*. US Consumer Product Safety Commission. Available from: www.usfa.fema.gov/.../pdf/escape-masks-human-factors.pdf. [Accessed: 2014].

KIKAR XHZLC 60 Fire Escape Mask. Purchased from Amazon.Com (2015).

McFadden, E. and Smith, R. (1970) *Protective Smoke Hood Study*. Available upon request from FAA. [Accessed: 5 November 2014].

Myers, F. and Stewart, F. (2002) *Motion and Time Study for Lean Manufacturing*. 3rd Ed. Prentice Hall, Upper Saddle River, New Jersey, USA.

Niebel, B. and Freivalds, A. (2009) *Methods, Standards & Work Design*. 12th Ed. McGraw-Hill, New York, USA.

Transport Canada (2011) *The Effect of Beards or Long Hair on the Efficiency of Demand Type, Continuous Flow Oxygen Masks, or Smoke Hoods*. Advisory Circular (No. 0185). Available from: https://www.tc.gc.ca/eng/civilaviation/standards/commerce-circulars-ac0185-1752.htm. [Accessed: 1 March 2015].

USA. ANSI/ISEA 110-2009 *American National Standard for Air-Purifying Respiratory Protective Smoke Hood Escape Devices*.

USA. ASTM E2952-14 *Standard Specification for Air-Purifying Respiratory Protective Smoke Escape Devices (RPED).*

Vant, JHB (1989). "Smoke Hoods Donned Quickly – The Impact of Donning Smoke Hoods on Evacuation Times." In Advisory Group for Aerospace Research and Development (AGARD) Conference Proceedings No. 467: Aircraft Fire Safety. Neuilly Sur Seine, France: NATO.

Zandin, K. (2001) *Maynard's Industrial Engineering Handbook*. 5th Ed. McGraw-Hill, New York, USA.