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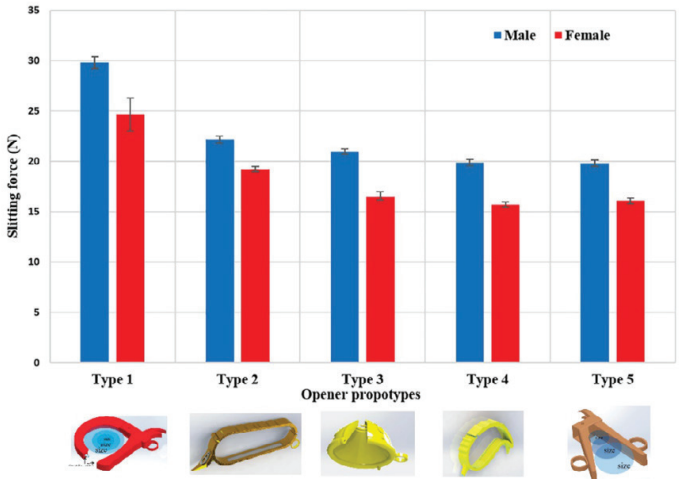

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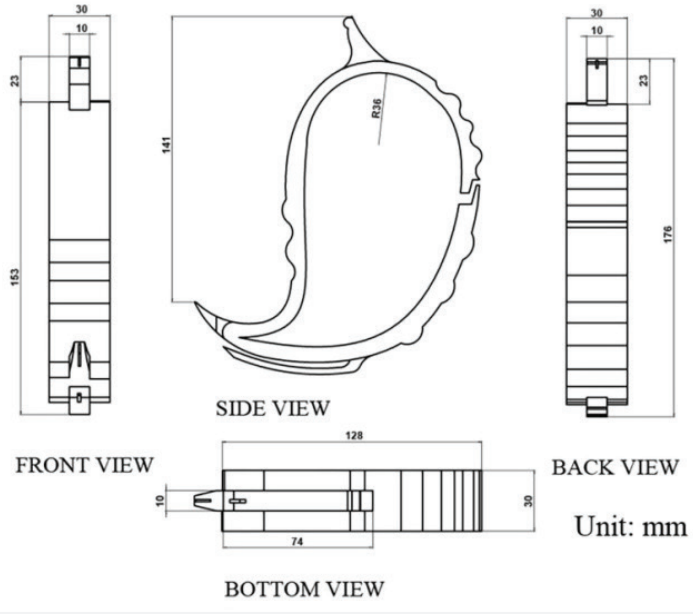

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The development of a virtual reality adventure game to prepare for a tsunami disaster

ABSTRACT

This research aimed to study and analyse the interaction between humans and a tsunami disaster simulation. Besides, it aimed to develop a virtual reality (VR) adventure game in regard to preparing for a tsunami disaster caused by an earthquake. It also assessed the effectiveness of virtual reality (VR) through three perceptions, namely visual perception, auditory perception, and kinesthetic perception with the connection between the human user and the Oculus quest 1 (VR glasses) to create virtual reality that was easy to understand and reflected interesting storytelling accompanied by beautiful patterns. The research objectives were 1) to study, collect, and analyse data related to the concept of creating virtual reality (VR), 2) to design and create virtual reality (VR) adventure game, and 3) to test and assess the perceptions of virtual reality (VR) to prepare for a tsunami disaster caused by an earthquake. The results of studies and analysis based on the learning style theory and participants' behaviour showed that the behaviour was often instilled from experiences that they had gained. This created clarity in the role of the participants and helped them learn and practice using virtual reality technology in training and deal with tsunami disasters caused by earthquakes. The results of the perception assessment of the virtual reality (VR) prototype, overall, indicated that the adventure game in a virtual reality (VR) setting to prepare for a tsunami disaster caused by an earthquake was feasible for use.

KEY WORDS
Virtual reality, tsunami disaster, adventure game, learning style

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Introduction

"Preparing for natural disasters with modern media" expresses the integration of science technology and creativity. It also develops the media to be up-to-date and clearly reach the target group in order to adapt and respond to changing environments. Empowering modern media with science technology and creativity will lead to the production of interesting media that must meet the needs of today's users and turn into innovations that lead to increasing economic added value in the future.

These days, there are various natural disasters occurring continuously in Thailand and in our world. These disasters impact humans and living things both directly and indirectly. Therefore, it is necessary to study and learn about various types of natural disasters in order to understand the nature of the occurrence and prevention of natural disasters that will occur, especially the provision of disaster education to teachers and educational personnel in risky areas. As a result, they will have knowledge and understanding of various natural disasters and can survive when disasters strike as well as pass on knowledge to others correctly (Pananont, 2018).

According to Moussa (2014), learning styles play a crucial role in the learning process. There are three main characteristics of learners, namely visual learners, auditory learners, and kinesthetic learners. Visual learners are those who best learn through visual stimuli such as images, colored depictions, and media. Auditory learners are those who prefer learning

through listening, and kinesthetic learners are those who best learn through movement. It can be said that understanding the characteristics of learners can absolutely enhance their overall learning process.

Virtual reality (VR) is a simulation of the environment purveyed under the atmosphere of virtual reality. The user perceives through devices called VR glasses so that he/she does not need to be in a real-world situation. For example, VR is used in an experimental design for collecting data on human behaviour and emergency response in a virtual reality subway environment (Sharma et al., 2014). This is based on the conceptual framework in the Narrative Mode which is linked to the user's behaviour, experience, enjoyment, and interest (Aylett & Louchart, 2003). Also, it is related to the theory of learning styles through three perceptions, namely visual perception, auditory perception, and kinesthetic perception. It is conducted by separating the user from the current environment to enter the environment created with a 3D visualization program. As a result, the user has actually entered that environment designed and created, which is in the form of virtual reality (VR). The researchers found that storytelling theory plays a key role in the link between the learning of the target group's behaviour and the various elements of virtual reality, from the beginning of the research to the perception of the target group. This is done continuously and systematically for effective and optimized work and can be applied to the theory of development in virtual reality. The researchers investigated the key factors that could be used to create perceptions in the use of virtual reality technology by determining the role to be appropriate according to the situation at that time in order to be connected to the perceived experience.

Koh Yao District, Phang Nga Province, is considered a world-class tourist destination since there are more and more tourists coming in each year. However, Koh Yao District is a vulnerable area to various disasters, including tsunamis.

Therefore, it must be prepared to cope with these disasters. There is disaster preparedness in various aspects, including training and educating the community and related agencies, and in both the public and private sectors. This aims to assist local residents and tourists in securing life and property. The researchers were interested in studying tsunamis caused by earthquakes and coping with tsunamis currently in order to find ways to create virtual reality to prepare for a tsunami disaster for people in the area. This can be done by applying the concept of disaster management with virtual reality (VR) technology. This study will help Koh Yao district, Phang Nga Province, to have the tool to prepare for the event of future tsunami disasters in the area.

Research objectives

1. To study, collect, and analyse data related to the concept of creating virtual reality (VR) to prepare for a tsunami disaster caused by an earthquake.
2. To design and create virtual reality (VR) adventure game to prepare for a tsunami disaster caused by an earthquake.
3. To test and assess the perceptions of virtual reality (VR) to prepare for a tsunami disaster caused by an earthquake.

Literature Review

The researchers examined, synthesised, and analysed the patterns/elements of the aforementioned virtual reality technologies and chose the elements for the creation of a virtual reality (VR) setting to prepare for a tsunami disaster caused by an earthquake that consisted of image, narrative mode, virtual reality graphical elements, simulation environment, colour, and roles and rules. The researchers also examined all elements of virtual reality technologies suitable for creating virtual reality (VR) to prepare for a tsunami disaster caused by an earthquake as shown in Table 1. Also, the simulation design for virtual reality is shown in Figure 1.

From Table 1, the researchers selected and compared the elements of virtual reality technology in 8 articles in order to identify their characteristics, strengths, and weaknesses. The storytelling and visual features created by various techniques were the basic tools for developing an adventure game in this present study. In addition, the differences under the framework of the theory of learning styles through three perceptions (i.e., visual perception, auditory perception, and kinesthetic perception) in relation to the interaction between the human body and the Oculus quest 1 (VR glasses) were identified. The obtained data were used to create virtual reality in this study, thus aiming to have the inclusion of interesting storytelling, beautiful design, and communicating to the user clearly. The data are summarised in Table 2.

From the virtual reality design table, the main focus is finding data in order to determine the action story and the relationship of time to send information to the operating system. This depends on the role assigned and the requirements of the virtual reality designer to link the data through the process. As a result, the participants would gain knowledge and understanding of the situation in which the designer had set the goals which were already used and established in real-world applications, such as knowing initial survival in the event of a tsunami. The process of creating virtual reality is shown in Figure 2 below.

Table 1 (part 1)

A summary of the elements of virtual reality

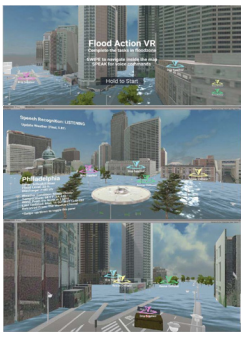
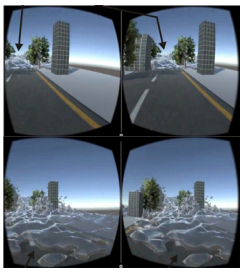
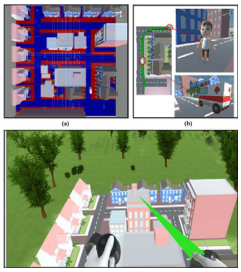
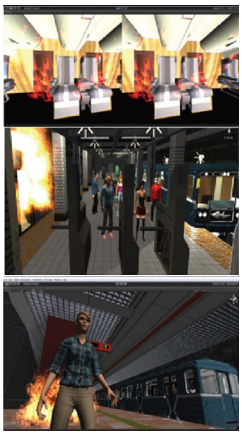
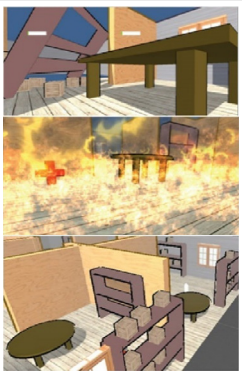
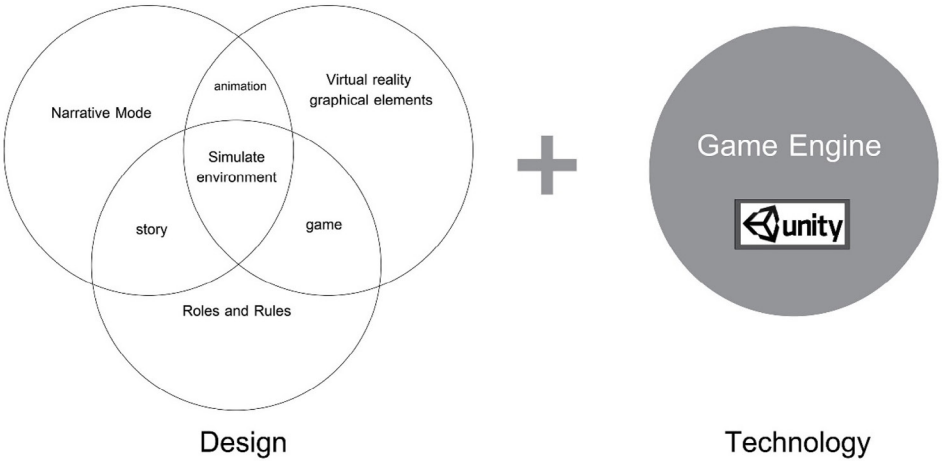
Title/Author	Image	Content	Strength	Weakness	How it relates to the present research
1. Flood Action VR: A Virtual Reality Framework for Disaster Awareness and Emergency Response Training (Sermet & Demir, 2019)	 Recreated from satellite imagery and mapped to the ArcGIS 3D model	This article presents a simulation of a flood situation.	It creates presentation scenes from a real situation to raise awareness about a disaster risk in the community.	The texture of the object in the picture is not very realistic.	The image can be used to experiment with designing virtual reality that looks simple and uncomplicated.
2. Tsunami Run-Up Simulation Using Particle Method and its Visualization with Unity (Saitoh, Noguchi & Inoue, 2018)	 Recreated from the MAYA 3D program.	This paper presents virtual reality simulation of an urban area with some buildings affected by the tsunami.	It creates presentation scenes from a real situation	The image shown still does not look realistic due to old equipment.	The image can be used to experiment with designing virtual reality that looks simple and uncomplicated.
3. 3D visualization tool for Virtual models of natural disasters (Pajorová et al., 2007)	 Created from 3D ortophotomap	This paper presents a tool to create 3D visualization in order to show the results of simulating various natural disasters such as severe fires, erosion, floods, or landslides.	It was the first research that used 3D visualization of natural disasters.	The emphasis is put on the basic use of virtual reality simulation of a landscape.	Creation of a 3D model of a city that was affected by disasters in the form of 3D landscape architecture using grid computing.
4. A Conceptual framework for 3D Visualisation to support urban disaster management (Kemec, Duzgun & Zlatanova, 2009)	 Created from 3D Lowpolygon	This paper presents a 3D city simulation built for earthquakes.	The creation of urban mode based on Level of Detail (LoD) concept. Most details in the scene are done by adding the objects to the game in order to make the scene realistic.	The emphasis is put on the basic use of a virtual reality simulation of the landscape in the form of boxes.	Creation of a 3D simulation of a city that was affected by disasters in the form of Lowpolygon 3D.

Table 1 (part 2)

A summary of the elements of virtual reality

Title/Author	Image	Content	Strength	Weakness	How it relates to the present research
5. A Virtual Reality Application for Disaster Response Training (Nguyen, Jung & Dang, 2019)	 Created from Unity3D	This article presents an in-process virtual reality called VRescuer to help train trainees and familiarize themselves with various disaster situations in the city. The scenarios are created with rescue service, ambulance, and rescuers.	It can allow users to participate in virtual reality more clearly with the Oculus Rift device.	The image shown is cartoon-like. It's not very realistic.	VR to train rescuers in disaster response in a simulated environment.
6. Immersive Virtual Reality Environment of a Subway Evacuation on a Cloud for Disaster Preparedness and Response Training, (Sharma et al., 2014)	 Created from 3D Studio Max	This paper presents an experimental design approach in order to collect data on human behaviour and emergency response in a subway environment.	The image is more realistic and clearer with the Oculus Rift device.	The texture of the object in the picture is not very realistic.	Using the knowledge gained from different situations can help people be better prepared to make decisions in emergency situations.
7. Minmin Escapes from Disaster: An Oculus Rift Disaster Simulation Game (Dumol et al., 2014)	 Created from 3D Lowpolygon	This article is a virtual disaster simulation game for teenagers. The research team focuses on adolescents because knowing how to prepare for a disaster should be learned as quickly as possible. It is a disaster escape of Minmin.	Storytelling in a game is fun. The goal of the game is to teach children what to do during a disaster in a fun manner by being in virtual situations.	The image shown is cartoon-like. It's not very realistic.	It prepares for realistic disaster by allowing players to see the calamities that happen around them. This can teach children better on how to survive a disaster.
8. Towards a narrative theory of virtual reality (Aylett & Louchart, 2003)	-	This article points out how VR works with storytelling theory. This affects how to make the story interesting.	The way to tell a story makes it interesting and connect to VR technology. This creates a new experience, allows enjoyment, and sparks interest.	-	It shows how to tell an interesting story with a simulated event.

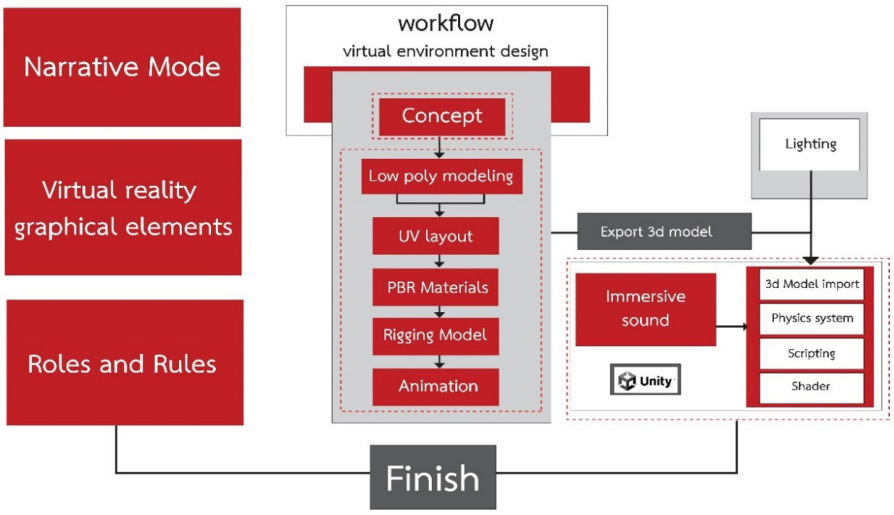


» **Figure 1:** *Simulation design for virtual reality*

Table 2

A comparison of the elements of 8 virtual reality simulations and the development of a virtual reality (VR) adventure game to prepare for a tsunami disaster designed in this present study

Elemental properties of 8 virtual reality simulations	An application of 8 virtual reality simulations to the design of the VR simulation to prepare for a tsunami disaster designed in this present study
1. Image	1. The designed image is Low polygon 3D Model PBR Materials. The model has a low polygon number, so the model is not heavy, focusing on the use of virtual reality with a texture suitable for use in designing games and virtual reality without complex details.
2. Narrative mode	2. There is no difference in this point. The way to tell a story to be interesting is connected to VR technology. It creates a new experience, allows enjoyment, and sparks interest.
3. Virtual reality graphical elements	3. There is a creation of a real environment into virtual reality through the perception of sight, objects, and scenes by cutting players off from the current environment in order to enter an interesting simulated image connected with VR technology.
4. Simulation environment	4. There is no difference in this point. The perception of sight and touch can be applied to sound design to match the environment.
5. Roles and rules	5. The behaviour of the participants is often instilled in the experiences they have gained. This creates clarity in the role of the participants and helps them to learn and practice using virtual reality technology in training and dealing with tsunami disasters caused by earthquakes. Therefore, it must be safe.



» **Figure 2:** *The process of creating virtual reality*

Research Method

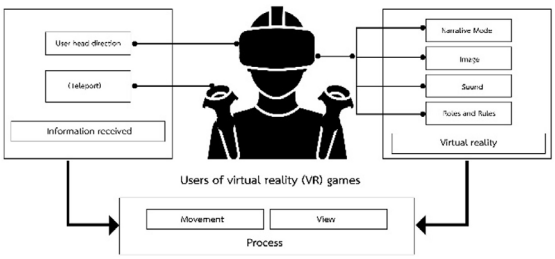
This research was conducted to study and analyse the interactions between humans and the tsunami disaster simulation in order to develop a virtual reality (VR) adventure game to prepare for a tsunami disaster caused by an earthquake. The research process is as follows.

1. Literature review: The secondary data were collected by gathering and analysing documents, textbooks, books, theories, research studies, and related academic articles, such as "Narrative Theory", "Learning Style Theory", and "Disaster Management Theory" as a conceptual framework for this research.

2. Data collection: In this study, the data were collected in three phases.
Phase 1: The data collection was to review documents, textbooks, books, theories, research papers, and academic articles related to this present research and interview key informants according to their expertise. This could be used as a guide for the creation of a virtual reality (VR) tool to prepare for a tsunami disaster.
Phase 2: After the research objectives and rationale for virtual reality design were determined, the design process was another very important step in designing virtual reality. The researchers selected the appropriate elements to design virtual reality. The process of designing virtual reality consisted of data collection, technological limitations, the concept of art-play, key features screens, player behaviour, and bringing design principles to design virtual reality.
Phase 3: After finishing the design process, the researchers tested and assessed the perceptions of virtual reality (VR) to prepare for a tsunami disaster caused by an earthquake. The participants were divided into two main groups. The first group was composed of three designers in the field of new media and two experts in the field of tsunami disasters. These participants were chosen through purposive sampling. The second group was composed of a group of 30 people who experienced a tsunami disaster in Koh Yao District, Phang Nga Province. They were chosen by convenience sampling and were divided into three groups according to their ages: 1) a group of people aged 19-25 years, 2) aged 26-40 years, and 3) aged 41-60 years. In this study, the research instruments included two sets of instruments: 1) a Likert-scale questionnaire and in-depth interview regarding elemental properties of virtual reality and 2) a Likert-scale questionnaire regarding the perceptions of virtual reality (VR) to prepare for a tsunami disaster. As for the group consisting of the designers and experts, a Likert-scale questionnaire and in-depth interview regarding the elemental properties of virtual reality were conducted. As for those who experienced a tsunami disaster, the questionnaire regarding the perceptions of virtual reality (VR) to prepare for a tsunami disaster was conducted by focusing on learning styles and perception evaluation.

3. Data Analysis: Regarding analysing the elements of virtual reality technology above, the researchers chose the elements of creating virtual reality (VR) to prepare for a tsunami disaster caused by an earthquake that consisted of image, narrative mode, virtual reality graphical elements, simulation environment, colour, and roles and rules. The researchers examined all elements of virtual reality technology to be suitable for creating a virtual reality (VR) environment to prepare for a tsunami disaster caused by an earthquake, thus selecting the visual characteristics of Low polygon 3d Model PBR Materials. This model was chosen since it is with fewer polygon numbers which is not weighty, emphasizing the use of virtual reality with a texture, suitable for use in designing games and virtual reality without complex details, and being in line with technology limitations to create a clear simulation environment. For the reasons mentioned above, the researchers concluded a specific guideline for creating virtual reality (VR) to prepare for a tsunami disaster with the elements of the image, narrative mode, virtual reality graphical elements, simulation environment, colour, and roles and rules. For the creation of virtual reality (VR) to prepare for tsunami disasters, the limitations of technology for creating a simulated environment should be clearly understood.

4. Design: It was a synthesis of variables obtained from the given analysis in order to determine the guidelines for designing a virtual reality (VR) environment to prepare for a tsunami disaster. During the design process, the data were collected from a research sample of the pilot study prior to actual use. The data gained were then analysed, synthesised, and used as the virtual reality (VR) model to prepare for a tsunami disaster, using Lowpolygon PBR material Oculus quest 1 as shown in Figure 3.



» **Figure 3:** *The working system of the VR simulation game to prepare for a tsunami*

5. Assessment: It was to assess the perceptions of virtual reality (VR) to prepare for a tsunami disaster. The sample group using media experimented with two types of games, namely 1) a virtual reality (VR) prototype to prepare for a tsunami disaster using Low polygon VR Cardboard in which the image was used to test the design of virtual reality that was simple, not complex, and 2) a virtual reality (VR) prototype to prepare for a tsunami disaster that was developed and had used Low

» **Figure 4:** *Lowpolygon VR Cardboard (up) Low polygon PBR material Oculus quest 1 (down)*

» **Figure 5:** *Virtual reality that the users see and the researcher using the Oculus Quest 1 device*

polygon PBR material Oculus quest 1, shown in Figure 4, in which the image was used to test the design of virtual reality that was simple, not complex, but the image was realistic. The questionnaire was then completed.

6. Final design: The final design was the reflection of the results obtained from the evaluation and identification of defects of programs and devices. It was then developed in order to get the complete game. Figure 5 shows virtual reality that the users see and shows the researcher using the Oculus Quest 1 device.

Results and Discussion

According to Research Objective 1 aiming at studying, collecting, and analysing data related to the concept of creating virtual reality (VR) to prepare for a tsunami disaster caused by an earthquake, it was found that the learners could learn from three types of perceptions, that is, visual perception, auditory perception, and kinesthetic perception. Additionally, they could determine the elements in each section appropriately. This makes the creation of virtual reality (VR) tools useful and interesting. This result is consistent with Denpaiboon & Pongpisit (2011) who note that, for creating participants' behaviour, the behaviour of the participants is often instilled in the experiences they have gained. Making a simulation game is a simulation in which some or all of the similarities or references to decisions are made in real situations. Roles and rules of play are defined in order to achieve balance in terms of player, simulation, and game by connecting humans and devices. On the basis of creating a virtual reality (VR) environment, the storytelling must be interesting. Moreover, the pattern needs to be beautiful and easy for the user to understand.

Designers must bring the elements mentioned above to fit the story and use it for maximum benefit. From Research Objective 2 aiming at designing and creating a virtual reality (VR) adventure game to prepare for a tsunami disaster caused by an earthquake, the researchers designed and created virtual reality (VR) design guidelines and determined the design concepts. The concept of simulation requires interactions between humans and simulations, including other elements. Sharma et al. (2014) discusses the principles of designing virtual reality environments for training that using the knowledge gained from various situations helps people to be better prepared for decision-making in emergency situations.

According to Research Objective 3 aiming at testing and assessing the perceptions of virtual reality (VR) to prepare for a tsunami disaster caused by an earthquake, the results are as follows.

Regarding elemental properties of virtual reality, it was found that, based on the interview data with the experts, the stories, actions, and relationships in the game were connected, and they provided a connection of information very well. The participants could also gain knowledge and understanding of the situation well. Also, the information could be easily accessed and communicated through virtual reality that was created based on the elements in a virtual environment. Moreover, the designed images were simple, and the texture was suitable for use in game design. The stories were told through simulated events and made the players feel they were in the real world. They responded to the experience they gained in the game, and they could use this knowledge in various situations. This would help the players to be better prepared for making decisions in emergency situations. In terms of virtual reality graphical elements, people, objects, and scenes in the game were made interestingly. The simulation environment was created clearly, and it provided knowledge through the media of infographics. Additionally, exciting sounds were added in order to increase the perception of virtual reality. As for roles and rules, the players understood their roles within the game and could play a role appropriately in that virtual reality environment. This made the players involved and aware of the magnitude of the problem. This was a learning process that could be applied in the real world.

As for the Likert-scale questionnaire regarding the perceptions of virtual reality (VR), it was revealed that, in terms of appropriateness, the image and simulation environment in the game was rated at the highest level ($\bar{x}$ = 4.6, S.D. = 0.54). It was followed by narrative mode ($\bar{x}$ = 4.2, S.D. = 0.44), roles and rules ($\bar{x}$ = 4.0, S.D. = 0.71), and virtual reality graphical elements ($\bar{x}$ =3.6, S.D. = 0.89), respectively.

Regarding the perceptions of virtual reality (VR) to prepare for a tsunami disaster, focusing on learning style and perception evaluation, the results showed that, in terms of learning style, most respondents had a high level of visual perception ($\bar{x}$ = 3.71, S.D. = 0.81). It was followed by auditory perception ($\bar{x}$. =3.4, S.D.=0.80) and kinesthetic perception ($\bar{x}$=2.99, S.D.=0.76), respectively. This indicates that most respondents in this study were visual learners who best learned through seeing the information presented as visual images according to Moussa's (2014) learning styles. As for perception evaluation, it was found that most respondents had a high level of virtual reality (VR) perception ($\bar{x}$ = 3.83, S.D. = 0.38). It was followed by other types of virtual reality environment (VR) design work, such as training and warning ($\bar{x}$ = 3.79, S.D. = 0.41).

» **Figure 6:** *An infographic video clip with specific words conveying the issue of perception to the respondents*

It should be noted that, to avoid misunderstanding, the researchers described the presentation of an infographic video clip with specific words that conveyed the issue of perception to the respondents as shown in the figure below. As a result, the respondents had an understanding of the issue. The simulation game would be able to help in transferring expertise and knowledge as well as helping to manage new expertise to the player.

One interesting finding in this study was that a group of people aged 41-60 years argued that they could not keep up with technology and avoided using applications that did not match their daily lives. They did not respond to the virtual reality (VR) that the researchers designed. Most of them argued that virtual reality (VR) technology was not suitable for them. This lends support to Dumol et al. (2014) who point out that, for a virtual reality disaster simulation game for adolescents, the research team focuses on the adolescent group because knowing how to prepare for disasters should be learned as early as possible.

Based on the above findings, the respondents who did not respond to the perception of virtual reality (VR) to prepare for a tsunami disaster were able to perceive the virtual reality (VR) environment in the form of storytelling. The people who were in the age range of 19-25 years and 26-40 years were those who told and narrated to a group of people aged 41-60 years since some of them were in the same community and family. Therefore, storytelling was another way of perception.

Conclusion

This research studied and analysed the interaction between humans and a tsunami disaster simulation in order to develop an adventure game in virtual reality (VR) to prepare for a tsunami disaster caused by an earthquake. Also, it assessed the effectiveness of virtual reality (VR) under Moussa's (2014) Theory of Learning Styles through three perceptions, namely visual perception, auditory perception, and kinesthetic perception in connection between the human user and the utilization of Oculus quest 1 (VR glasses) to create virtual reality. It was revealed that the storytelling was interesting, and it specifically involved beautiful patterns. This makes the simulation game easy to understand. This research successfully designed and created an adventure game in a virtual reality (VR) setting to prepare for a tsunami disaster caused by an earthquake. Regarding the assessment of the perceptions of virtual reality (VR) to prepare for a tsunami disaster caused by an earthquake, it was found that the behaviour was often instilled from experiences that they had gained. This created clarity in the role of the participants and helped them learn and practice using virtual reality technology in training. As a result, they could prepare and deal better with tsunami disasters caused by earthquakes. Overall, this virtual reality (VR) adventure game to prepare for a tsunami disaster caused by an earthquake is feasible for use.

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Legibility: Sinhala typeface features for Directional Informative Sign Boards

ABSTRACT

*Typefaces designed for the purpose of directional informative sign boards (DISB) communicate legible information related to drivers and passengers to navigate within road systems to: maintain road discipline and assist drivers to make instant decisions within a short period while operating a vehicle. The legibility of these typefaces works as a fundamental requirement. The reader's preference test (RPT) highlights that a typeface is unique due to its visual features–the anatomy of a typeface and it influences legibility performance, comprehension, memorability, priming, persuasion, perceptual fluency, and practical usage. This visual perception and the neurotic process of connecting human vision and brain is the intellectual cognition between; reader and information that acutely affects the reader to process information. When considering the amount of research work towards the advancement of DISB and typefaces designed for this purpose is at large within the western context, and more evident in Latin script but lacks in scripts such as Sinhala and Tamil within the Eastern regions. To fill this knowledge gap, the research contributes to Sinhala script discussed within the domain of typography research and proposes a draft typeface for Sri Lankan DISB. Considering legibility to be a required key factor in typefaces designed for the purpose of DISB the research methodology was structured into three stages. The **first stage** reviews legibility test methods, its measurements, testable factors usability and identifies the most relevant test to analyse typeface features. This section concludes by identifying RPT as the most relevant test with two variables: typeface personality traits and anatomy. **Second stage** adopts the two variables and tests six Sinhala typefaces that contain personality traits required for DISBs. It concludes with the identification of three typefaces that contain the required personality traits for DISB. The **third stage** analyses the anatomy of the three typefaces and proposes a draft Sinhala typeface for DISB. This stage redefines the two variables specific to Sinhala script and typography research. The stage concludes with a summary of the anatomical features of the proposed draft typeface and confirms a list of anatomical features required for Sri Lankan DISBs. The research also contributes to developing a methodology to analyse Sinhala typefaces, and draft new typefaces for specified communicative purposes. As for further research, the research the draft typeface to be developed and tested to font and to adapt to similar scripts and advanced typography research.*

KEY WORDS

Legibility, Reader preference test, Sinhala typeface, Directional informative signboards, typography research

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Typefaces: communicative purpose and road informative signboards

Typefaces play a significant role in our everyday life. They are created as a contribution to express information. Typefaces and its related technical tactics are supported to improve the communication purpose in whichever format they are placed or displayed. Typefaces as individual typography systems or in context work to deliver meaning to messages with a tone of voice and feelings while influencing communication ideas and purposes.

Typefaces do not always remain static as designers constantly refine and revisit the governing system as it evolves. Creating type is a lengthy process involving numerous revisions to individual characters until it fulfils the purpose. The fonts *Georgia, Verdana* are designed to optimise reading on screens (Franken, Podlesek & Možina, 2014) while *Times* and *Arial* are designed for digital output and hard copy (Coronel-Beltrán & Álvarez-Borrego, 2010). Among thousands of Latin typefaces, *Helvetica* is identified as a font used for general purposes. Meanwhile, fonts that contain a visual character of script-style are usually used for the purpose of wedding invitations. It can be stated that specific visual characteristics convey strong messages and are well used for specific purposes such as *Stencil* for building or structures, *Black letter* for logos of technology-related companies, *Collegiate* for advertisements related to academic purposes, *Scotch Roman, Garamond, Antique* for body text and *Bodoni, Old Style, Caslon* and *Cheltenham* for design purposes (Webster & Tinker, 1943) etc. Moreover, some typefaces are designed and tested for specific purposes such *Highway Gothic* and *Clearview* for the purpose of directional informative sign boards (DISB). Either way, typefaces or fonts used to communicate ideas and purposes have a personality that is conveyed it's the visual features. The most successful typefaces are a fine balance of the aspirations and constrictions of their concepts with the compromises, idiosyncrasies, and practicalities of application and legibility (Willen & Strals, 2009).

Among many unique typefaces, typefaces used in DISB play an important role in a sustainable manner to maintain road safety. Latin typefaces such as *Highway Gothic, Clearview, DIN 1451, Gill- sans* are some of the used for directional information sign boards. They are applied in many countries: *Highway Gothic*; United States, Turkey, Malaysia, Brazil, Canada, Mexico, Australia, New Zealand, Italy, and Spain (Silva, 2014). *Clearview*; United States, Canada, Indonesia, and Sri Lanka. DIN 1451 later replaced with *Gill- sans*, Germany. However, these typefaces designed for the purpose of DISB do not work in isolation as it is a composition of many elements; numerals, arrowheads, icon graphics and in some cases (other script/s) typefaces etc. and the DISB itself has its own communicative purpose. The distance through numerals and direction through arrowheads and icon graphics are used to communicate road safety and effective information. These graphical elements together with the typeface/s communicate legible information related to drivers and passengers to navigate within road systems to: maintain road discipline, assist drivers to make instant decisions within a short period while operating a vehicle. Road signs are placed at access points to ensure the best viewing height for drivers and pedestrians (Ministry of highways and road development and road development authority, 2007), they are placed as attractive way findings signs to drivers within cluttered backgrounds. Usually, the placement is located on the opposite side of the driver's line of sight from the road (Calori & Vanden-Eynden, 2015). According to the environmental graphic design system, unique shape, form, and structure support identifying road signs. Further, factors such as brightness, resolution during daylight and night vision and weather conditions are also considered when designing DISB as it impacts legibility. Thus, legibility of these graphical elements, placement of road signs and typefaces work as a fundamental requirement. Yet, the scope of this research is forced to legibility and typefaces.

In the case of DISB typefaces, letter height, type or style of typeface, upper case, lower case and sentence case, line spacing and background colour etc. influence legibility on DISB (Calori & Vanden-Eynden, 2015). Within DISB, multiple-scripts are applied in bi-lingual and/or multilingual countries. At such instances the different typefaces representing different scripts, and its visual variation play a vital role. Countries such as Slovakia, Austria, Germany, Greece, Ireland discuss the complexity of a typeface, text size, text line-height and height ratio, and inner lines, script, and display layout (Eglin, Bres & Emptoz, 1998) when designing new typefaces for DISBs. Yet, this type of practice of designing a specific typeface for DISB is not very evident within non-Latin scripts. For example, Sri Lanka; a multilingual country, that uses three typefaces (Latin, Tamil, and Sinhala) in their DISBs only represents the use of *Highway Gothic* and *Clearview* for the Latin, while the other two typefaces that represent other two scripts are selections from a pool of existing typefaces designed for other purposes.

Context of Latin script: Latin typefaces and typeface series commonly used for DISB are: *Akzidenz Grotesk, Motorway, Transport heavy, Transport medium, DIN, Highway Gothic of the FHWA series, Clearview, Gill Sans, TERN series, Astrs Frutiger, S.N.V.,Old Soviet Standard GOST 10807-78, Caratères, Drogowskaz, Tratex* etc. In practice, the use of two typefaces is used in DISB of bi-lingual or multilingual countries. Significance of this application is that two or more Latin typefaces in a single DISB containing different typefaces in response to the readers and the communicative purpose. The use of the

Typefaces *Akzidenz Grotesk* and *DIN* used in countries such as Germany, The Czech Republic and Lativa is an example of it. Another aspect is that typefaces designed for the DISB are constantly being developed or modified with time. For example, the typeface *Transport* found in Portugal, Ireland, Iceland, Cyprus and Greece is modified as *Motorway* (Lund, 2003; Silva, 2014). Such applications and modifications are constantly being reviewed by researchers and type designers. These subtle visual variations entrapped in the anatomy of a typeface makes the typeface unique and subjective to the reader. The interlink between a typeface's visual features and its personality connote linguistic meaning conveyed by words in a reader's cognitive space. The emotional weight carried by the personality traits of a typeface improves the reader's experience of the text, this influences legibility.

Anatomical features explained in Figure 1 demonstrates *Akzidenz Grotesk* typeface used in Germany to have open and semi-enclosed counters and diagonally cut terminals of letters a, c, e and s. The lowercase *'i'* and *'j'* contain square dots (Lund, 2003). Similarly, the typeface *New Motorway* contains open, semi-enclosed counters with diagonally cut terminals in letters 'a', and obliquely cut terminals in letters 't' and 'y', yet the lowercase *'i'* and *'j'* are constructed as round dots. What's significant about the *New Motorway* typeface is its unique spacing system, which eliminates confusion between letters to increase legibility. On the other hand, the typeface *DIN* elaborates its anatomical features to have a narrow-rectangle form with vertical and horizontal terminals. Its uppercase letters have semi-enclosed counters cut at inconsistent angles. The counters are open, semi-enclosed and terminals of lower case letters a, c, e and s are obliquely cut. Its lowercase *'i'* and *'j'* contain square dots (Lund, 2003; Silva, 2014). The typeface *Transport* too is like typefaces *Akzidenz Grotesk* and *DIN*.

Within the practice of Latin script, it is evident that there are many discussions and literature on the significance of having a unique typeface for a specific purpose. Therefore, the conscious decisions taken during the typography research and the type-design process fulfils its communicative purpose.

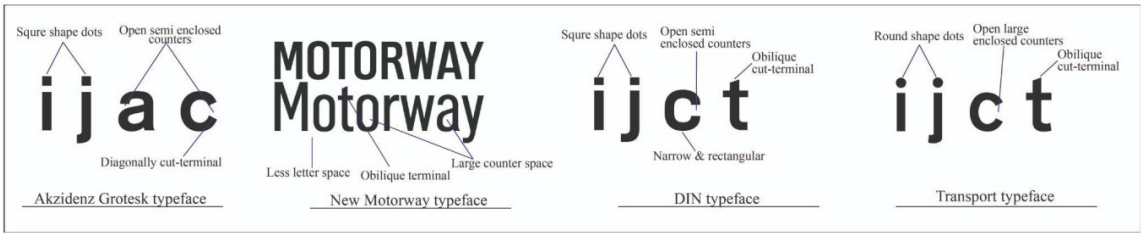
Context of Sinhala script; There is no literature on Sinhala typefaces related to DISB within the context of Sinhala script or Sinhala typography. Thus, this research works as a pioneer. The construction of the Sinhala script is different in comparison to Latin script. Sinhala script has 60 letters (18 vowels and 42 consonants), the vowels are represented as individual letter forms and as vowel signs placed adjacent to consonants, the script included special characters, non-alphabetical signs and combined-consonants. According to the National Education Institute in Sri Lanka, 60 letters take 46 letter variations, 12 letters contain 46 basic letter forms without diacritics or consonants. Visually it is considered as a circular/ rounded script with minimum straight lines. Its anatomical features are placed within five reference lines, its base character height is specified with the letter 'pa' ප, terminology used to define the anatomical properties/features are biased to each letter shape. 46 letters are constructed from a total of 89 sub-features, distinct to each letter and are summarised into 19 visual features (Samarawickrama, 2016).

Sri Lanka adopted the current use of DISBs with the development of expressways around 2011. According to the Road Development Authority (RDA), the applied Sinhala typeface is *DL-Araliya* and Tamil is *Paranthan*. The adaptation of these two typefaces were based on a committee decision, selected from the then available Sinhala and Tamil fonts (Sudath, 2018). *DL-Araliya* was designed by A.M.D Lenarolle and observations on it claim that it was designed for the purpose of print media. On the other hand, typefaces *Highway Gothic* and *Clearview* that are used to represent English, were adopted considering their recognition as international standard typefaces developed for the purpose of DISBs.

When considering the amount of research work towards the advancement of DISB and typefaces designed for this purpose is at large within the Western context, and more evident in Latin script but lacks in scripts such as Sinhala and Tamil. To fill this knowledge gap, the research contributes to Sinhala script discussed within the domain of typography research. Considering legibility to be a required key factor in typefaces designed for the purpose of DISB the research methodology was structured into three stages.

Stage 01

Review of Reader Preference test method (RPT) among legibility test methods



» **Figure 1:** *Visual differences and similarities of three different Latin typefaces designed for DISB*

Legibility is the scientific approach to recognise displayed objects within a very short time (Tinker & Paterson, 1929). It is about the ease of reading fast by recognising individual letterforms, structures and visual shapes (Beier, 2009). It acts as a function of type design and is measured through scientific methods of reading speed in normal reading context and different environmental conditions (Weingerl, Nedeljković & Pušnik, 2022, Chandra, Bokil & Kumar, 2017; Beier, 2009; Beier, 2012; Haley, 2009; Waller, 2011; Tracy, 1986, as cited by Chandler, 2001; Wijnholds, 1996, as cited by York, 2008; Weisenmiller, 1999). To proceed with the research; legibility and different methods used to test it are discussed here to learn on the most appropriate method to test *DL-Araliya*.

Legibility test methods

Most typefaces vary in appearance and character; it has different levels of legibility (Brumburger, 2003; Mackiewicz, 2005; Shaikh, Chaparro & Fox, 2006). Therefore, the clarity of a single character within an aesthetically attractive typeface is a fundamental contributor to legibility. And, to measure legibility, factors related to the human eye and typography parameters related to reading documents are considered in Tinker and Patterson's four legibility test methods: The continuing reading method, The search task, The visual accuracy threshold, and The reader's preference test. These four methods introduced in the early 1900s by Tinker and Patterson–pioneer researchers on legibility are the most frequently used legibility test methods in current day research. These test methods and others; Daniel Starch test, Ovink test, Tachistoscope test etc. (Arditi & Cho, 2007; Beier, 2009) were reviewed here. These test methods constantly debate between the idea of legibility and readability. Most tests on readability are developed to test comprehension and measure reading ability, accuracy of eye vision and quality of typefaces. Similarly, legibility test methods are developed to test comprehension but measure the ability to recognise single letters within test material. Therefore, by reviewing each method, its measurements, methodology and the testable factors/usability, the research learns the most relevant methods to analyse a typeface's legibility.

Since this paper is a compilation of a completed master's research, only a summary of Tinker and Patterson legibility test methods are reviewed here: (1) The Continuous reading test method; measures reading speed and comprehension while noting the number of errors by measuring reading time. It tests knowledge based on comprehension. (2) The search task test examines spelling errors in words or specific words on typography materials. This method is related to the scanning process rather than the actual reading. The method is not considered for real-life reading situations. (3) The visual accuracy threshold measures letters or word identification rate in a context. The test is based on a vision test, usually conducted in laboratories to identify the ability to recognise words. This test method includes Colour tests, Short exposure and distance study. (4) The reader's preference test is based on attitude toward a unique typeface. It measures the aesthetic knowledge of a typeface; its personality. It is based on readers' preference on a typeface and observes unique visual features; the anatomy of the typeface (Pušnik et al., 2019; Schriver, 2013; Beier, 2009; Beier, 2012; Carter, Day & Meggs, 2007; Arditi & Cho, 2007; Reynold, 2007 as cited by Beier, 2009; Sheedy et al., 2005; Legge et al., 1989; Levitt, 1971 as cited by Arditi & Cho, 2007). Learnings on the objective of each of these test methods, measurements etc. it is evident that only the latter test method was focused on typefaces and demonstrated possible adaptation to DISBs.

The readers preference test (RPT): highlights that a typeface becomes unique due to its visual features–the anatomy of a typeface. And it is the anatomy that influences legibility performance, comprehension, memorability, priming, persuasion, perceptual fluency, and practical usage (Jordan et al., 2017). Further, RPT considers this influence with visual perception; neurotic process of connecting human vision and brain. The intellectual cognition between; writer, reader, and information acutely affect the reader to identify the most suitable typeface for the specific communicative purpose. This is because a typeface carries the emotional weight of a text and creates the tone of a message while improving the reader's experience of the text (Saltz, 2009). The emotional weight or the semantic qualities are portrayed through typeface personality traits: strength, elegance, friendliness, romance and humour, potency (strong/weak), evaluation (clean/dirty), elegance, novelty and antiquity, evaluation, mood and activity (Brumburger, 2003b) cheapness, dignity, economy, luxury, strength, refinement and precision (Spencer, 1969 as cited by Brumbuger, 2003b; Wendth, 1968 as cited by Brumbuger, 2003b), confident, elegant, casual, bold, romantic, friendly nostalgic, modern, delicate, sassy (Sushan & Wright, 1989 as cited by Jordan et al., 2017) etc.

Information is communicated through the linguistic-meaning of words and different tones of voice. The same information can be communicated more effectively through different tones of typefaces captured in a typeface's personality. This typeface application connotes the meaning over and above the primary meaning, and type personality connotes meaning over and above the primary meaning of words (Lewis et al., 1989 as cited by Shaikh, Chaparro & Fox, 2006). Therefore, the interlink between anatomy and the semantic quality of a typeface determines the reader's preference when perceiving information. The different tones and connoted meaning of typefaces are analysed by type-designers, researchers via observations of a typeface's micro aesthetic details (Kunz, 2000 as cited by Mackiewicz, 2005). These details are considered as letter parts that

make up a character which contains a unique quality that expresses opinions, valuations, and judgments (Mackiewicz, 2005). It distinguishes one typeface from another creating contrast between letters which influence legibility of typefaces (Carter, Day & Meggs, 2007).

RPTs conduct experiments to identify the interrelationship of typeface personality and typeface features of different typefaces as the reader's preference is a subjective measurement and it is based on the objective of nature. In practice, information on readers' preferences of a typeface is collected through questionnaire surveys (Weisenmiller, 1999). These personal preferences are denoted with two adjectives on either side of a Likert scale. Sample groups are expected to score their preference by observing stimuli containing sample text or specifics. By calculating the results confirms the personality traits of a typeface or a font. These finding of a typeface's personality traits leads researchers to identify appropriate typeface for appropriate communicative purpose. The use of RPT is applied to learn the preference on point size of typeface (Shaikh, Chaparro & Fox, 2003), styles of typeface, printing quality, paper quality, paper surface, leading, type size, line width, lowercase versus italics, simultaneous variation of line width and typeface size, space and lines between columns, regularity of alignment versus indentation of alternate lines at left and right end and simultaneous variation of type size (Tinker & Paterson, 1942). RTP is also tested to learn the preference on leading between displayed typefaces and body text used in billboards, advertisements, business letters, instruction manuals, newspapers, greeting cards, websites, and computer manuals (Mackiewicz, 2005) etc.

RTP as a legibility test method highlights the significance of a typeface. Its variables are typeface and their personality traits. The test is used to identify a reader's preference of a typeface used for a specific purpose. The preference is tested on the required personality traits a typeface has for the specified purpose. In this case, the purpose is a legible typeface for the purpose of DISBs. A typeface's personality traits are entrapped in its anatomical features, and it is what impacts the type personality which enhances the legibility performance. This section concludes with this understanding and applies RPT for Sinhala typefaces in the next.

Stage 02

Reader preference test: Personality traits for DISB and Sinhala typefaces

To identify Sinhala typeface personality traits for DISB, the section starts by listing out the personality traits required for DISB via literature. This knowledge is then tested on Sinhala typefaces. The selected Sinhala typefaces are based on the existing pool of typefaces available in Sri Lanka and the visual features of *DL-Araliya*: the typeface used in current DISB's of Sri Lanka. The objective of this section is: to learn if *DL-Araliya* has the personality required for DISB. To achieve this (a) Discusses personality traits required for DISB and builds the pairs of adjectives for the stimuli. (b) Explains the selection of the sample typefaces, composition of the stimuli and testing. (c) Analyses the responses and concludes the learnings of this stage.

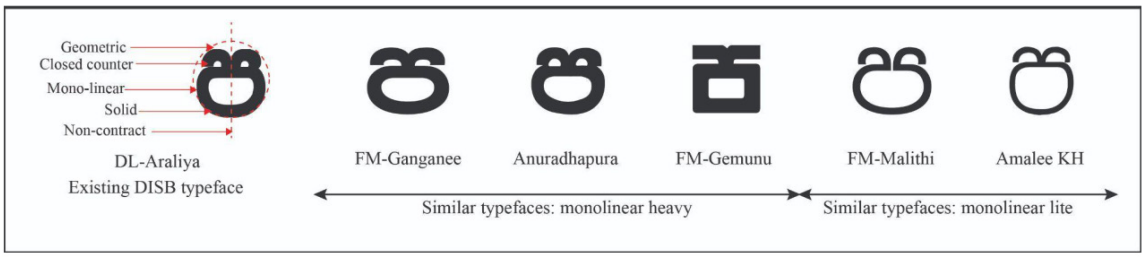
(a) Identifying Sinhala typeface personality traits for DISB and testing

Typeface personality traits for directional informative sign boards discussed in literature are traditional, professional, practical and a classic (Hyndman, 2016), short, fat/solid, simple and fast readable (Smiley, 1978) unique, individual personality, taste, traditional, relevant, fashionable and heavy (Lund, 2003) etc. to build the adjective pairs for the test each of these pairs were reviewed and eight pairs of adjectives were listed for the test: Slow readable-fast readable, common-unique, grouped-individual, short-tall, light-bold, unfashionable-fashionable, classic-modern, fragile-solid. These pairs are placed in the stimuli demonstrated in Figure 3.

The first pair was decided to learn on how fast a typeface can be read as reading influences the driver while manoeuvring a vehicle. Second pair; highlights the importance of portraying the typeface to be unique for the purpose of DISB, as it cannot be mis-read with an advert or other communication media. Third pair; interprets the requirement of the need of more space between letters rather than it being visualised as a group of text which influences legibility, similarly fourth pair discusses the large counter space entrapped in taller letters (larger Pa-height) in comparison to short letters. Fifth pair; focuses on the stroke width to be heavy. Sixth pair; elaborates on the elegance of the stroke to be fashionable. Seventh pair; speaks of the requirement of a modern typeface rather than a typical classic typeface and eighth pair discusses the solidness of the stroke. In summary based on literature eight pairs of personality traits were identified for the test and to compose the stimulus.

(b) Selection of Sinhala sample typefaces, composition of the stimuli and testing

The selection of the sample Sinhala typefaces was based on the anatomical features of *DL-Araliya*: the typeface used in current DISB's of Sri Lanka. As illustrated in Figure 2, it is a monolinear, heavy stroked, non-contrast typeface with a very high grey value. Considering these basic anatomical features: tool, hand, flesh and grey value of Sinhala typefaces were selected. Due to the limited number of Sinhala typefaces available in Sri Lanka, three typefaces; *FM-Ganganee, Anuradhapura, FM-Gemunu* were included in the test, and due to the limit of heavy Sinhala typefaces, *FM-Malithi* and *Amalee*



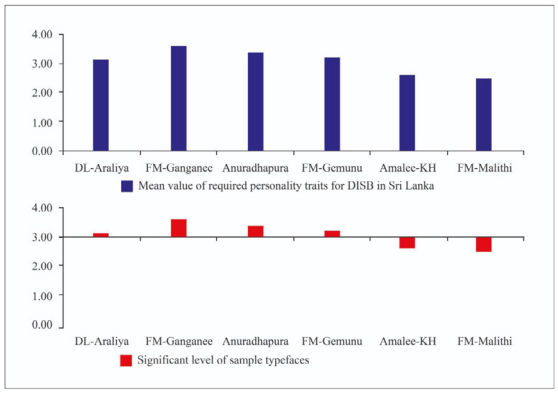
» **Figure 2:** *Selected sample typefaces for RPT*

were included based on the mono-linearity. In summary five Sinhala typefaces mentioned above and *DL-Araliya* conclude the selection of six typefaces for the testing.

Stimuli: Having selected the sample typefaces the stimuli were composed as seen in Figure 3. The composition included a name of an (unfamiliar) city in white on black at the top, Likert scale at the centre and the adjective pairs representing the required personality traits on either side. This was then shared in a classroom setting, with a sample group of 60 design graduates who are familiar with Sinhala typeface features and the research objective. With the necessary instruction on the task, their preference was marked. The adequacy of respondents was confirmed using the SPSS software (Statistical Package for Social Sciences, version 20) and the non-probability judgmental sample was considered 'approximately acceptable'. Using Microsoft Excel, the mean value was analysed; if the mean value was greater or equal to 3 (≥3), it was considered as the typeface with the 'most' personality traits for DISB, and if less than 3 (<3), it was considered as the 'least'.

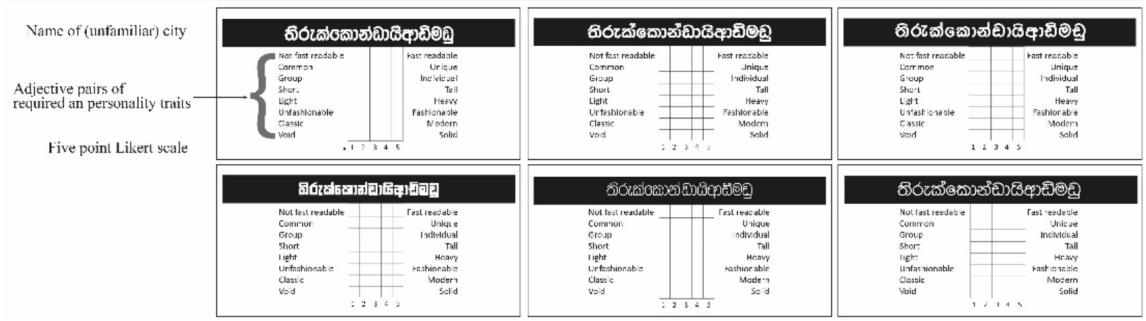
(c) Analyses the responses

Six stimuli representing the six typefaces were distributed among each member of the sample group for testing. The data was collected and statistically analysed as demonstrated in Figure 4. The results showed that; *FM-Ganganee, Anuradhapura,* and *FM-Gemunu* had the most significant personality traits for DISB. However, *DL-Araliya* was ranked fourth (with a mean value of 3.13), and *FM-Ganganee* scored 3.62. The results confirmed three Sinhala typefaces have the required personality traits for DISB and the currently used typeface for DISB in Sri Lanka *DL-Araliya* does not.



» **Figure 4:** *Mean value and significant level of sample typefaces*

To identify Sinhala typeface personality traits for DISB this section questioned if the typeface *DL-Araliya* has the personality required for DISB and it was tested using the RPT. The results proved that *DL-Araliya* does not have the required personality for DISB as it scored a lower mean value. Yet, the overall result of this stage proved that another three typefaces have the personality required for DISB as they scored a higher mean value. The three typefaces are *FM-Ganganee, Anuradhapura*, and *FM-Gemunu*. Therefore, to explore the requirement for Sri Lankan DISBs the three typefaces need to be visually analysed.



» **Figure 3:** *Sample Stimuli for RPT*

Stage 03

Visual analysis and proposed anatomical features for a Sinhala typeface for DISB

To identify the Sinhala anatomical features for DISB, this section applies the knowledge gained from the previous stage and proposes the required. To achieve this (a) Re-defines the variables for analysis as the anatomical features of Latin differs from Sinhala. (b) Visual analysis and drafting of a Sinhala typeface for DISB. The drafting process reconfirms the objective of this section by applying the gained knowledge: to learn the Sinhala anatomical features for DISB. (b) is conducted in three steps to achieve the objective outcomes.

(a) Re-defining the variables for analysis

The anatomy of a typeface is built on the reference lines, the base character height (x-height for Latin and pa-height for Sinhala) and the anatomical features. In comparison to Latin the Sinhala script is visually complex. The anatomy of the Sinhala script contains 19 visual features that includes 89 sub features (Samarawickrama, 2016) and the Sinhala alphabet has 60 letters. To identify anatomical features, this section explains the variables: sample number of letters (table 01) that captures the anatomical features and the three selected typefaces.

Table 1

Selected sample letters for visual analysis

Typeface	Sample 26 letters; represent 89 visual features of Sinhala script
FM-Ganganee	පpa මma ඬnda ණna බba යya ඝgha නna කka තta රra ලla අa දda ජja චcha ඹbha උu ගga ශsha ළla වva ඩd ඵpha හha සsa

Independent variable: anatomical features of Sinhala typeface, the 19 visual features demonstrated in Figure 5, contains 89 sub features. These sub-features are categorised under 46 Sinhala letters (Annex 01). Yet the research observes only 26 letters as a single letter demonstrates multiple features. Therefore, a sample number of 26 Sinhala letters that captures 89 sub features were selected.

Dependent variable: sample Sinhala typeface, the result in stage 02, identified three Sinhala typefaces that had the highest mean value proving the required personality traits for DISB. Therefore, the research selected FM-Ganganee, Anuradhapura, and FM-Gemunu as the sample Sinhala typefaces.

(b) Visual analysis and drafting a typeface for DISB

The visual analysis and the application of knowledge towards drafting a typeface was conducted simultaneously within three steps:

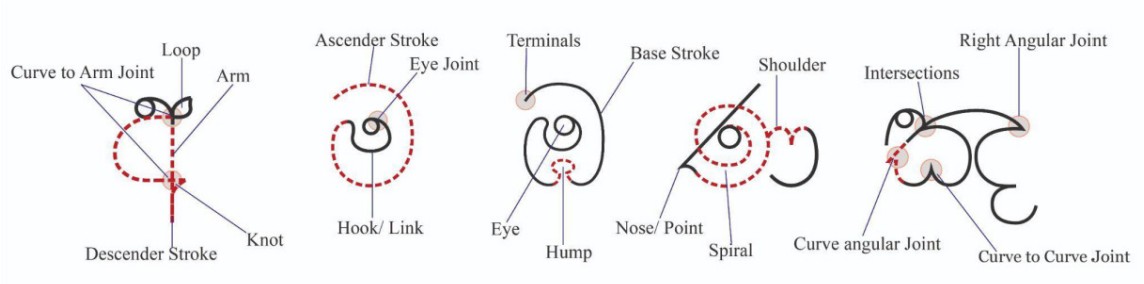
Step 01- Observation of the tool, hand, flesh, and grey value

This step observes the tool, hand flesh and the grey value of the typeface and concludes with an overall understanding of all the three typefaces and proposes the basic visual qualities when drafting Figure 6.

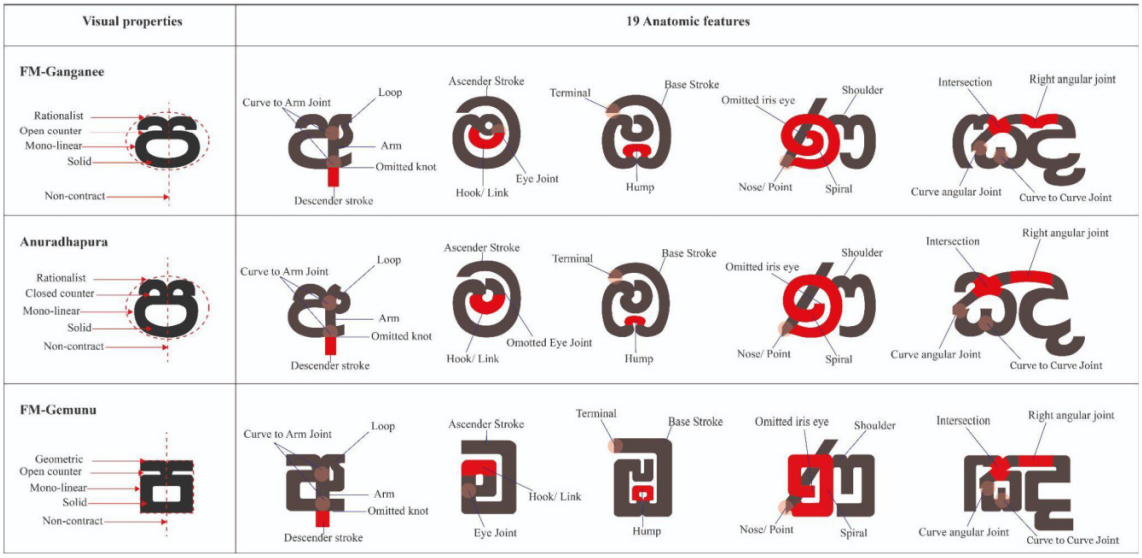
Tool: the tool is what speaks the loudest in a typeface as it determines the stroke thickness, weight, and the terminals. In the case of the three typefaces, the tool can be defined as a mono-liner pen as the strokes are constructed with the same weight. This also determines the proposing draft to be a non-contrast typeface.

Hand: the hand is determined by the tool and its movement. It was observed that *FM-Ganganee, Anuradhapura*, and *FM-Gemunu* have a combination of a rationalist and a geometric hand. The first two typefaces take a more circular nature, while the latter takes a square shape. Therefore, the proposed hand for the draft typeface should contain a composition of both.

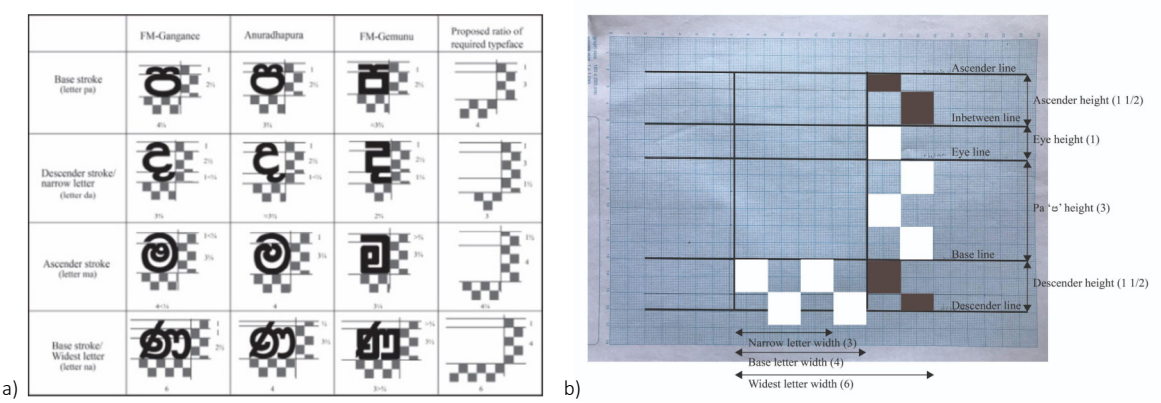
Flesh and grey value: the flesh of a typeface is identified by the boundaries of the stroke. In this case the flesh of all three typefaces has a solid flesh: resulting a high grey value. Therefore, this is proposed for the draft. In summary the proposing draft typeface should be a non-contrast typeface with a combination of a geometric and a rationalist hand. It should have a high grey value with a solid flesh.



» **Figure 5:** *19 visual features in Sinhala script*



» **Figure 6:** *19 visual features of FM-Ganganee, Anuradhapura and FM-Gemunu*



» **Figure 7:** *a) Measurement of selected 3 typefaces with the proposed proportions b) reference lines*

Step 02- Determining the proportions

This step analyses the proportions of the typefaces which is determined by the reference lines, the base character height and the width of the widest and the narrowest.

Proportions: to determine the proportions, four letters illustrated in Figure 7 were selected to represent the: base character, ascender, descender, widest and the narrowest letters among the sample 26 Sinhala letters. The analysis was conducted by placing the sample typefaces on the 5 (existing) reference lines to calculate the proportions with a common measurement 'x'. The common measurement (x) is the size of the eye of the letter *pa*, it is found between the eyeline and the in-between line. The analysis was conducted by calculating the three sample typefaces and arriving at a mean-proportion.

Therefore, the proportions for the proposing draft typeface should have: the base character letter to be equal in height and width 4x by 4x, the ascender height to be 1.5x above the in-between line and the descender to be 1.5x below the baseline. The proposed mean for the widest is 6x and narrowest to be 3x. Using the eye height (x) as the common measurement, the width of the stroke thickness should be ¾. be ¼x less.

Step 03- Analysing and applying anatomical features

This stage analyses the three typefaces across the sample 26 letters. Figure 6 demonstrates the 19 visual features (that captures the 89 sub features) of the sample typefaces. During this analysis process it was evident that the visual variation among each typeface was very high. Therefore, the research observed the ideal letter features explained with three visual features: hook, spiral terminal in the first column of Figure 8, followed by the sample typefaces. To achieve the full potential each letter was drafted to capture the mean visual qualities and drafted. The visual drafting process observed the ideal letter features, the application of it in the sample typefaces and proposed the anatomical features and a letter (Figure 8). The drafting process was done by manually tracing sample letters, placing it on a graph sheet

and manually drafting multiple times revising steps 01 and 02. It was after a rigorous development process; a draft was confirmed (found in Figure 8 last column). Using this process 26 Sinhala letters that capture all 89 sub visual properties of Sinhala were drafted.

In conclusion, the Sinhala anatomical features required for DISB can be listed as below, and the summary is illustrated in Figure 9:

step 01:

- monoline, non-contrast typeface,
- combination of a rationalist and a geometric hand,
- solid flesh with a high grey value

step 02:

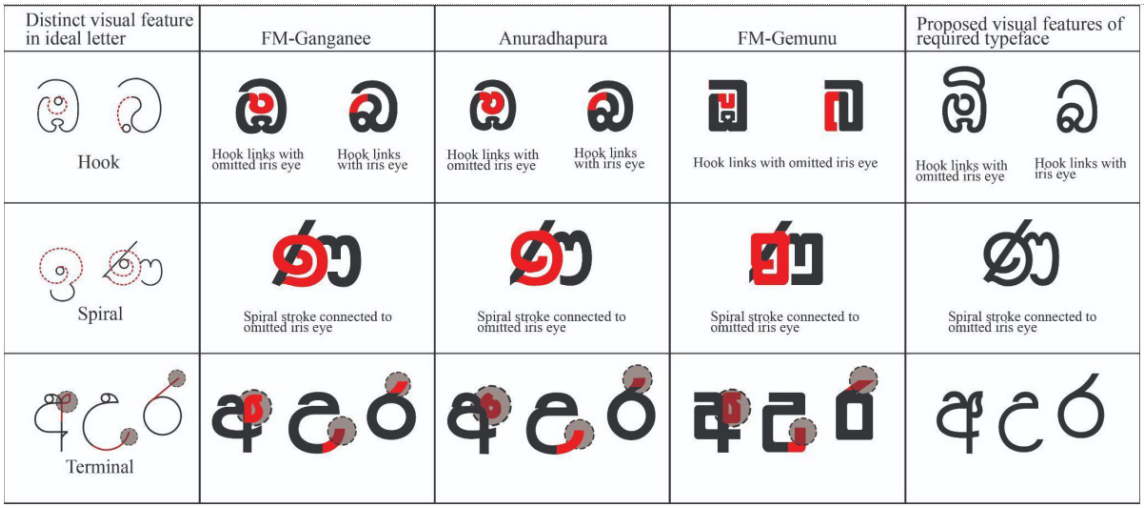
- the base character to be equal in height and width.
- large base height with equal ascender and descender height
- six reference lines (5 already existing and 1 additional to accommodate ascender strokes)

step 03:

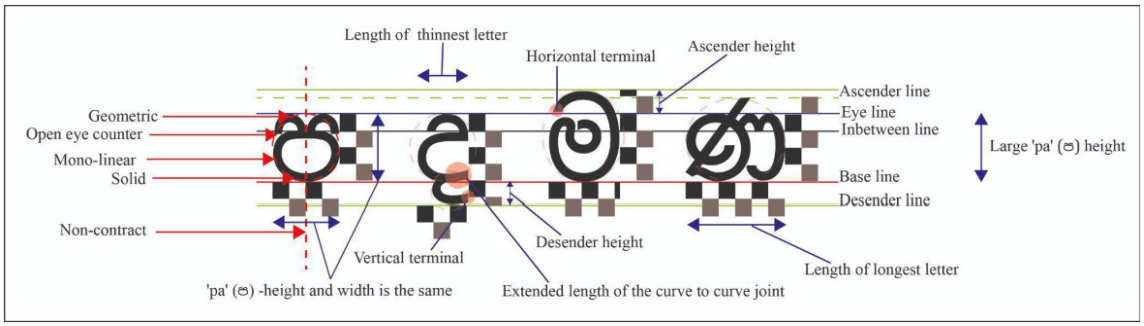
- Terminals to be either horizontal or vertical with no diagonal or rounds.
- application of the visual feature 'omitted eye'
- open counters and semi-open counters
- extended length of the curve-to-curve joint

Discussion and Conclusion

The research discussed the significance of the role of typefaces in general and specified to DISB. It highlighted legibility as a fundamental requirement and discussed the large amount of research and development within the context of Latin typefaces but lacks in scripts such as Sinhala and Tamil used in (multilingual) Sri Lanka. To fill this knowledge gap, the research contributes to Sinhala script discussed within the domain of typography research. The research justified and applied RPT by defining its variables: the personality traits and anatomical features for Sinhala. To arrive at the overall aim of describing: what typography knowledge you required to design a legible Sinhala typeface for DISB, the research looked to two objectives: to learn if DL-Araliya (existing DISB typeface) has the personality required for DISB and, to learn the Sinhala anatomical features for DISB.The findings on the first objective concluded that DL-Araliya does not have the required personality traits for DISB,



» **Figure 8:** *Visual analysis selected distinct visual features: Hook, Spiral and Terminal*



» **Figure 9:** *Basic letterform structure with visual properties of the required typeface for DISB in Sri Lanka*

» **Figure 10:** *Existing DISB (with existing Tamil and Latin typefaces) with a proposed Sinhala typeface*

but three other Sinhala typefaces did. Therefore, to achieve the second objective the research visually analyses the typefaces and applies the gained knowledge in inquiring the anatomical features required for DISB. In conclusion the overall research presents a list of anatomical features required for Sri Lankan DISBs and the methodology to analyse typefaces, and draft new typefaces for specified communicative purposes. The research also proposes the possibility of adapting the methodology to similar scripts and advanced typography research. or further research, the research proposes the draft typeface to be developed and tested to a font.

Acknowledgement

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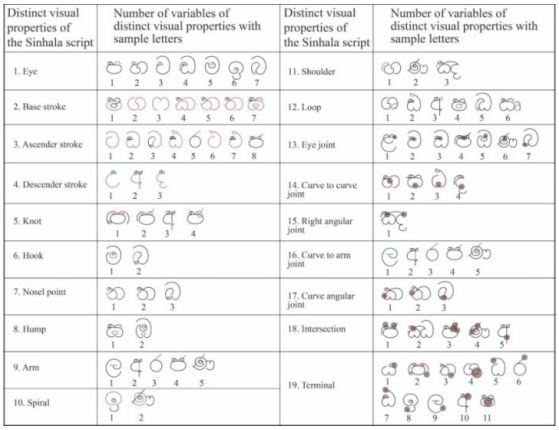
Annex 01 - Division of 89 sub-features within 19 visual features demonstrated with 46 Sinhala letters



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Developing prototypes of the assistant opener of packaging for consumer accessibility

ABSTRACT

The purpose of this research was to focus on the design of packaging openers for consumer access to the contents. The packaging opener was created to make opening easier and safer. In this study, online questionnaires were used to investigate the problems and solutions of user experiences when opening packaging. According to the findings, a major issue among the responding participants is that they should have a strong hand force. However, the hand force not only had enough energy to open the packaging, but it was also unable to open the closure at the specified location. When participants encountered opening problems, they preferred to use an assistant tool rather than ask for assistance. The risk of packaging materials, scissors, knives, and wrist and finger twisting occurred during opening packaging. According to the respondents' experiences, the four functions of the packaging opener were integrated together for the corrugated box, ring-pull a can, lug cap closure, and flexible packaging. As a result, the newly designed packaging opener required less opening force, a safer hold, and optimized hand ergonomics. The attractive configuration and comfortable grip were also important factors to consider when designing the packaging openers in this study. Opener prototypes were modelled using SolidWorks and were formed by a 3D printer. The FSUDE system was employed to evaluate the functions, safety, usability, design, and engineering of all prototypes. Based on the results of this study, form, dimension, surface, friction, and grip posture were factors affecting torque force exertion, slitting and cutting force, and openability of consumers.

KEY WORDS
Opener, opening packaging, product design, opening assistant tool

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Introduction

The COVID-19 outbreak has changed the lifestyle of consumers. Over recent years, they are concerned about health care, and avoiding the risk of infection; therefore, online shopping is one of the interesting choices due to the avoidance of contagious diseases, convenient purchases, and fast delivery. To promote online shopping, the strong packaging of the product is essential so that the products do not get damaged during shipping to the customers. The requirement for durable packaging is for the customer's confidentiality, product distribution, and product storage. Unfortunately, these packages cause problems opening for customers. Opening packaging with knives, scissors, teeth, and hands is not convenient and leads to injury to the hands and fingers. Many studies have reported effective packaging opening methods in various groups. Among over 60-year-old consumers, they encountered problems with the ergonomics in terms of size, shape, and opening and closing features; therefore, they desired changes in food packaging (Świda et al., 2019). Based on a study by Bell, Walton & Tapsell (2016), a number of the elderly staying in hospitals were unable to open the packaging due to the dexterity of hand function. Daphne et al. (2014) investigated whether packaging can cause problems in daily practice, espe-

cially among older people with medicine packaging. The findings indicate that pharmaceutical manufacturers needed to understand the effects of packaging and how to cause problems for patients. In other words, the opening problems of flexible packaging were dependent on a strong heat seal, film thickness, limited force, and user dexterity of both genders or ages (Nilmanee et al., 2018). For safety issues, Cengiz & Melvin (2010) reported that certain types of packaging, such as tinplated steel cans, cause injuries when consumers attempted to open them. In addition to the sharp edges of the packaging, objects used to open the packaging also contribute to injuries. In some cases, the opening tools are the sources of injuries. For instance, the most difficult container is a can that needs a tool to open. Impaired physical and cognitive functions influence the elderly's ability to open medical containers (Beckman et al., 2005). They also reported that they were unable to open the screw cap bottles, bottles with a snap lid, as well as blister packs. Parkinson's disease, rheumatoid arthritis, cognitive impairment, and impaired vision were associated with a decreasing ability to open the packaging. In 2017, Giana & Daniel (2017) reviewed the relationship between older patients and the impact of packaging on medical usage. According to the reviews, the studies can be divided into two following ways. The first method involves considering opening package problems due to physical functionality and user capability, whereas the other studies focus on medical management, packaging, and user orientations.

Ward, Buckle & Clarkson (2010) found that patients taking methotrexate had several difficult experiences with medical packaging, which might increase the risk of error doses. In addition to opening packaging problems, instructions on labels are important to ensure that patients take the right doses and are also available to open the package. As a result, the packaging and labels should contain distinctive information and comprehensible opening instructions. Easily opening packaging is necessary for consumer accessibility, either with bare hands or with a packaging opener. To understand essential grip and finger movements, Kamat et al. (2010) demonstrated pain frequency and pain level during gripping activities. The results indicated that the distribution forces depended on the styles of grip, such as a comfortable grip and a power grip. The grip style and finger position applied different pressure and distribution forces. In 2011, Chavalkul, Saxon & Jerrard (2011) indicated the engagement of hand positions, hand actions, hand direction and adequate opening for novel packaging. According to ergonomics of hands, Rowson & Yoxall (2011) showed a further study whereby consumers were asked to apply the most common grips with a torque measuring device. Different grip styles were seen to produce different peak torque values. Using a jar simulation, Huang et al. (2014) investigated the posture effect on finger behaviour during jar opening. The resultant force of the thumb produced greater tangential torque contributions, and the index-middle had similar torque contributions. Yoxall, Gonzalez & Rawson (2018) investigated finger motion coordination during packaging interaction. The results showed that finger correlations were relevant to the dexterity of pack opening. The packing format was related to finger movement. Therefore, the purpose of this paper is to explore the concept of opener improvement for functional safety and easy opening with corrugated boxes, ring-pull a can, lug cap closures, and flexible packaging. The packaging openers were designed based on attractive form, suitable packaging dimension, and hand ergonomics, which supported surface friction and force exertion. Furthermore, the packaging opener prototypes were also measured by human force during interaction with packaging and were evaluated for user satisfaction.

Material and Methods

Questionnaire of packaging opening problems

In this study, eighty-four Thai people were consumers in a city in southern Thailand and participated using the convenient sampling technique. The online questionnaire was divided into the following 2 sections. The first section asked for general information about the participants, and the second section related to opening problems when they encountered specific packages such as a corrugated box, flexible packaging, a ring-pull can, and a glass jar with a lug cap.

Conceptual development of equipment prototypes to aid in opening packaging

The designed prototyping of opening assistant tools was based on function, safety, usability, design, and engineering systems (FSUDE). A function of the user was improved by cutting flexible packaging, slitting corrugated boxes, lifting the easy-pull ring of a can, and gripping and twisting the lug cap and screw cap. The easy-grip, ergonomics, and universal were applied for safety, while usability was referred to as the openability of consumer accessibility, finger coordination, and grip posture on packages. The designed opener prototypes were dependent on the identification of form, shape, ratio, dimension, the friction of the surface, and satisfaction evaluation. The last one was related to engineering as human force measurement. Based on the grip postures of humans when consumers open the packaging, the concept of the prototype's design was divided into five following patterns. The mockup of each object was modelled using SolidWorks software, and all mockups were built layer by layer using 3D printing filament technology for making the prototype (Pro 2Plus, Raise3D printer, United States). Before using the 3D printer, all objects as mockups were converted to

the STL format with the open source Ideamaker software to gcode format. Polylactic Acid (PLA) is a filamentous material used for forming rapid prototyping objects.

Opening force measurement and satisfaction evaluation

For measuring opening force and evaluating user satisfaction, 28 healthy consumers participated in the test. Before testing of slitting maximum force measurement on the metal plate and torque force exertion on the lug cap, each participant was trained for each specific handle style of the manipulated position on five opener prototypes with four packaging categories. In the first section, all participants handled naturally on five opener prototypes at specific grip postures with their right hand and left hand. Then each subject had to test the slitting force exerted on a 50-mm-diameter piece of paper until it split. A piece of paper was fixed on the metal circle plate with a digital force gauge as shown in Figure 1 (Desik DS-50, Germany).

» **Figure 1:** *Digital force gauge and grip posture of force measurement*

Maximum force data for each subject were recorded. In the second section, a torque meter (Mechanical Torque Meter: Tohnich, Japan) was employed for measuring the maximum torque force for human opening on a vacuum jar lug cap of 60-mm in diameter with the opener prototypes and without a tool for a convent hand, either precision grip or power grip using in accordance with ASTM D3192 (Figure 2).

» **Figure 2:** *Mechanical torque meter and grip posture of force measurement*

All participants were determined to be in the typical experimental standing postures. For the section on satisfaction evaluation, after the participants were done completely using the openers with corrugated boxes, ring-pull a can, lug cap closures, and flexible packaging. All participants needed to assess the prototypes of the issue lists, including the ergonomics, geometry, utility, safety, commercial, and design, using a rating scale of 1–5.

Results and Discussion

Participant experiences of opening for packaging

A total of eighty-four Thai participants were asked to complete the questionnaire online. The female and male participants in this study were 81% and 19%, respectively (Table 1). The mean weight and height of participants are displayed in Table 1. The data shows the percentage of participant responses that encountered problems when they opened the packaging (Figure 3).

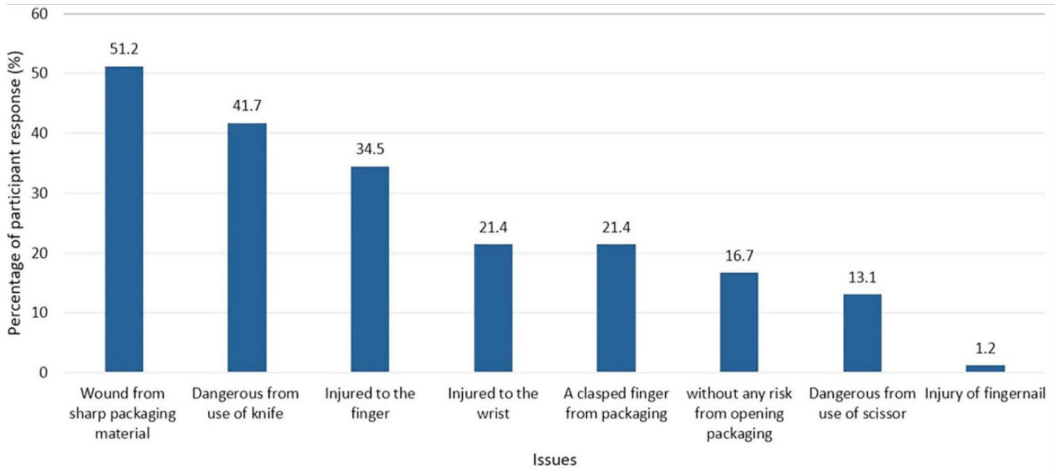
According to the findings, more than 40% of respondents effectively related the problems to human force and durable packaging closures. In addition, participants pointed out that they preferred the tools to open the flexible packaging and corrugated boxes due to cohesion. Figure 4 presents the risk and the painful experiences of the participants when they encountered difficulty in opening packaging. Packaging material that was sharp and strong, dangerous from using a knife or scissors, and injuries to fingers and wrists were often caused by the barrier to consumer accessibility of the products in the survey.

Table 1
Description of Thai participants

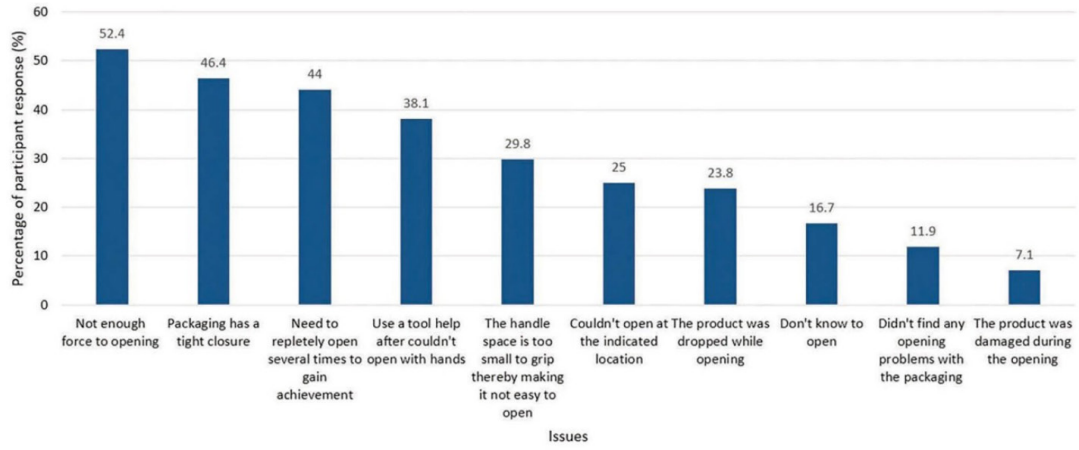
Participant information	Frequency % (n)
Gender	
Male	19 (16)
Female	81 (68)
Age group (years)	
>20	21.4 (18)
21-30	54.8 (46)
31-40	8.3 (7)
41-50	6 (5)
51-60	10.7 (9)
Weight (kg)	
40-45	20.2 (17)
46-50	14.3 (12)
51-55	13.1 (11)
56-60	19 (16)
>60	34.5 (29)
Height (cm)	
141-150	13.1 (11)
151-160	44 (37)
161-170	32.1 (27)
171-180	10.7 (9)
>180	2.4 (2)

Conceptual design of the packaging opener stage

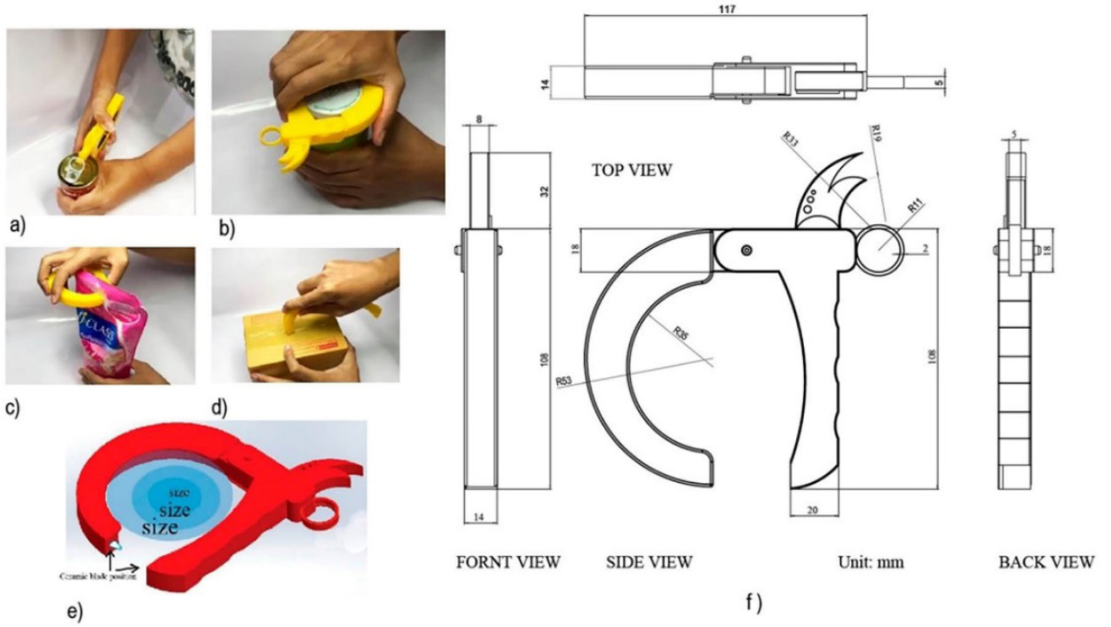
Many factors influence the human capability of a safe and easy opening process on packaging, including opening posture, ergonomics, force increase, hand physicality, and so on. As a result, function, safety, usability, design, and engineering (FSUDE) were based on the improvement of the conceptual design of user-friendly open-aided tools. The concept of the opener design is to integrate four functions of opening into a packaging opener. In this study, compatibility of multi-function in packaging opener design was associated with distinguishing the utilities of human ergonomics for cutting, slitting, twisting, and pulling through the designs. The designed opener prototypes were then further classified into five features. The dimensions and shape of each prototype were identified in accordance with hand and finger size as well as grip posture styles during the opening of corrugated boxes, flexible packaging, lug cap, and a can. The first feature of the prototype in Figure 5 depicts the grip feature while using an opener with four functions on four different types of packaging. Figure 5a is typically used for a handgrip on the curve-shaped opener to pull



» **Figure 3:** *Percentage of participant response for issues with using and opening packaging*



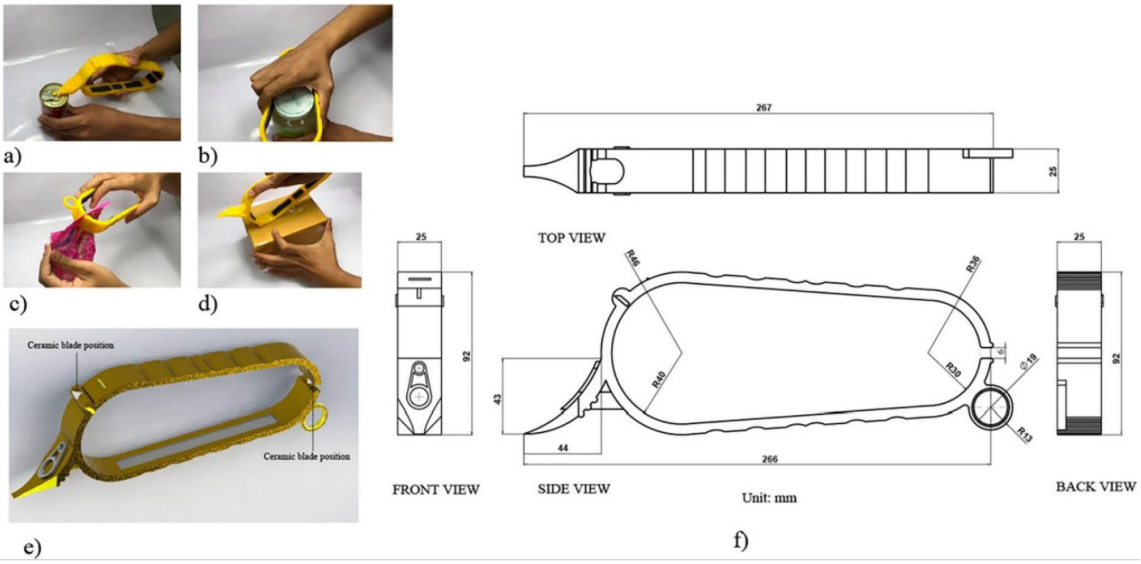
» **Figure 4:** *Percentage of participant response effecting with packaging opening problems*



» **Figure 5:** *Grip posture features on 4 packaging with prototype 1*

up a ring on top of a can. Figure 5b shows the spherical grip of an opener applied to a vacuum jar lug closure that is suitable for jars of various sizes and ease of grip. Furthermore, the effective friction was increased by placing rubber coaster pads with an adhesive liner on the inside surface of the container lug closure surface. Figures 5c and Figures 5d display grip positions for cutting flexible packaging and slitting cohesive tape on a box. Two ceramic blades were inserted into specific locations on the prototype. The packaging opener of type 1 was designed with two elements: a ring-pull can handle and a semicircular shaped part. Both elements were connected by functions to provide a comfortable hand grip and finger coordination. Figure 5e depicts the prototype features and position of the ceramic blade. Figure 5f illustrates a fabrication drawing of the elements.

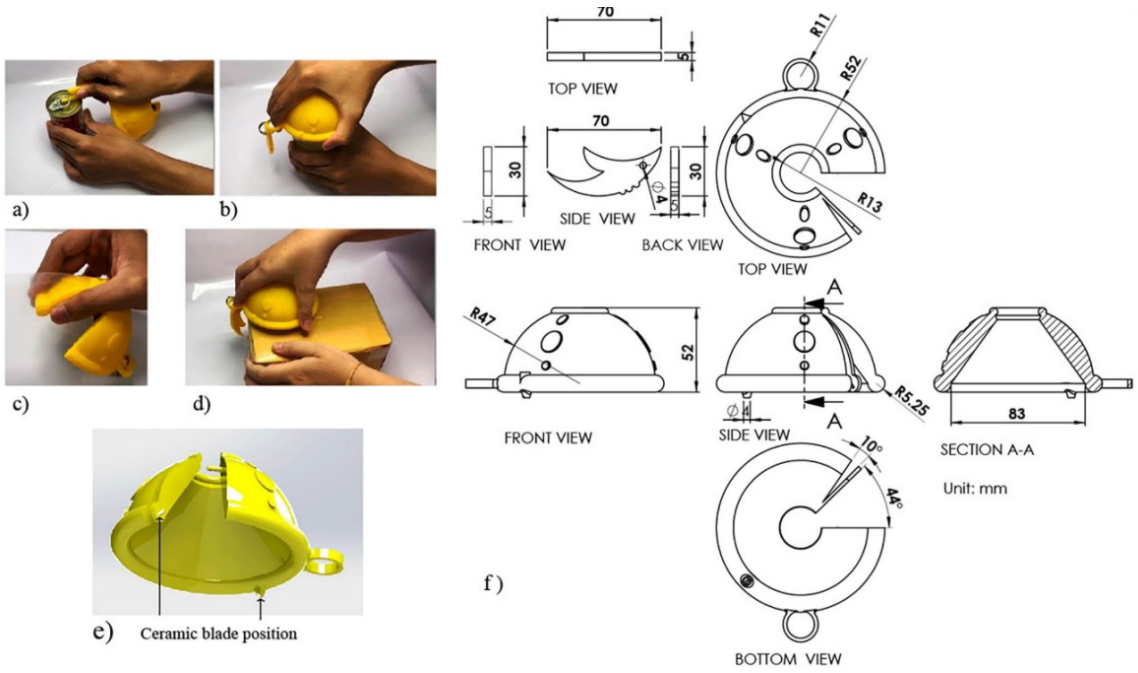
Figure 6 shows the grip features of the opener in the second prototype that were created based on the stage of interaction between human opening posture manipulation and packaging characteristics. The prototype was a shaped-curve design in one piece. The potential of the handgrip was related to the dimensions of the palm, finger, and packaging. The designed position was appropriate for the four packaging types' opening functions. The small shaped curve was designed as the can opener to pull up on the easy opening ring and is placed at the front of the prototype (Figure 6a). In addition to the jar opener, the spherical grip on the lug closure of the cylindrical container had different dimensions (Figure 6b) because the rubber coaster pads with adhesive liner had effective friction to increase between the closure and the rubber surface when consumers twisted a bottle or jar.



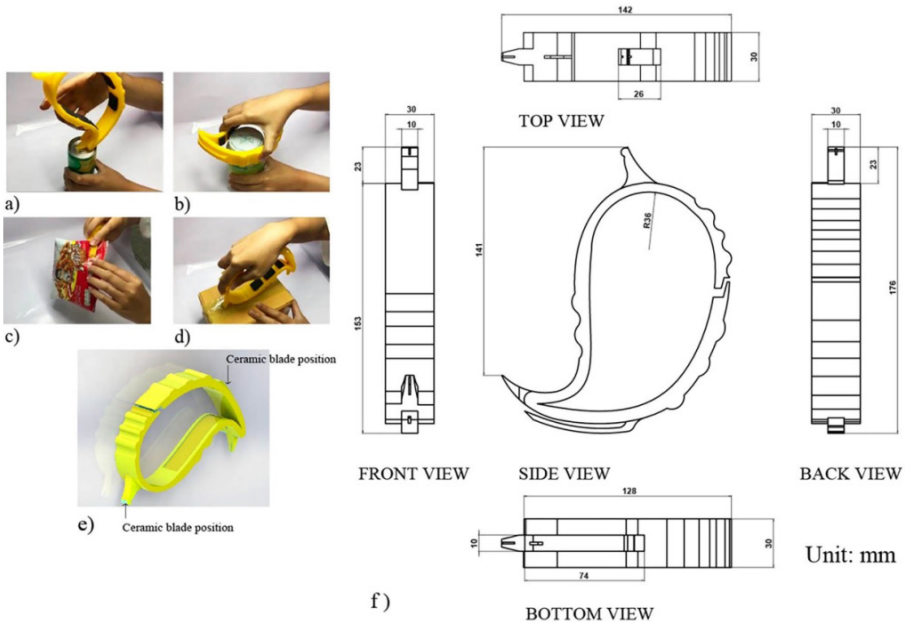
» **Figure 6:** *Grip posture features on 4 packaging with prototype 2*

Figure 6c depicts cutting the flexible packaging for the characterization of opener usage. To remove the seal, the ceramic blade was inserted into the two sides for cutting and slitting on the flat surface of the removable seal. The handy opener was designed with a ceramic blade to easily grip when slitting on the flat surface of packaging. Figure 6d depicts the hand posture when slitting adhesive tape on a corrugated box while gripping the opener. A ceramic blade was inserted on the outside in a comfortable position, allowing consumers to easily grip and increase the cutting force. Figure 6e depicts the ceramic blade positions and a mockup of the second prototype. The structural features of prototype 2 are depicted in Figure 6f.

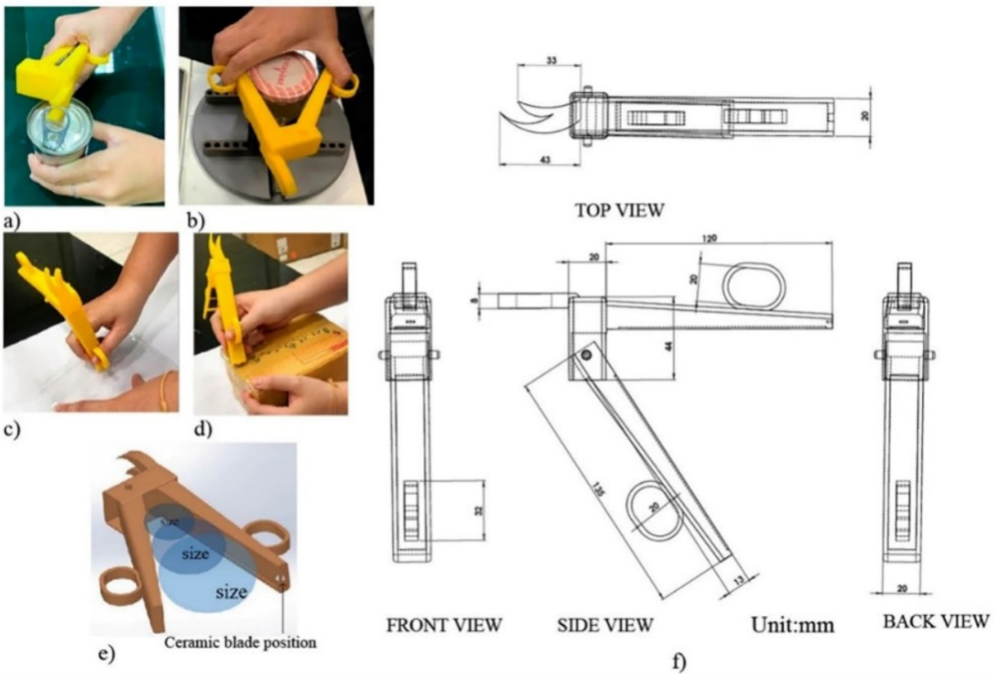
Figure 7 depicts the feature of opener type 3. It was composed of two parts. The first part featured a curved shape for pulling up the easy ring on a can (Figure 7a), while the second part featured a revolved shape of an opener for opening a bottle lug cap or cylindrical screw cap (Figure 7b), cutting flexible packaging (Figure 7c), and cutting the corrugated box (Figure 7d). Figure 7e shows a feature of the third prototype's 3D mockup. For contacting friction when opening a lag



» **Figure 7:** *Grip posture features on 4 packaging with prototype 3*



» **Figure 8:** *Grip posture features on 4 packaging with prototype 4*



» **Figure 9:** *Grip posture features on 4 packaging with prototype 5*

cap, the ceramic blade was placed on the rubber coaster pads with an adhesive liner on the inside surface. Figure 7f depicts the size and shape of prototype 3.

Opener type 4 was designed as the can opener for pulling the easy ring with a J-shaped curve at the end of the product for consumer safety and comfort when opening the packaging, as shown in Figure 8a. The vacuum lug cap's spherical grip was specifically designed to open a variety of sizes. The contacted cap surface was covered with rubber coaster pads with an adhesive liner for the inside surface (Figure 8b). As shown in Figure 8c, the ceramic blade was located inside the extruded part as the opening part for cutting the flexible packaging. The thumb finger can be forced into position and is easy to grip. Figure 8d depicts a simple grip as the lateral posture of the prototype on the corrugated box with the slitting function. Figure 8e shows the 3D Mockup feature and ceramic blade position of the opener type 4. The 2-D engineering drawing shows the shape and dimensions of prototype 4 in Figure 8f.

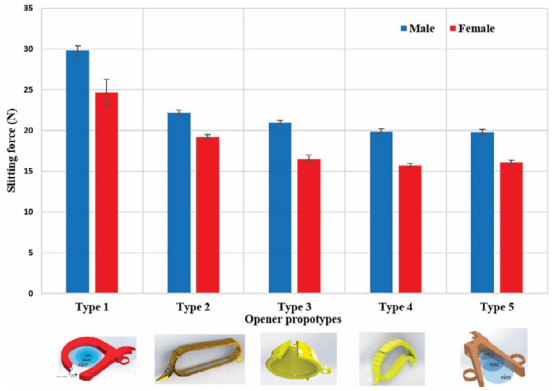
Figure 9 illustrates the final type of opener developed in this study. There were two parts that interlocked together throughout the four functions of the opening-aided tool for packaging. Figure 9a depicts a consumer's grip posture after pulling the easy ring on a can. The finger rings on both parts can be made to increase grip strength, whereas the rubber coaster pads increase finger friction between the fingers and the container cap outside of the surface (Figure 9b). The ceramic blade for tip grip postures on the opener handle was designed to slit flexible packaging and cut the adhesive tape on the corrugated box, as shown in Figures 9c and Figures 9d, respectively. The prototype 5 was created by combining two elements with the multi-function of opening the packaging (Figure 9e). The drawing of opener prototype 5 is depicted in Figure 9f. The five prototype packages were developed in the study, which included formed transparent plastic sheets and paper board lamination (Figure 10).

» **Figure 10:** *Packaging design of 5 prototypes*

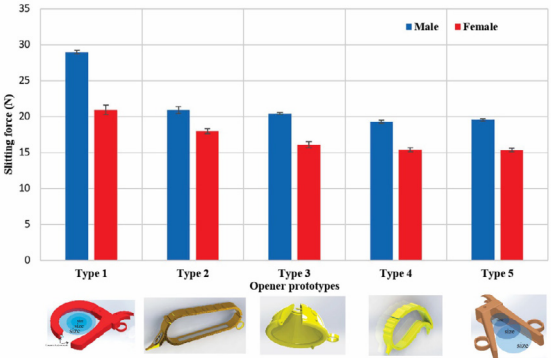
Evaluation of human force and satisfaction by participants

There were 28 participants in total, with fifteen females (53.5%) and thirteen males (46.5%), ranging in age from 20 to 45 years old, with a mean weight of 61 kg and a mean height of 160 cm. Figures 11 and Figures 12 show that the mean slitting male force was greater than the slitting female force in both the right and left hand of both genders. In comparison to the other prototypes,

prototype 1 had the highest mean slitting force. The results indicated that one of the factors influencing the increase in slitting force was the contact surface areas of the hand, fingers, and an assist tool during the test due to the different strengths of both genders. Second, in the gripping style of prototype 1 with pulp grip (Figure 5d), participants produced more slitting force by coordinating their hand and physical finger patterns. The index finger produced a high force value. The function of the thumb finger was directly controlled by the tool's grip position, whereas the middle-ring-little finger group was supported by an originating force contribution from grip manipulation. A similar tendency was obtained by Kamat et al. (2010), Huang et al. (2014) who reported that grip posture patterns, the pressing force, and the position arrangement of each finger affected strength distribution on the surface. For five opener types, males generated higher average slitting force values than females. Females' physical strength is possibly lower, and their hands are smaller than males. This finding is consistent with previous research by Huang et al. (2014), Nilmanee et al. (2018), and Yoxall et al. (2010). As a result, the grip postures of the participants while testing the slitting measurement are depicted in Figure 5d, Figure 6d, Figure 7d, Figure 8d, and Figure 9d.

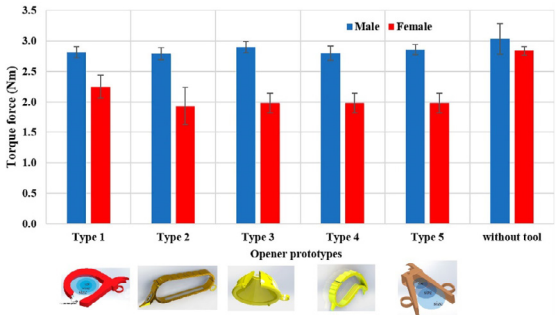


» **Figure 11:** *Mean slitting force of 5 prototypes applied to the plate with the right hand by both genders*



» **Figure 12:** *Mean slitting force of 5 prototypes applied to the plate with the left hand by both genders*

On the basis of force application, the two most common methods of opening grip postures were classified. The first method applied gripping pressure to the prototype in the above direction, as shown in prototype 3 (Figure 7b). On the other hand, human pressure performed in the side direction of the closures can be seen in prototypes 1, 2, 4, and 5 (Figure 5b, Figure 6b, Figure 8b, and Figure 9b). In terms of torque force exertion, all participants were able to open a 60-mm lug cap diameter using only 5 prototypes and their bare hands, as shown in Figure 13. The mean torque force of using the five openers was 2.83±0.05 Nm of males and 2.02±0.13 Nm of females, while without tools, it was 3.04±0.25 Nm of males and 2.84±0.07 Nm of females. When comparing torque force values with and without the tools, the results were slightly different. The previous study found that the torque force effect of the subject's grip posture features differed on the lug closure for the precision grip and the power grip (Yoxall & Rowson, 2014). According to another study by Nilmanee et al. (2018), the force measurement between human and machine speed in the attempt of an opening and peeling test could transmit force difference. These findings indicated that males exerted a greater average torque force than females. Similarly, Bonfim et al. (2016) found that men exerted greater opening torque than women, both with and without gloves. In general, the effectiveness of the opening posture is dependent not only on the physical strength of ordinary packaging under the aided tools of each prototype geometry, but also on the user's hand strength, as in the case of emerging by gender. Furthermore, torque force testing results revealed that friction force against using aided tools is an important factor affecting the absolute implication in opening lug closure with five prototypes. The rubber pads were placed on the prototypes' specific contact areas, increasing the friction force during the opening. Yoxall and Rowson (2018) confirmed these findings, stating that the cap material-skin friction coefficient had a significant effect on the opening torque force. Malea et al. (2020) designed the packaging of innovative toothpaste by considering the mechanism used with the hand and its interaction with the user- friendly.



» **Figure 13:** *Mean torque forces applied by both genders on the jar lug cap of participants for a comfortable hand with the 5 openers and without the opener*

Table 2

Frequency of participant satisfaction score with the prototype of assistant tools (n=28)

Factor	Percentage of satisfaction (%)				
	Type 1	Type 2	Type 3	Type 4	Type 5
Ergonomics and geometry					
1. Comfortable grip posture in hand and finger	91.4	57.1	87.1	69.3	55.7
2. Shape, form, and dimension are suitable for functions for cutting, torqueing, pulling, and slitting	86.4	60.0	87.9	74.3	51.4
Utilities					
3. It can be cut easily	90.0	60.0	87.1	74.3	60.0
4. It can be gripped easily	88.6	60.7	87.1	71.4	61.4
5. Easy to carry during use it	84.3	75.0	68.6	67.9	72.9
Safety					
6. Feel safe and reduce the risk of harm after using	88.6	75.7	89.3	82.1	42.9
7. Good force contribution during use it	87.1	66.4	87.9	72.9	58.6
Commercial and design					
8. Commercial application possibility	82.9	58.3	85.0	72.1	63.6
9. Contemporary trendy and innovation	84.3	62.9	82.1	70.7	52.1
10. Attractive and creative design	83.6	77.1	89.1	80.0	42.1

According to satisfactory evaluation, Table 2 summarizes the percentages of the participant responses using the five opener prototypes after the participants tested opening the packaging. The ergonomics and geometry sufficiency assessment scores of prototypes 1 and 3 were both above 80%. Prototype 1 received higher appreciation scores for user accessibility by cutting, slitting, twisting, and gripping when compared to the other prototypes. More than 80% of participants chose prototypes 1, 3, and 4 based on the results of the safety of use and grip strength tests. Participants were acquainted with prototypes 1, 3, and 4 to imply commercial design.

Conclusion

The functions of user accessibility have sufficiently improved the opener by cutting flexible packaging, slitting off the tape of a corrugated box, twisting the jar lug cap, and pulling the opening ring of a can. The opening enhancement has been combined with four functions into a single tool. The easy-grip, ergonomics, and universal safety features were implemented. On the packages, usability and openability were referred to as finger coordination and grip posture. The design principle of the opener prototypes was created based on form, shape, ratio, dimension, surface contact friction force, and attractiveness. Ultimately, problems with opening packaging can be solved by utilizing the ease of the openers and understanding the user's opening mechanisms. The main concepts of this study were ergonomics and functionalities. The dimension of the packaging openers should be suitable for the hand ratio of both genders to provide further indication of the design concept. These opener analysis results are useful as guidelines for designers and manufacturers to estimate the actual opening postures, product forms, and product conduction before production based on human evaluations of usage, strength, and satisfaction. Function, safety, usability, design, and engineering are important factors to consider when evaluating each product.

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Analysis of factors and construction of prognostic quality models of flexographic printing process of packaging with solvent based inks

ABSTRACT

The presented article shows the results of the analysis of the factors influence on the flexographic printing process with solvent based inks. The main factors influencing the printing process quality are identified, a semantic network of influence and dependencies of these factors is constructed. The priority of factors, taking into account their influences and dependencies, is established by the ranking method. Using the Pareto rule and the construction of the corresponding diagram, four main factors are identified, the influence of which provides 70 % of the studied process quality. It is established that the most priority factors are the parameters of the printing plate, the rheological parameters of the ink, the lineature of the anilox roller and the surface properties of the material to be printed, with the following calculated values: 150, 120, 105 and 90 units, respectively. The selected factors are used to analyse their impact on the flexographic printing process by means of fuzzy logic. Accordingly, a universal set, corresponding terms and a fuzzy knowledge base with the condition "If-Then" are established for these factors in the form of linguistic variables. The formed knowledge base is tested with the help of the Fuzzy Logic Toolbox package of the Matlab technological computing environment and the corresponding prognostic models of the influence of the selected factors on the printing process quality are constructed.

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KEY WORDS
Flexography, semantic network, priority factors, ranking method, Fuzzy logic, term, linguistic variable, quality

Introduction

Despite ecological challenges, the global solvent-based printing inks market is expected to grow from $ 11.63 billion in 2021 to $ 13.49 billion in 2025 at a compound annual growth rate (CAGR) of 4 %. The growth is mainly due to the companies rearranging their operations and recovering from the COVID-19 impact, which had earlier led to restrictive containment measures involving social distancing and the closure of commercial activities that resulted in operational challenges (The Business Research Company, 2021). Flexographic printing method of flexible packaging with solvent based inks for food and industrial products maintains a leading position in this segment compared to other printing methods (Siegwerk, 2017). Its development is accompanied by constant improvement of materials and technologies. The use of new types of polymers in combination with the latest technologies of exposure and processing has completely changed the plate making processes. Ukrainian flexographic printing companies are not far behind world leaders and are actively implementing the latest developments. These processes require constant and thorough testing, analysis and research. Accordingly, the analysis of the factors influence on the flexographic printing process of flexible packaging with solvent based inks and the creation of a prognostic model of their influence is extremely relevant.

Literature Review

In the work (Gurgal et al., 2013), the factors analysis of narrow-web flexographic printing of a labels by UV inks was carried out. If one talks about flexographic printing technology with solvent based inks, this printing method differs from the narrow-web one in a more complex preparation of consumables for printing. This primarily applies to the preparation of printing inks (Harper Anilox & Coating Division, 2020), control of its viscosity, control of the surface energy of printed materials (Kukura, Kukura & Repeta, 2010). The influence of the surface properties of polymer films on the optical parameters of imprints and the adhesion of flexographic inks was studied by Repeta (2013). It is established that the optimal optical and adhesive values of the imprints can be obtained at the surface energy above 38 mN/m.

Another element of the ink supply systems in flexographic printing method is a doctor blade, which is designed to remove the excess ink from the surface of the anilox roller and thus adjust the amount of ink supplied to the photopolymer printing plate and consequently printed material. Manufacturers of doctor blades produce blades of different configurations and of different materials (Repeta, 2018). There is no opinion about the use of a certain universal doctor blade. According to practical recommendations, different types of doctor blades are used for different inks in one printing press, for example, with white inks and inks with metallized pigments it is necessary to install thick doctor blades, and with increasing the image lineature it is recommended to select a blade with a thinner working edge (Daetwyler, 2021).

Double-sided adhesive mounting tapes are used to install the flexographic plate on the sleeve or plate cylinder and hold it firmly during the printing process. According to the results of the study (Eggleston, 2007; 3M, 2022), it is found that with increasing the tape stiffness increases the solid area saturation, and squeezing begins in 2% of the halftone value. In the case of the plate mounting that contains solid and halftone areas at the same time, a universal tape with intermediate stiffness is selected.

Photopolymer properties (thickness, roughness and surface properties) and reproductive characteristics of the printing plate are very important in terms of quality of the finished imprint, determining the lineature of the raster image, the accuracy of all its elements reproduction, the uniform printing of solid areas and the plate wear resistance (Hamblyn, 2015; Valdec, Miljković & Čerepinko, 2018). That is why the improvement of manufacturing technology of printing plates and the use of new types of polymers have revolutionized flexography, allowing one to raise the quality of the reproduced image to a new level (Vest, 2017). This breakthrough would be impossible to achieve without improving the technology of manufacturing anilox rollers, the parameters of which are a determining factor in the formation of the ink layer on the printing plate elements (Harper, 2005; Savickas, Stonkus & Jurkonis, 2020) and a key element in the ink transfer system in flexography (Bould et al., 2011).

The regulating element of this system is the pressure between the anilox and the printing plate and between the printing plate and the printing cylinder, which ensure the optimal ink application on the imprint (Bohan et al., 2003). As for the solvent based printing ink itself, its main technological parameter, which requires constant monitoring during the printing process, is its viscosity (Gencoglu, 2012; Kukura & Kukura, 2008). And since the fixation of alcohol-soluble inks occurs as a result of the solvent evaporation, a significant influence on this process has the drying temperature of the imprints (Olsson et al., 2007).

All these parameters, influencing each other, as a result determine the final quality of the imprint, which is characterized by the optical density parameters as well as squeezing of printing elements in addition to the accuracy of the original reproduction (Żołek-Tryznowska et al., 2020).

Thus, the flexographic printing process of packages with solvent based inks can be considered as a set of elements that are in certain relationships and connections with each other, interact with each other and create a certain integrity – the system.

The aim of the article is to establish the importance of factors, determine the optimal parameters and construct prognostic models of the impact of selected priority factors on the quality of the flexographic printing process using fuzzy logic tools.

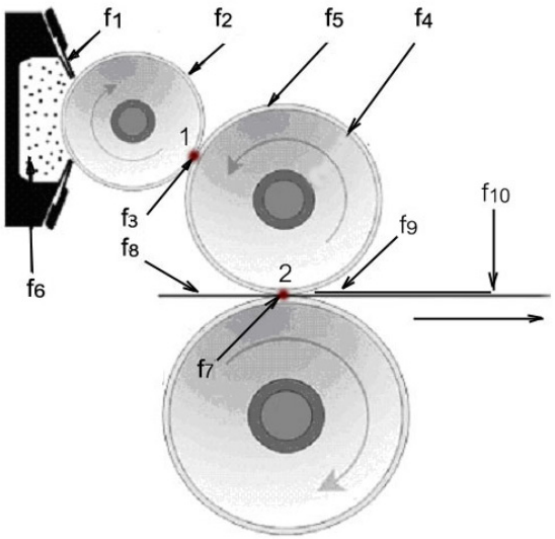
Methods, Results and Discussions

Analysis of Factors by Ranking Method

Accordingly, the following factors are established that determine the quality of the flexographic printing process with solvent based inks:

f_1 – is a type of knives of Doctor Blade system (DB)
f_2 – is a type of an anilox roller (AN)
f_3 – is pressure between an anilox roller and a plate (PR1)
f_4 – is a type of an adhesive mounting tape (TE)
f_5 – are parameters of a photopolymer printing plate (PP)
f_6– are rheological parameters of the ink (VI)
f_7 – is pressure in the printing NIP (PR2)
f_8 – are surface properties of the printed material (SP)
f_9 – is thickness of the ink layer (IL)
f_{10}– is a drying mode of imprints (ID).

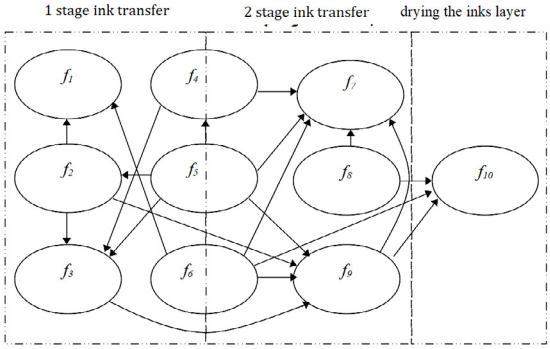
Figure 1 shows the scheme of operation of the flexo–graphic printing press and the influence of selected factors on the printing process.



» **Figure 1:** *Scheme of the operation of the flexographic printing press: f_1-f_{10} are factors that determine the printing process quality; 1 and 2 are areas where the ink transfer happens*

One of the tools for constructing the output information field in the analysis of processes is the semantic network.

The set of factors that determine the flexographic process quality is a set $F=(f_1, f_2, f_3 \ldots f_n)$. The set of factors F and possible relationships between them are presented in the form of semantic network (oriented graph). The vertices of the graph (Figure 2) indicate the presence of the set elements, and the arcs connect these vertices according to the established connections. The use of such a semantic model allows one to clearly describe the basic procedures of the process, identifyty the factors of influence, the relationship between them, and to ensure the appropriate level of their formalization for further study by the appropriate mathematical apparatus.



» **Figure 2:** *Stages of the ink layer formation and the oriented graph of the quality factors of the flexographic printing process with solvent based inks*

Factors, as elements of a semantic network (Figure 2) are placed taking into account the stages of the ink layer formation on imprints as it can be seen from Figure 1. Thus, the factors f_4 – a type of an adhesive tape, f_5 – the parameters of the photopolymer printing plate, f_6 – the rheological parameters of the ink are involved in two stages of the ink layer formation, which clearly makes it one of the most important. To establish the importance of all factors in the flexographic printing process of flexible packaging with solvent based inks, the ranking method is used (Senkivskyy et al., 2020; Tymchenko et al., 2022).

To begin with, the number of calculated influences and dependencies for each of the factors is schematically shown in Table 2. Based on the semantic network (Figure 2) partial graphical models are constructed for each of the factors showing the hierarchy of influences or dependencies between factors. These partial models (Figure 3) will also be the input base for numerical values to quantify and determine their importance.

Table 1

Number of influences and dependencies of factors

The Ways	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}
influences	0	3	1	2	5	4	0	2	2	0
dependencies	2	1	3	1	0	0	5	0	4	3

Total weight and rank of factors taking into account direct and indirect influences and dependencies is calculation as follows: For our semantic network, the following conditions are set (Senkivskyy, Pikh & Melnykov, 2013):

1. Let k_{ij} - is a number of influences ($i = 1$ – direct and $i = 2$ – indirect) or dependencies ($i = 3$ – direct, $i = 4$ – indirect) for j–th factor ($j = 1,\ldots,n$); w_i – is the weight of i–th type.
2. A factor that has no relationships is assigned a value of zero.
3. The conditional values for the weight coefficients of direct and indirect influences in conventional units are the following: $w_1 = 10$, $w_2 = 5$, $w_3 = -10$, $w_4 = -5$;
4. The total weight values are denoted by S_{ij}:

$$S_{ij} = k_{ij} w_i \ (i = 1,2,3,4; \ j = 1,\ldots,n) \tag{1}$$

where n – is the number of the factor;

5. For the semantic networks (Figure 1) in view of (1), the formula for calculating the total weight values for each factor is received:

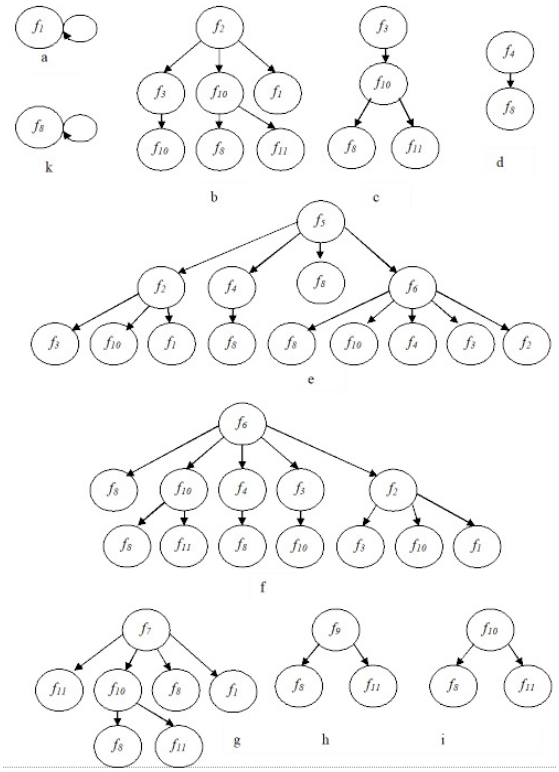
$$S_{ij} = \sum_{i=1}^{4} \sum_{j=1}^{10} k_{ij} w_i \tag{2}$$

6. The weight values are $S_{3j} < 0$ and $S_{4j} < 0$, because according to the given initial conditions $w_3 < 0$ and $w_4 < 0$;

7. To reduce the total weight values of the factor with the lowest priority to zero and the rest to a positive value, the formula (2) is transformed into the form:

$$S_{Fj} = \sum_{i=1}^{4}\sum_{j=1}^{10} k_{ij} w_i + P \qquad (3)$$

where $P = \max|S_{3j}| + \max|S_{4j}|$



» **Figure 3:** *Graphic models of the influence of factors of the flexographic printing process (a – k)*

The coefficient k_{1j} are determined direct influences. Dependencies are determined by obtaining the coefficients are determined by obtaining the coefficients k_{3j}. The combined consideration of indirect influences or dependencies of the factor (i. e. the influence or dependency due to other factors) determines the coefficients k_{2j} and k_{4j}.

The results of the calculations form a table with the subsequent establishment of the ranks of the factors (Table 2).

When determining the total weight and ranking factors, both direct and indirect influences and dependencies for each of them are taken into account (Senkivskyy, Pikh & Melnykov, 2013).

Analysing the semantic network, four coefficients can be calculated for each factor that will characterize all the options for the relationship between them.

Table 2

Calculated data of coefficients and factor ranking

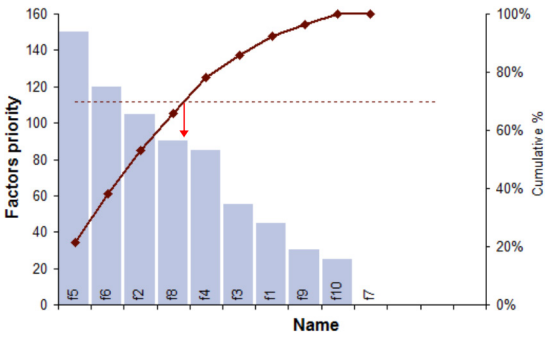
Factor number j	k_{1J}	k_{2J}	k_{3J}	k_{4J}	S_{1J}	S_{2J}	S_{3J}	S_{4J}	S_{FJ}	Factor rank r_j
f_1	0	0	2	1	0	0	-20	-5	45	7
f_2	3	3	1	0	30	15	-10	0	105	3
f_3	1	2	3	1	10	10	-30	-5	55	6
f_4	2	1	1	0	20	5	-10	0	85	5
f_5	5	6	0	0	50	30	0	0	150	1
f_6	4	2	0	0	40	10	0	0	120	2
f_7	0	0	5	4	0	0	-50	-20	0	10
f_8	2	0	0	0	20	0	0	0	90	4
f_9	2	0	4	4	20	0	-40	-20	30	8
f_{10}	0	0	3	3	0	0	-30	-15	25	9

As it can be seen from Table 2, the value *P* (formula 3) will be obtained from the sum of numerical values $\max|S_{3j}| = 50$; and $\max|S_{4j}| = 20$ will be 70 units. As a result, one obtains the resulting quantitative weight of factors, which is the basis for establishing the appropriate rank for each of them, which is equivalent to the priority of their impact on the flexographic printing process of packaging with solvent based inks.

Construction of a prognostic model of the factors influence using the fuzzy logic tools

Using the Pareto empirical rule, the most important factors are selected that determine 70% of the quality of the flexographic printing process. As it can be seen from Figure 4, these will be the following factors:

f_5 – parameters of a photopolymer printing plate (PP);
f_6 – rheological parameters of the ink (VI);
f_2 – a type of an anilox roller (AN);
f_8 – surface properties of the printed material (SP).



» **Figure 4:** *Diagram of Pareto factor selection*

Having obtained four selected factors, their impact on the quality of the flexographic printing technological process of packaging is analysed. Taking into account that the information obtained in the survey on the

factors influence on the process is characterized by fuzziness, the basis of fuzzy logic is used to analyse it.

Fuzzy logic is seen as an attempt to formalize two human capabilities: 1. The ability to communicate, consider and make rational decisions in an environment of inaccuracy, uncertainty, incomplete information, conflicting information, partial truth and partial possibilities; 2. The ability to perform various physical actions and mental tasks without any measurements and any calculations (Zadeh, 2008). The concept of a linguistic variable was introduced in the work of Latfi Zadeh (1970), who laid the foundations of fuzzy logic. Each lingvistic variable stands for a hypothetical proposition, it may assume either of the two truth values; the variable is not committed to either truth value unless a particular proposition is substituted for it (Klir & Yuan, 1995). The main stage of fuzzy logic is the fuzzyfication operation, i. e. the transformation of the original numerical data into a distribution that corresponds to the terms of the linguistic variable. In this case, each numerical value is described by one or more terms, and its degree of correspondence to the term is given as the degree of belonging to a fuzzy set (Zadeh, 1970).

The quality of the flexography printing process *Q* depends on the priority factors presented as linguistic variables such as Parameters of photopolymer printing plate (*PP*), Type of anilox roller (*AN*), Rheological ink parameters (*VI*) and Surface properties of the printed material (*SP*):

$$Q = f\,(PP, AN, VI, SP) \tag{4}$$

These linguistic variables, which ensure the quality of the printing process and assessment terms, are presented in Table 3.

Table 3

Linguistic variables of factors influence on the flexography printing quality

№	Variable	Universal set	Assessment terms
1	Parameters of photopolymer printing plate (lineature)	46-54 l/cm	Low
			Medium
			High
2	Type of anilox roller (lineature)	250-420 l/cm	Low
			Medium
			High
3	Rheological ink parameters (viscosity)	16-20 sec (Cup 4 mm)	Low
			Medium
			High
4	Surface properties of the printed material (surface energy)	34-40 mN/m	Low
			Medium
			High

As a result, the expert knowledge base which corresponds to the printing process for the highest level can be presented as follows:

if (PP = Low) or (PP = Medium) or (PP = High)
and (AN = Low) or (AN = Medium) or (AN = High)
and (VI = Low) or (VI = Medium) or (VI = Big)
and (SP = Low) or (SP = Medium) or (SP = High)
then (Q = Low) or (Q = Medium) or (Q = High)

Based on technical recommendations on the factors influence on the flexographic printing quality, the membership functions are constructed. Accordingly, the value of the variable "Parameters of photopolymer printing plate (lineature)" is determined on the universal set: u_1 = 46 l/cm; u_2 = 48 l/cm; u_3 = 50 l/cm; u_4 = 52 l/cm; u_5 = 54 l/cm. To linguistically assess this parameter, a set of fuzzy terms is used: *T (x) = <Low, Medium, High>*. In accordance with these terms, the membership functions of the linguistic variable "Parameters of photopolymer printing plate (lineature)" are obtained. The value of the variable in the form of fuzzy sets is as follows:

$$\text{Lineature of Printing Plate is Low} = \left(\frac{1}{46};\frac{0,90}{48};\frac{0,67}{50};\frac{0,33}{52};\frac{0,11}{54}\right),\ \text{l/cm};$$

$$\text{Lineature of Printing Plate is Medium} = \left(\frac{0,11}{46};\frac{0,67}{48};\frac{1}{50};\frac{0,67}{52};\frac{11}{54}\right),\ \text{l/cm};$$

$$\text{Lineature of Printing Plate is High} = \left(\frac{0,11}{46};\frac{0,33}{48};\frac{0,67}{50};\frac{0,90}{52};\frac{1}{54}\right),\ \text{l/cm}.$$

For the linguistic variable "Type of anilox roller (lineature)", the parameter is defined on the universal set: u_1 = 250 l/cm; u_2 = 300 l/cm; u_3 = 340 l/cm; u_4 = 370 l/cm; u_5 = 420 l/cm. To assess the variable, a set of fuzzy terms is used: *T(y) = <Low, Medium, High>*. Therefore, in relation to this parameter according to these terms, the value of this variable in the form of fuzzy sets is received as follows:

$$\text{Lineature of anilox roller is Low} = \left(\frac{1}{250};\frac{0,78}{300};\frac{0,55}{340};\frac{0,33}{370};\frac{0,11}{420}\right),\ \text{l/cm};$$

$$\text{Lineature of anilox roller is Medium} = \left(\frac{0,11}{250};\frac{0,55}{300};\frac{1}{340};\frac{0,55}{370};\frac{11}{420}\right),\ \text{l/cm};$$

$$\text{Lineature of anilox roller is High} = \left(\frac{0,11}{250};\frac{0,33}{300};\frac{0,55}{340};\frac{0,78}{370};\frac{1}{420}\right),\ \text{l/cm}.$$

For the linguistic variable "Rheological ink parameters (Viscosity)", the parameter is defined on the universal set: u_1 = 16 s; u_2 = 17 s; u_3 = 18 s; u_4 = 19 s; u_5 = 20 s. To assess the variable, a set of fuzzy terms is used: *T(z) = <Low, Medium, High >*. Therefore, in relation to this parameter according to these terms, the value of this variable in the form of fuzzy sets is received as follows:

$$\text{Viscosity is Low} = \left(\frac{1}{16};\frac{0,88}{17};\frac{0,55}{18};\frac{0,33}{19};\frac{0,11}{21}\right),\ \text{s};$$

$$\text{Viscosity is Medium} = \left(\frac{0,11}{16};\frac{0,55}{17};\frac{1}{18};\frac{0,55}{19};\frac{0,11}{21}\right),\ \text{s};$$

$$\text{Viscosity is } \textit{High} = \left(\frac{0,11}{16};\frac{0,33}{17};\frac{0,55}{18};\frac{0,88}{19};\frac{1}{21}\right),\ \text{s}.$$

The linguistic variable "Surface properties of the printed material (surface energy)", as another factor in the printing process quality, is defined on the universal set:

u_1 = 34 mN/m; u_2 = 36 mN/m; u_3 = 38 mN/m; u_4 = 40 mN/m; u_5 = 42 mN/m.

For linguistic assessment of the parameter, a set of fuzzy terms is used: *T (r) = <Low, Medium, High>.*

Different values of the variable "Surface properties of the printed material (surface energy)" are presented in the form of fuzzy sets:

$$\text{Surface energy is Low} = \left(\frac{1}{34};\frac{0,88}{36};\frac{0,55}{38};\frac{0,33}{40};\frac{0,11}{42}\right),\ \text{mN/m};$$

$$\text{Surface energy is Medium} = \left(\frac{0,11}{34};\frac{0,55}{36};\frac{1}{38};\frac{0,55}{40};\frac{0,11}{42}\right),\ \text{mN/m};$$

$$\text{Surface energy is High} = \left(\frac{0,11}{34};\frac{0,33}{36};\frac{0,55}{38};\frac{0,88}{40};\frac{1}{42}\right),\ \text{mN/m}.$$

A fuzzy knowledge base is formed on the selected quality parameters of the flexographic printing process with solvent based inks:

1. For the flexographic printing quality term «Low»:
- If «PP» is «Low», «AN» is «Medium», «VI» is «Medium», «SP» is «High»
or
- If «PP» is «Medium», «AN» is «Low», «VI» is «Big», «SP» is «Low» then Q is «Low»

2. For the flexographic printing quality term «Medium»:
- If «PP» is «Medium», «AN» is «Medium», «VI» is «Medium», «SP» is «Medium»
or
- If «PP» is «Medium», «AN» is «High», «VI» is «Big», «SP» is «High» then Q is «Medium»

3. For the flexographic printing quality term «High»:
- If «PP» is «High», «AN» is «High», «VI» is «Low», «SP» is «High»
or
- If «PP» is «High», «AN» is «High», «VI» is «Medium», «SP» is «High» then Q is «High».

According to the knowledge base, fuzzy logical equations are formed to prognostic variant of the quality of printing process of packaging:

$$\begin{aligned}&\mu^{low}(Q)=\mu^{low}(PP)\wedge\mu^{med}(AN)\wedge\mu^{med}(VI)\wedge\mu^{high}(SP)\vee\mu^{med}(PP)\wedge\mu^{low}(AN)\wedge\mu^{big}(VI)\wedge\mu^{low}(SP);\\&\mu^{med}(Q)=\mu^{med}(PP)\wedge\mu^{med}(AN)\wedge\mu^{med}(VI)\wedge\mu^{med}(SP)\vee\mu^{med}(PP)\wedge\mu^{high}(AN)\wedge\mu^{big}(VI)\wedge\mu^{med}(SP);\\&\mu^{high}(Q)=\mu^{high}(PP)\wedge\mu^{high}(AN)\wedge\mu^{low}(VI)\wedge\mu^{high}(SP)\vee\mu^{high}(PP)\wedge\mu^{high}(AN)\wedge\mu^{med}(VI)\wedge\mu^{high}(SP).\end{aligned} \quad (5)$$

When substituting the degrees of belonging to the system of fuzzy logical equations, one of the options for calculating the quality of the flexography printing process of packaging is obtained:

$$\begin{aligned}&\mu^{low}=0,33\wedge0,78\wedge0,55\wedge0,88\vee0,67\wedge0,22\wedge0,88\wedge0,33=0,33\\&\mu^{med}=0,67\wedge0,78\wedge0,55\wedge0,55\vee0,67\wedge0,89\wedge0,88\wedge0,55=0,55\\&\mu^{high}=0,9\wedge0,89\wedge0,55\wedge0,88\vee0,9\wedge0,89\wedge0,89\wedge0,9=0,89\end{aligned}$$

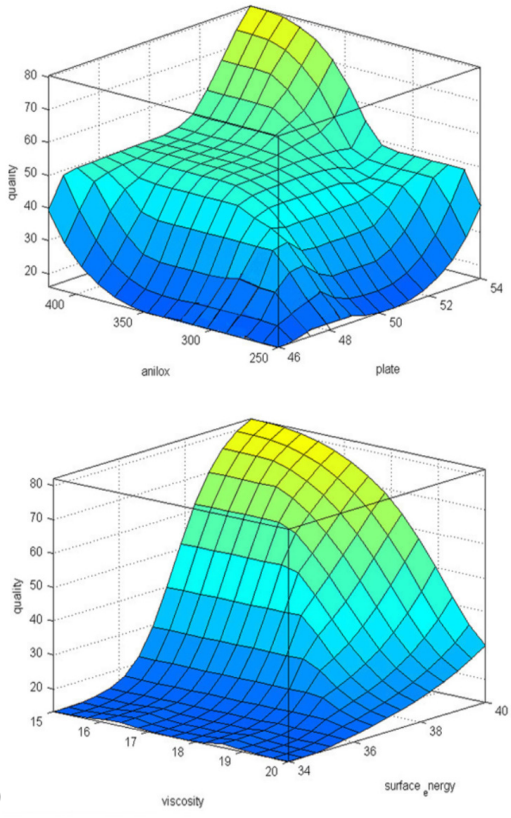
After performing the defuzzyfication operation "centre of gravity" principle using the factors values, the numerical value of the quality parameter of the flexography printing process is obtained (Rotshteyn, 1999):

$$Q=f(PP,AN,VI,SP)=\frac{\sum_{i=1}^{m}u_i\cdot\mu(u_i)}{\sum_{i=1}^{m}\mu(u_i)} \quad (6)$$

Therefore, having performed the defuzzyfication operation, a quantitative parameter of the process quality is obtained:

$$Q=\frac{1\cdot0,33+50\cdot0,55+100\cdot0,89}{0,33+0,55+0,89}=66,0\%$$

To test the formed knowledge base and construct a prognostic model of the influence of priority factors, a package for developing fuzzy control systems – Fuzzy Logic Toolbox system of the Matlab technological calculation environment and Mamdani principle is used (Mamdani & Assilian, 1975). Figure 5 presents the constructed membership functions for three linguistic variables.



a)

b)

» **Figure 5:** *Prognostic models of the influence of selected factors on the flexographic printing process of packaging: a - the influence of the parameters of the anilox roller and the printing plate; b - the influence of the viscosity of the printing ink and the surface energy of the substrate.*

The simulation results (Figure 5) show the adequacy of the developed knowledge base and the possibility of its use for forecasting assessment of the quality of flexography printing process when selecting the priority factors weight.

Conclusions

The quality factors of flexographic printing process of flexible packaging with solvent based inks were determined. By constructing semantic networks of the influence and dependencies of factors and the ranking method, the factors priority has been established by giving them the appropriate weight. Using the Pareto rule and the construction of the corresponding diagram, four main factors are identified, the influence of which provides 70 % of the studied process quality. It is established that the most priority factors are the parameters of the printing plate, the rheological parameters of the ink, the lineature of the anilox roller and the surface properties of the material to be printed, with the following calculated values: 150, 120, 105 and 90 units, respectively.

As a result of the simulation of the influence of priority flexographic printing factors using fuzzy logic, a base of knowledge and fuzzy logical equations are formed to calculate the membership functions of linguistic variables with the corresponding given terms. Their logical analysis and the defuzzyfication operation had allowed obtaining a quantitative assessment of the quality of the flexographic printing process. In addition, the Fuzzy Logic Toolbox system of the Matlab technological computing environment has constructed prognostic models of the influence of parameters of the printing plate, anilox roller, printing ink viscosity and surface energy, which will a priori predict the quality of flexographic printing process with solvent based inks.

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