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E-PiPEline: Quick to Market Emulated-PPE using Commonly Available Materials

Grant A. Rossman
Isaac C. Avina
Bradley A. Steinfeldt

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1. OVERVIEW AND APPROACH

1.1. Overview

The Center for Disease Control has recommended the public to wear cloth face coverings in public settings that reduce potential exposure to COVID-19 where other social distancing measures are difficult to maintain (e.g., grocery stores and pharmacies) especially in areas of significant community-based transmission. These face coverings and other Emulated-Personal Protective Equipment (E-PPE) can be made by using Commonly Available Materials (CAMs). As part of the Sandia COVID-19 LDRD effort (funded under the Materials Science Investment Area), the Sandia E-PiPEline task evaluated E-PPE design options for face coverings and face shields considering their effectiveness, durability, build difficulty, build cost, and comfort. Observations from this investigation are presented here to provide guidelines for home construction of E-PPE. This executive summary includes a brief roadmap of the analysis methodology, two one-page handouts geared to be distributed to the public at large (one for E-PPE face coverings and one for E-PPE face shields), and additional observations regarding the potential solutions for E-PPE face coverings and face shields included to further support the one-page handouts.

1.2. Methodology

Analysis methodology techniques that are transparent and defensible were used to provide an analytic framework that articulates the design options, enumerates the assumptions, and provides a semi-quantitative assessment of the alternatives while providing a clear linkage between analysis steps. The methodology employed followed the following steps:

1. Understand Design Alternatives in the Literature
2. Define the Design Space Identifying Design Characteristics and Options
3. Enumerate the Alternative Designs
4. Develop Evaluation Metrics and Scoring Rubrics
5. Score Alternative Designs
6. Analyze Design Space for Trends and Develop Recommendations

1.3. Face Covering Design Space

A large design space was examined for the face coverings (over 200,000 design combinations) using a systematic process. This design space includes the following design options

Number of Layers: 1, 2, or 3
Mask Material in Each Layer: (1) Tight Non-Woven Hydrophilic Coated Polypropylene Based, (2), Non-Woven Polypropylene Based, (3) Non-Woven Polypropylene/Polyester Blend Based, (4) Lignocellulosic Based; (5) Non Woven Cohesive Polyester/Elastomer Blend Based; (6) Woven Cotton Based <600 Thread Count Based; or (7) Tight Woven Cotton Based >600 Thread Count Based
Layer Connection Location: Around Edge, Around Edges and Center, or None
Layer Connection Mechanism: Staple, Glue, Sew, Friction, or None
Strap Attachment Material: Same as Layer 1, Same as Layer 2, Same as Layer 3, Elastic Band, Tourniquet Band, Velcro Straps, Rubber Band, Cohesive Bandage, or Latex Gloves
Strap Attachment Mechanism: Staple, Glue, Sew, Tape, Compression, or Integrated

1.4. Face Shield Design Space

The face shield design space (900 design combinations) using a systematic process includes the following design options

- **Shield Material**: Cellulose Acetate, Polypropylene & Vinyl, Polyethylene Terephthalate, Polypropylene, or Polyester
- **Structure**: Foam, Safety Glasses, Velcro Straps, Cardboard, Tongue Depressor, or Rolled Paper
- **Strap Attachment Material**: Rubber Band, Cotton Fabric, Velcro Straps, Cohesive Bandage, Elastic Band, or Latex Gloves
- **Strap Attachment Mechanism**: Staple, Glue, Sew, Tape, or Compression

2. ONE-PAGE HANDOUTS

2.1. Emulated Personal Protective Equipment Face Coverings

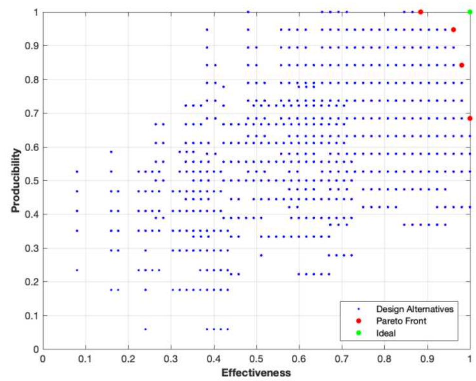
See Page 7 for the one-page handout developed describing Observations Regarding Commonly Available Materials for Face Covering Emulated-Personal Protective Equipment.

2.2. Emulated Personal Protective Equipment Face Shields

See Page 8 for the one-page handout developed describing Observations Regarding Commonly Available Materials for Face Shield Emulated-Personal Protective Equipment.

Observations Regarding Commonly Available Materials for Face Covering Emulated-Personal Protective Equipment

The Center for Disease Control has recommended that to reduce potential exposure to COVID-19 the public should wear cloth face coverings in public settings where other social distancing measures are difficult to maintain[1]. These face coverings and other Emulated-Personal Protective Equipment (E-PPE) can be made by using Commonly Available Materials (CAMs). As E-PPE recommendations continue to flood the media, a Sandia COVID-19 LDRD effort, the Sandia E-PiPEline Team, evaluated E-PPE design options considering their effectiveness, durability, build difficulty, build cost, and comfort. Using qualitative and semi-quantitative evaluation tools, results of the investigation are presented here to provide guidelines for home and office construction of E-PPE.



DESIGN SPACE

The principle design characteristics and alternatives considered for the construction of an E-PPE face covering are listed below.

Number and materials of material layers: 1-3 layers, woven cotton materials, paper-based materials, synthetic fabrics

Connection method and location between layers: sewn, glued, stapled

Treatments of the top layer: machine wash, bake in oven, iron, machine dry

Attachment methods: integrated designs, compression straps, Velcro straps

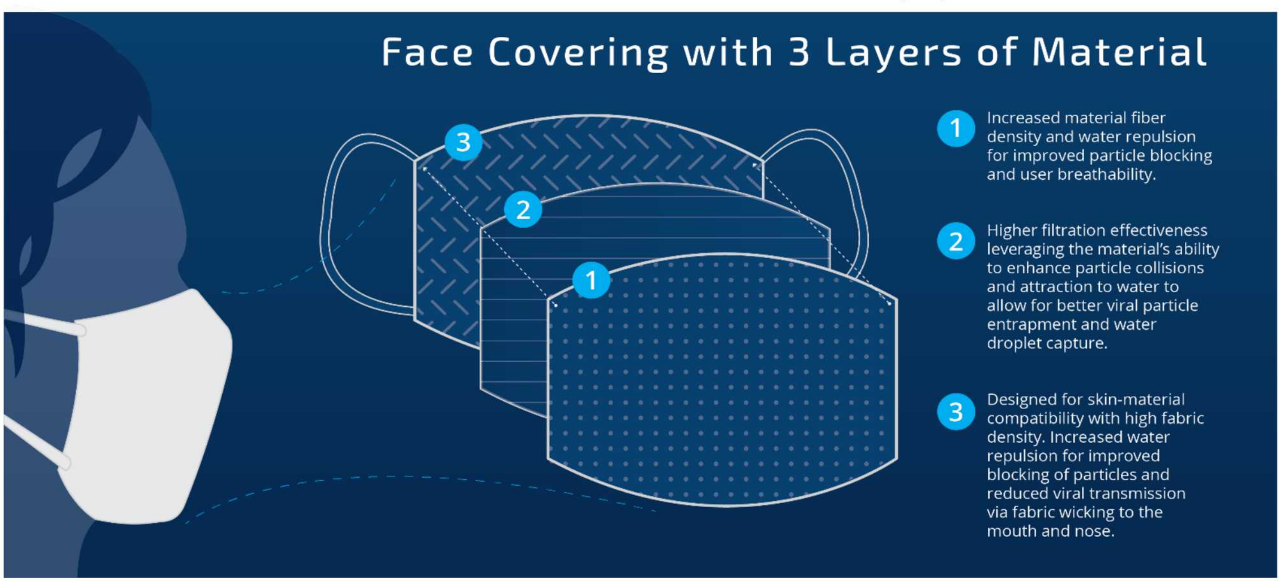
The graphic at top illustrates the scores of the more than 200,000 designs evaluated for face coverings using CAMs. The normalized design scores are shown in blue, with the best options shown in red.

MATERIAL OBSERVATIONS

- Leverage cotton and paper-based materials to capture aerosolized water droplets within the fiber matrix
- The material placement of natural-based materials sandwiched between two water repelling synthetic based materials decreasing the probability of viral transmission by decreasing liquid movement towards the face
- Select materials with high fabric density to improve particle filtration while maintaining user breathability
- Prioritize user safety by selecting materials that reduce loose material particle inhalation hazards

DESIGN OBSERVATIONS

- Full coverage over mouth and nose reduces chance of viral transmission
- Mask conformability improves filtration effectiveness



[1] https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/cloth-face-cover.html

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Observations Regarding Commonly Available Materials for Face Shield Emulated-Personal Protective Equipment

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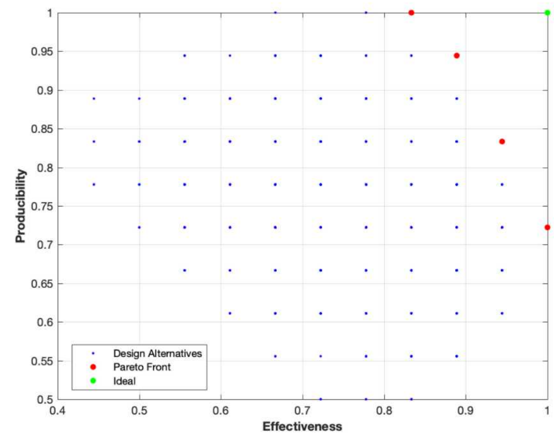
The Center for Disease Control has recommended that to reduce potential exposure to COVID-19 the public should wear cloth face coverings in public settings where other social distancing measures are difficult to maintain[1]. These face coverings and other Emulated-Personal Protective Equipment (E-PPE) can be made by using Commonly Available Materials (CAMs). As E-PPE recommendations continue to flood the media, a Sandia COVID-19 LDRD effort, the Sandia E-PiPEline Team, evaluated E-PPE design options considering their effectiveness, durability, build difficulty, build cost, and comfort. Using qualitative and semi-quantitative evaluation tools, results of the investigation are presented here to provide guidelines for home and office construction of E-PPE.



DESIGN SPACE

The principle design variables considered for the construction of E-PPE face shield were:

Primary shield material: polyethylene, polypropylene, cellulose acetate

Structural material: foams, safety glasses, cardboard, wood

Attachment methods: sewn, glued, stapled

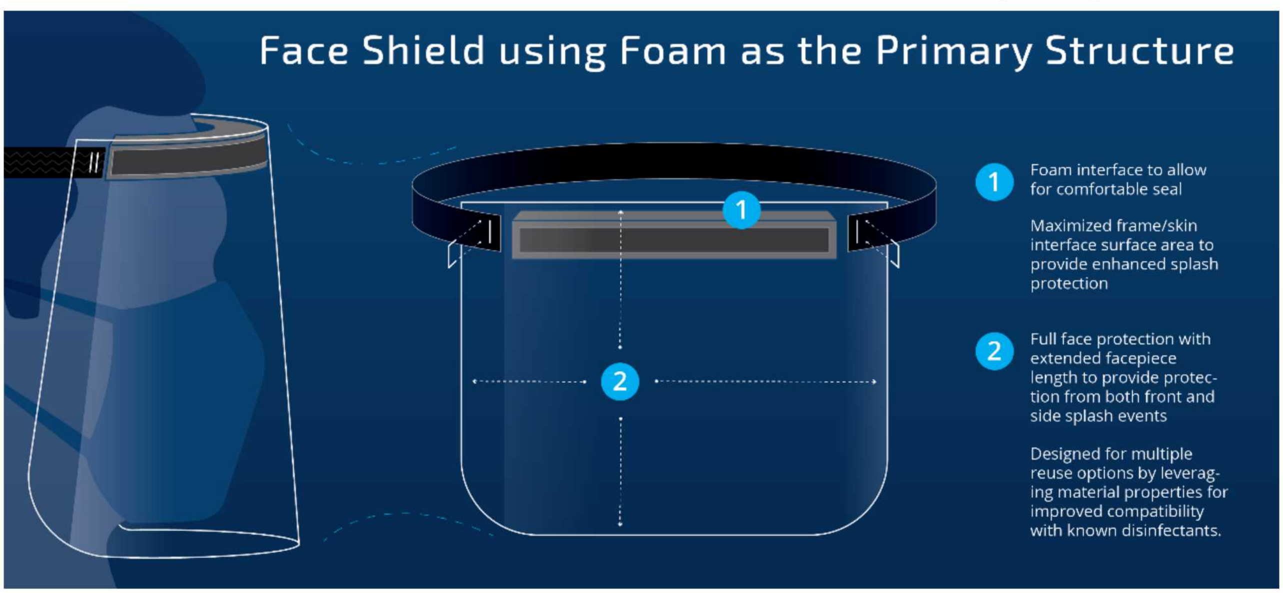
The graphic at top illustrates the scores of the more than 900 designs evaluated for face shields using CAMs. The normalized design scores are shown in blue, with the best options shown in red.

MATERIAL OBSERVATIONS

- Using foam as the primary frame/face interface material provides an effective splash protection
- For reuse of the face shield, choosing materials that are compatible with solvents like polypropylene

DESIGN OBSERVATIONS

- Minimizing the gap between the face shield and the forehead will help to reduce the chance of viral transmission via liquid splash to the eyes
- It is important that the face shield extended down past the nose and mouth and stretch around the full-face area
- Designs that use compression to attach the face shield to the face were observed to be promising



[1] https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/cloth-face-cover.html

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3. ANALYSIS OBSERVATIONS

3.1. Face Covering Material and Design Observations

3.1.1. Observations

The following observations from the data in the E-PiPEline study were made for the face covering:

- Leverage cotton and paper-based materials to capture aerosolized water droplets within the fiber matrix.
- The material placement of natural-based water absorbent materials sandwiched between two water repelling synthetic based materials decreasing the probability of viral transmission by decreasing liquid movement towards the face.
- Select materials with high fabric density to improve particle filtration while maintaining user breathability.
- Prioritize user safety by selecting materials that reduce loose material particle inhalation hazards.
- Full coverage over mouth and nose reduces chance of viral transmission.
- Mask conformability improves filtration effectiveness.

It was observed that the more layers the better. Assuming a three-layer face covering the following observations regarding the selection of materials for each layer:

For the *layer furthest from the mouth*, one should increase inertial impaction factor by maximizing fabric fiber density. This will increase probability of blocking aerosolized viral particles. Selecting first layer materials that have a **low water absorption** may also reduce water saturation and increase mask durability and breathability.

The *middle layer* should be designed for material interchangeability. Using **non-woven fabrics with high fiber density** will increases filtration effectiveness by providing a tortuous path for particles resulting in increased particle collision and wandering paths as well as overall particle entrapment in the middle layer. Materials with increased water absorbance provide a matrix for aerosolized liquid water capture. Additionally, the middle layer should have design features that allow for material interchange after high particle loading and water saturation which can reduce filtration effectiveness and user breathability.

The *layer closest to the mouth* should be designed for mouth and nose interface compatibility and with **high water repelling properties**. Select materials with a **high fiber density**. Do not select loose materials or weaves to prevent inhalation of material borne particles. By choosing these materials the user can reduce the chance of viral transmission via water wicking to the mouth and nose.

3.1.2. Using the Observations for Practical Steps to Materials Selection for Face Coverings

The following are steps to interpret, evaluate, and use the observations provided in the design and creation of a face covering.

1. Understand the material's fiber parameters. Categorize your materials based on whether base fibers are synthetic or natural and if the fibers are small or large in diameter. Synthetic fibers

are usually stronger and more durable for longer use situations as well as usually maintain a low water absorption while small fibers usually indicate a high fiber density.

2. Determine if the material stretches when pulled indicating a knitted or loose weave structure or if conversely the fabric is very stable under tension indicating an increase in fiber density with a non-woven or tight weave structure. Choose materials with a high fiber density that will maintain their shape when put under tension.
3. Determine if the fabric has any coatings, ink, or other surface treatment. A quick way of determining this is simply testing the fabric under water and check if water is repelled or absorbed by the material. Additionally, check if the treatment is applied to one or both sides of the material. With the understanding that the water absorbing material faces should point away and from the mouth or nose and placed further away from the mouth. This will minimize water wicking towards the mouth and nose interface of the mask.

3.1.3. Material Observations

Table 3-1 provides an assortment of the materials examined in this study for the face coverings, some observations regarding these materials, and some observations regarding the location in the design of a face covering.

Table 3-1. Practical Description of Materials, Observations, and Locations

Material Types	Examples	Water Saturation Potential	Face Coverings Observations	Highest Scored Face Covering Layer
Cotton with High Fiber Density	Pillowcases, flannel, high tread count clothing	Medium	Easy to wash, absorbent, fairly durable, high fabric density.	Layer closest and furthest from the mouth
Cotton with Medium to Low Fiber Density	Shirts, bandanas, woven gauze, scarfs	Medium	Easy to wash, absorbent, fairly durable, low fabric density	Middle Layer
Polypropylene	Professional/shop towels, Haylard surgical wraps, medical grade fabrics.	Very Low	Low water absorption, high fabric density, very durable	Layer closest and furthest from the mouth
Polyester Blends	Surgical masks, general shop towels, non-woven gauze, sports and performance apparel	Low	Low water absorption, high fabric density, dries quickly, durable	Layer closest and furthest from the mouth
Paper Based	Coffee filters, paper towels, stretcher tissue paper	High	High water absorption, varying degree of fabric density	Middle Layer

3.2. Face Shield Material and Design Observations

The following observations were made from the analysis of the data regarding materials for the face shield.

- The most highly scored options used a foam as the primary frame/face interface material to provide the most effective liquid splash protection
- For reuse of the face shield, choosing materials that are compatible with solvents like polypropylene is crucial.

The following observations were made from the data regarding the design for the face shield.

- Minimizing the gap between the face shield and the forehead will help to reduce the chance of viral transmission via liquid splash to the eyes.
- It is critical that the face shield extended down past the nose and mouth and stretch around the full-face area allowing for complete splash protection.
- Designs that use compression to attach the face shield to the face scored well, while designs requiring sewing performed poorly due to construction time.

From a design perspective, for the skin to frame interface, it is desired to maximize frame/skin interface surface area to provide enhanced splash protection along with foam interface to allow for comfortable seal. For the location of the window, it is desirable for full face protection with extended facepiece length to provide protection from both front and side splash events. Design for multiple reuse options by leveraging material properties for improved compatibility with known disinfects and solvents.