Easy to Produce and Low-Cost Ergonomics Full-Face Mask Design Against Airborne Transmission

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Abstract
A new variant of the coronavirus known as Covid-19 was declared as a global pandemic virus at the end of 2019. The spread of a virus's outbreak can occur in various ways, such as contact with an infected person through droplets. The nature of the virus, which is easily transmitted between people, will exacerbate the spread of Covid-19. The shortage of mask supplies has happened globally, and the price of the mask became costly. Surgical masks or cloth masks are the minimum personal protective equipment recommended by the authorities to control the spread of diseases in many countries. The surgical masks or cloth masks or even the N95 type of mask still have the vulnerability in an environment with the potential for airborne spread of viruses. The safer and more effective personal protection equipment (PPE) against possible airborne transmission of the virus is the full-face mask equipped with an air filter. Unfortunately, providing the full-face mask during the pandemic, especially at the beginning of the pandemic, was not possible since its complexity and made the price expensive. This study aims to share our design and experiment of a full-face mask as a PPE for mitigating virus transmission. There are three aspects in designing a full-face mask, i.e., ergonomics design, availability of materials, and ease to produce. Anthropometric dimensions of the face are applied in designing product sizes to fit with the user size. The full-face mask design creates two segments of the mask, namely the mouth and nose segment and eye segment. A rapid prototype has been applied to design the mask's mold using 3D printing and resin solid casting. The mask's primary materials must accommodate the two requirements, i.e., easy to get and low-cost material. The required materials to produce a full-face mask are PVC plastic sheet (3mm), rubber seal, and air valve or filter. The vacuum forming production concept is the most applicable to create a mask easy to produce and in a short cycle time. A full-face mask prototyping has been created in our study and offered the alternative of PPE to protect people from virus transmission. Future development of our mask design might be considered the PPE rapidly with a low selling price.

Keywords
Full-Face Mask, Vacuum Forming, Ergonomics Design, Product Design.

1. Introduction
Pandemic diseases caused by animal-borne or human-borne viruses have had a major effect on human life. More than 40 million human deaths were caused by the influenza pandemic (H1N1) between 1981 and 1919. Some viruses are designated by the WHO as global pandemic viruses, which means that they can spread over a large region and become a threat to all countries across the world (WHO, 2020). SARS (2003), MERS-COv (2012), and Ebola are several other virus outbreaks designated by WHO as viruses of global pandemics (2013). The Case Fatality Rate (CFR) is a calculation of the disease-caused impact of death, the greater the CFR rating, the more significant the human impact of death. The Ebola virus has a CFR of between 83%-90% to be classified as a virus with a very high impact on mortality (WHO, 2020).

A new coronavirus variant called COVID-19 was declared as the global pandemic virus at the end of 2019. Covid-19 cases first appeared in Wuhan, China, and have spread across the world quite rapidly. COVID-19 has been contracted by almost all nations, as shown in Figure 1. As of February 2021, more than 105 million people have been exposed by Covid-19, and more than 2 million people in different countries have died (WHO, World Health Organization, 2020). Indonesia, which was officially the first confirmed case on March 2021, was also struck by COVID-19. The spread of Indonesia is relatively high with a CFR rate of 2.7%. Therefore, it requires support for effective and creative actions to take advantage of various limitations.
In various ways, the spread of an outbreak can occur because they have contacted with an infected person through droplets (respiratory fluids) when a person coughs or sneezes, saliva and sweat (Soma et al., 2020). Transmission of nanometer-scale virus outbreaks from humans to humans might be by droplet or even via aerosol (Atangana & Atangana, 2020). The application of health protocols by limiting the distance between people becomes mandatory and practical to be applied. In addition, the use of masks to everyone is also effective to reduce the risk of exposure to the virus. The possibility of spreading the virus by airborne strengthens the importance of wearing masks. Closing the entryways through the nose and mouth can prevent a person from being exposed to the virus. By protecting the mouth and nose as virus entry points and by using personal protection such as a face mask, the spread of the virus will be reduced (Atangana & Atangana, 2020).

The required for PPE becomes essential in the situations of Covid-19 virus spreading that are very difficult to detect, have long-lasting ability and can spread very quickly. In preventing the spread of Covid-19, WHO has published the importance of wearing masks during activities outside the home. The demand for masks as the most practical PPE soared very high during the pandemic outbreak in a region. The shortage of mask supplies is becoming increasingly large and expensive. In the early period of Covid-19 distribution in various countries, many victims were affected due to the lack of PPE supply. The ability and flexibility of companies capable of producing PPE is quite limited, thus it takes a long time to normalize the supply (Wu, Huang, Zhang, He, & Ming, 2020).

Surgical masks or cloth masks are minimal PPE recommended by the authorities to overcome disease spread in many countries due to the unanimity of highly efficient masks such as type N95 (Chaabna, Doraiswamy, Mamtani, & Cheema, 2020). Whereas surgical masks or cloth masks and masks other than N95 can filter viruses such as Covid-19, which is smaller than 40% (Bowen, 2010). The facial mask still has some vulnerability to protect users while the viruses spread by air in an environment. Due to the presence of air gaps, the use of face shields with masks still provides opportunities for transmission of the virus to the human body. Using a full-face mask fitted with an air filter is the safest protection in the face of possible transmission of viruses through the air (Bowen, 2010).

The threat of virus spread through humans and with high CFR is an insensible possibility. If the virus with the speed of spread such as Covid-19 and CFR is equivalent to Ebola, severe impacts will occur in various parts of the world. Personal protective equipment becomes a critical need to avoid the transmission of deadly viruses. It requires personal protective equipment that is 100% capable of warding off viruses entering the human body. As the consequence of this condition, the PPE have to be produce quickly and easily to overcome and minimize the Covid-19 virus spreading. Moreover, the PPE should be comfortable to use for a long duration (Matioc, 2009). The opportunity to design PPE which able to protect humans from virus spreading and easily produced during pandemic is essential.
This research's main objective is to design a full-face mask as PPE during an airborne virus outbreak or human-to-human transmission. This study also developed a full-face mask prototype with vacuum forming technology oriented towards a forming tool that is easy to produce and low-cost production. This research consisted of 2 main stages: the full-face mask design stage and the full-face mask forming tool. The findings of this research could be an important parameter to develop full face mask to enhance the effectiveness of PPE to prevent Covid-19 virus.

2. Literature Review

2.1. Thermoforming

Thermoforming is a method of forming a product by heating and deforming a thin thermoplastic sheet (Groover, 2013). The main phase in thermoforming is heating the thermoplastic sheet for bending and shaping according to the mold. This method is widely used in consumer goods, packaging, and products with a simple form. The thermoforming method can be classified into three categories, those are vacuum thermoforming, pressure thermoforming, and mechanical thermoforming (Groover, 2013).

Vacuum thermoforming applies negative pressure to pull the heated sheet into the mold cavity (concave cavity) (Groover, 2013). The general vacuum thermoforming steps involve heating a flat plastic sheet to soften it; placement of a soft plastic sheet over the hollow mold cavity; the process of drawing the sheet into the cavity by sucking air; the plastic hardens and is removed from the mold (Yam, 2009). The pressure thermoforming stage is similar to vacuum forming. Pressure thermoforming uses the concept of positive pressure to force the heated plastic into the mold cavity (convex shape). Ventilation holes are provided in the mold to remove trapped air. The mechanical thermoforming process uses positive and negative molds simultaneously to press the heated plastic sheet to the shape of the product. Mechanical thermoforming does not use suction or air pressure because it applies mechanical pressure between the 2 designed molds. Visually, the various types of thermoforming are described in figure 2.

![Thermoforming Diagram](image)

Figure 2. Illustration of vacuum thermoforming (a) the plastic sheet is flexed using a heater with a certain temperature and duration (b) press and point the plastic sheet into the mold cavity (b) the air vacuum will suck and pull the plastic sheet according to the mold surface (c) The plastic sheet that has been flexed is lowered and pressed with a clamp to fit the shape of the positive (convex) mold and the plastic sheet will be pulled by the air vacuum straw to the mold surface.(Groover, 2013)

2.2. Anthropometry

Anthropometry is a study that measures the dimensions of the human body, including muscles and bones, to design tools and workstations to be more effective and comfortable. Anthropometry includes various measurements of the human body such as body weight, position when standing, when stretching arms, body circumference, leg length, etc. (Kroemer, 2016). Anthropometric data can be applied for many purposes, such as designing workstations, work facilities, and product design to obtain appropriate and proper sizes for humans' dimensions. The anthropometric design will provide a comfortable, comfortable, safe, and healthy condition for humans and create efficient working conditions with effective results to achieve an ergonomic state (Helander, 2006).

The human body's dimension variation is one aspect of design have to consider getting the fit design from the user. Designing a product or workstation that does not conform to specific standard dimensions will result in discomfort and even cause injury. Anthropometry is applied in the design of workstations, work facilities, and product design to obtain appropriate and proper sizes for the dimensions of the human limb used (Bridger, 2018). According to
Anthropometric measurements, designing physical dimensions will result in more comfortable and safer products so that they can increase work effectiveness. Anthropometry considers designs that are oriented towards easy access to controls and input devices.

Anthropometric data for the Indonesian population may refer to the Indonesian anthropometry data (www.antropometriindonesia.org). Standards of dimension measurement techniques, and dynamic dimension references are provided entirely and applicable for product and workstation design. The Indonesia anthropometry data has processed measurement samples from various ethnic groups in Indonesia and a specific age range and follows data processing standards according to scientific principles. The head or face dimensions are not yet available in anthropometriindonesia.org, so this study uses data collected from the Ergonomics laboratory of ITS. Anthropometric data for head dimensions is a collection for the years 2019-2020 with a total data of 334 people. The anthropometric data of the head dimensions are presented in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>ALL 334</th>
<th>MALE 142</th>
<th>FEMALE 192</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Standard Deviation</td>
<td>95 Percentile</td>
</tr>
<tr>
<td>Head Length</td>
<td>19.19</td>
<td>2.09</td>
<td>22.64</td>
</tr>
<tr>
<td>Head Height</td>
<td>22.26</td>
<td>2.33</td>
<td>26.10</td>
</tr>
<tr>
<td>Head breadth</td>
<td>16.68</td>
<td>2.63</td>
<td>21.03</td>
</tr>
<tr>
<td>Lower face length</td>
<td>7.27</td>
<td>2.25</td>
<td>10.97</td>
</tr>
<tr>
<td>Lip width</td>
<td>5.88</td>
<td>1.61</td>
<td>8.53</td>
</tr>
</tbody>
</table>

Table 1. Head anthropometry (measurement unit in cm) (Ergonomic Labs, 2020)

3. Methodology

The study of full-face product and tool follows the general stages of product design. The main stages were divided into two parts, namely, the full-face mask prototyping and the vacuum forming tool design. In sequence, the design stages follow these following steps:

- Designing the product/tool concept
- Determining the dimensions of the product/tool size
- Modeling the product/tool concept (engineering drawing and 3D models)
- Making mockup designs (prototyping)
- Testing the product/tool

For the full-face product development, a customer voice survey has not conducted but a specific interview to get the user experience applied and the benchmarking with similar products to compare several prospected features.

The main objective of the full-face mask utilizes materials which available in emergency situations, such as when a disease pandemic occurs. The thermoforming method was chosen because it was in accordance with the availability of the main material for the full-face mask, namely the thin plastic-type PVC (Polyvinyl chloride) with a thickness of 3mm to 5mm. This thin PVS plastic material is known as "plastic mica" in the local language and widely available in building shops or stationery shops at affordable prices. Vacuum forming using positive molds was chosen to perform the thermoforming method. The design of the vacuum forming tool was easy to apply and it can use a mold that was easy to design and print.

The full-face mask design and vacuum forming tool consider the anthropometric dimensions to determine the detailed size of the product and tool. The determination of the vacuum forming tool size considered the reference dimensions on anthropometriindonesia.org. Meanwhile, the full-face mask size refers to the head / facial anthropometric data collection from the Ergonomics and Work System Design laboratory shown in figure 3. Mockup of the full-face mask was designed with 3D model and printed using a 3D printing machine. The mockup will be a product master in mold making. The mold was made using a resin material because it was easy to form and...
hard sufficient to use as a mold. The trial phase of full-face mask run while the mold and vacuum forming tool were ready to make the testing product. Product testing was run by inspecting the quality of formed mask includes the suitability of shape, size, and the thickness. Furthermore, the mold's quality required to be evaluated to obtain the master mold matches with the expected standard of product.

4. Results

4.1. Vacuum Forming Machine Design

The full-face mask forming tool was designed using a simple thermal forming concept by forming a thin plastic material in a face mask's mold. This tool's product forming mechanism was to heat the shape material to make it flexible and then shape it into a mold with intense air pressure and suction. The process of forming masks with a vacuum forming machine was quite fast, approximately 3 minutes per product, and can use widely available materials in building or stationery stores.

![Vacuum forming tool design](image)

Figure 3. Vacuum forming tool design

The vacuum forming tool design has considered the posture and dimensions of the human body in determining the shape and size of the tool. This forming tool was designed to be easily accessible to the user, does not result in a bending work posture, and considers the gravity factor for ease of operation of the tool. Figure 3 was depicted the vacuum forming tool design. The vacuum forming tool has three parts: heating insulation, mold base, and air suction chamber. The materials used in the tool's manufacture were multi-plex, frame wood, heater and control panel, and an air suction device. Vacuum forming tools used readily available materials, and an ordinary craftsman can do the process of making tools. The primary process in making vacuum forming tools was simply cutting and assembling wood materials. The estimated time to manufacture the forming tool was approximately two days.

The main dimensions of the vacuum forming tool refer to Indonesian anthropometric standards. Dimension adjustment used the average size to cover the reach of users and all genders evenly. The tool's dimensions were determined by referring to the anthropometric measure as height, the height of the moulding base, width, and height of clamer on the heating position. Other detailed sizes of the tools were proportionally adjusted and followed the
moulding base's dimensions, 30cm x 30cm. Table 2 shows a breakdown of tool sizes that refer to anthropometric data.

Table 2. Several dimensions of vacuum forming tool that refers to anthropometry data (PEI, 2010)

<table>
<thead>
<tr>
<th>Vacuum Forming Tool’s Dimension</th>
<th>Anthropometry Dimension</th>
<th>Length (cm)</th>
<th>Adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total height</td>
<td>Standing eye height (D2)</td>
<td>147.38</td>
<td>Average: Female, percentile 50, +2cm</td>
</tr>
<tr>
<td>Height of molding base</td>
<td>Standing elbow height (D4)</td>
<td>100.36</td>
<td>Average: Female, percentile 50, +2cm</td>
</tr>
<tr>
<td>Total Width</td>
<td>Inter elbow span (D33)</td>
<td>83.69</td>
<td>Average: Female, percentile 50</td>
</tr>
<tr>
<td>Height of clamper on heating position</td>
<td>Standing shoulder height (D3)</td>
<td>131.78</td>
<td>Average: Female, percentile 50, +2cm</td>
</tr>
</tbody>
</table>

4.2. Full Mask Design

The primary function of the full-face mask product designed in this study was to protect the user from exposure of external particles. Specifically, the full-face mask can protect the user from exposure to the spread of viruses in free air. The full face mask must able to cover all the existing faces and gaps. The full-face mask was designed to cover all parts of the user's face. The full face mask's design has considered the dimensions of the face, which refers to anthropometry's standard dimensions.

This research has designed and tested the initial full face mask prototype. The initial or first prototype aims to get the fastest, easiest, and cheapest master print design method. In the early stages of designing the mold of mask, the research team has used plasticine and resin moulding techniques but the mould's shape was difficult to resemble the product master, and the mould size was not precise. Figure 4 shows the full face mask design, which was referred to as the initial prototype. Moulds were processed using a master mould from 3D printing, resulting in more precise mould dimensions. The use of resin is recommended to produce a stronger and more practical mould quality.

One of the deficiencies of existing full-face masks is the presence of fog or dew in the area of vision that comes from blowing air from the nose or mouth. Fog or dew when using a full-face mask can disturb the user's vision. The 2-segment mask concept was applied in our full-face mask design to separate the breathing area from the visual area. The first segment, named as mouth and nose segment, was the respiratory area. The second segment, named as eye segment, was the area of vision. Those two segments were designed separately with a rubber seal to meet the user's requirement to avoid the inhalation vapor.

Prototype full-face mask designed for users of all genders and largest size. Product dimensions were determined according to anthropometry's size especially the height mask, mask breadth, height of the first segment, the breadth of the 1st segment and the strap length. Details of product dimensions are shown in table 3. Size of the full-face mask can be customized based on small, medium, large, and can also be adapted to the child's size. Customization size of the full-face mask can refer to www.antropometryindonesia.org already accommodate some level of product size.
A mockup of full-face mask is shown in figure 5. Making the mold using a product mockup produces a more precise mold in shape and size. Mold was formed using resin as the primary material and required a hardening time of more than 2x24 hours. The use of resin as a raw material for mold was relatively cheap, easy to purchase, and easy to apply.

Table 3. Full-face mask’s dimension that refers to facial anthropometry (Ergonomic Labs, 2020)

<table>
<thead>
<tr>
<th>Mask’s Dimension</th>
<th>Anthropometry Dimension</th>
<th>Length (cm)</th>
<th>Adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strep length</td>
<td>Head Length</td>
<td>22.64</td>
<td>Maximum, All Gender, Percentile 95</td>
</tr>
<tr>
<td>Mask height</td>
<td>Head Height</td>
<td>26.10</td>
<td>Maximum, All Gender, Percentile 95</td>
</tr>
<tr>
<td>Mask breadth</td>
<td>Head breadth</td>
<td>21.03</td>
<td>Maximum, All Gender, Percentile 95</td>
</tr>
<tr>
<td>Height of 1st segment (mouth cover)</td>
<td>Lower face length</td>
<td>10.97</td>
<td>Maximum, All Gender, Percentile 95</td>
</tr>
<tr>
<td>Breadth of 1st segment</td>
<td>Lip width</td>
<td>8.53</td>
<td>Maximum, All Gender, Percentile 95</td>
</tr>
</tbody>
</table>

The process to form a full face mask begins with preparing the plastic sheet on the clamp. It must be ensured that the plastic sheet was installed and clamped so that there was no bending of the material during the forming process. The mica installed was placed on the moulding area and then raised to the heating bulkhead to approach the heater. Set the temperature to be achieved, which depends on the thickness of the mica material. The plastic sheet material's condition must be inspected intensively during the heating process. When the plastic sheet becomes flexed, then the clamp must be lower immediately to the mould. Press the insulation material so that the flexible mica follows the mould shape. Forming a full face mask that fits the mould will be accelerated and assisted by the sediment of air in the vacuum process. The following process bellow was a full face mask product using vacuum forming. Figure 6 is a documentation of the full face mask forming process.
Standard processing time for producing full-face masks was an important consideration for high production capacity. Rapid methods or technology in pandemic conditions need to consider the production speed as the main parameter in addition to ease of production. Based on experiments with vacuum forming devices, the cycle time to produce one full-face mask was 90 seconds or less than 2 minutes. If all the supporting parts of the mask were available, table 4 shows the estimated cycle time for a piece of full-face mask. The standard time for making one full-face mask (without packaging) was 346.5, seconds or 0.096 hours. If one production day was allocated one forming machine within a work duration of 8 hours, then the production capacity per day was $1 / 0.096 = 10.39$ pcs / hour or the equivalent of 83 pcs / day.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forming the product</td>
<td>90</td>
</tr>
<tr>
<td>Cutting and polishing</td>
<td>60</td>
</tr>
<tr>
<td>Filter's assembly</td>
<td>60</td>
</tr>
<tr>
<td>Valve's assembly</td>
<td>60</td>
</tr>
<tr>
<td>Strep assembly</td>
<td>30</td>
</tr>
<tr>
<td>Cycle time</td>
<td>300</td>
</tr>
<tr>
<td>Standard time (including performance 90%, dan Allowance 5%)</td>
<td><strong>346.5</strong></td>
</tr>
</tbody>
</table>

5. Discussion

Fulfillment of PPE supply quickly becomes a critical and urgent action at the beginning of a disease pandemic (Wu et al., 2020). Lack of access to information and limited knowledge of a pandemic disease's characteristics is one of the reasons for the slow anticipation to try effective personal protective solutions. The anticipation of the highest risk of disease impact and the speed of disease spread needs to be prepared at the beginning of the pandemic. The
community's panic response has also triggered the scarcity of personal protective equipment and even raw materials for producing personal protective equipment (Wu et al., 2020). Therefore, responsiveness in the ability to make protective equipment independently at the lowest level of society needs to be built. Personal protective production technology that is practical and can be implemented by the community will be more effective in dealing with disease pandemics.

Vacuum forming was an easy and practical method process to be applied by ordinary people. Materials and components for making your vacuum forming tools are easy to find. The most expensive component was the heater and the regulator, but it is still very affordable when managed in the community. The primary material for vacuum forming was thin PVC plastic, which was easy to get and cheap. The process of making the tool and mold a full-face mask has been applied successfully in this study and worthy to serve as an alternative to the independence of the provision of personal protective equipment. Documentation of the process of making simple vacuum forming tools, equipment, and material specifications, as well as the mask-making process, is expected to be useful knowledge in the mitigation of emergencies.

A full-face mask with PVC sheet plastic material is a cheap alternative to personal protection. The estimated selling price for a full-face mask is between the US $10-15 (for only one vacuum forming tool). With a very affordable price estimate, a full-face mask design is expected to protect society at large at the start of a pandemic virus that spreads through droplets or airborne. The production cost of a full-face mask should be lower with a higher production volume. In addition to cheap and easy to produce, a full-face mask uses a transparent plastic sheet so that almost all parts of the face can be seen clearly. Aesthetically, the use of masks will be preferably transparent because users do not cover the face. However, the more impermeable plastic sheet mask made of PVC, the user's voice is reduced to some degree.

The air in and out of the full-face mask only goes through 2 filters in the first segment. The ability to circulate air and filter out unwanted foreign objects such as viruses is vital. Filters are applied to our full-face mask and use the standard filter consisting of a fabric filter. Study more about the application filter on a full-face mask needs to be conducted. Many types of air filters can filter particles with nano size, and it is possible to be applied on a full-face mask. Filter on a full-face mask should be developed to filter out viruses that spread through the air. Tests on particular particle filterability when wearing a full-face mask also need to be done in the laboratory (Matic, 2009). The testing phase of technical capability in aspects of the air filter has not been performed to our full-face mask.

6. Conclusions

The design of a full-face mask provides an effective and efficient alternative to fulfill the need for self-protection from the virus's spread through the respiratory system. The vacuum forming tool's design can produce a full-face mask following the full-face mask technical design. The short vacuum forming time per product provides an overview of the promising capacity of mass production. PVC plastic sheet as the primary material for the full-face mask is a material that is readily available and at an affordable price. The concept of a two-segment full-face mask needs to be tested in the technical laboratory stage to see the ability to filter against undesired external particles such as viruses. Furthermore, future studies are needed to design a filter that effectively yet still efficient.

7. References


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8. Biographies

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**Retno Widyaningrum** is a lecturer in the Department of Industrial Engineering, Institut Teknologi Sepuluh, Nopember. She received her PhD degree in Department of Industrial Management, National Taiwan University of Science and Technology. She received her DEGREES in industrial engineering from Institut Teknologi Sepuluh, November, Surabaya, Indonesia, in 2013. She received awardees of Fast Track (Bachelor to Master) and Dual degree programs. She received her dual degree program in Industrial Engineering Department of Institut Teknologi Sepuluh November, Surabaya, Indonesia (MEng) and the Department of Industrial Management, National Taiwan University of Science and Technology (MBA) in 2014. She has published journal articles and international conference articles. Her research interests include human computer interactions, user experience, and human performance in virtual and augmented reality.

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