Formative Evaluation of Diverse Flexible Display Product Concepts Using Mock-Ups and Strategy Canvas

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ABSTRACT

This study evaluated flexible display concepts (foldable, rollable, and bendable) using the strategy canvas, and determined screen sizes suitable for each of five major smartphone tasks on foldable display concepts and preferred folding methods. Before using the strategy canvas to compare design concepts, two focus group interviews were conducted. The first interview was done with four design major students and the second with four human factors engineering major students. A total of 44 evaluation criteria obtained from these interviews were comprised of advantages, disadvantages, and characteristics of each flexible display concept. Thirty three evaluation items were selected and used when five researchers independently evaluated each flexible display concepts. The means of five evaluations were used to draw the strategy canvas. The foldable display concepts were scored the highest while therollable display concept was scored the lowest. For the preferred screen sizes and the folding methods, a small screen size was preferred for the calling task, while a medium screen size was for the search and game tasks. An outward-folded screen type was preferred over an inward-folded type for one-fold screen concepts, while a z type (outward- and inward- folded screen) was preferred among three two-fold screen concepts. Overall, the z type was the most preferred concept. These findings will help to design ergonomic foldable display products and to improve rollable design concepts.

Keywords: Flexible Display, Rollable Display, Foldable Display, Two-Fold, Smart Devices

1. Introduction

Though many flexible display smartphone concepts have been proposed, only a few studies have investigated usability of such concepts. Following curved displays, foldable and rollable displays are expected to be adopted to smartphones. Display curvature can provide both positive and negative effects depending on the tasks. Yi, J. (2016) have found that the grip of curved smartphone varied by the type of task, and that there is no curvature with absolutely positive grip experience on all tasks.

Similarly, it is necessary to examine the usability of foldable and rollable displays. This study first compared flexible smartphone concepts to identify strengths and weakness involved in each flexible smartphone concept. It also determined appropriate screen sizes for foldable smartphone concepts in consideration of typical smartphone application tasks. Finally, it determined preferred folding concepts.

2. Method

2.1 Evaluation Criteria

In order to compare flexible display concepts using the strategy canvas, evaluation criteria need to be determined. Forty four evaluation items for flexible smartphones were obtained through two focus group interviews - one with four industrial design major students and the other with four human factors engineering major students. These 44 items were divided into 3 groups: advantages (15 items), disadvantage (18 items), and characteristics (11 items). The first two item groups were used to draw strategy canvas of flexible displays.
2.2 Strategy Canvas

Five researchers evaluated each of five different types of flexible displays ( Bendable, Rollable, In-foldable, Out-foldable, and In & Out-foldable) using the 15 advantage and 18 disadvantage evaluation items defined in 2.1. These items were classified into 6 categories: Usability, Durability, Productivity, Performance, Product, and Interaction Methods; the Usability category was then divided into subcategories of: Grip, Display, Control, Screen Extension, and Portability. Each researcher marked each evaluation item on a 3-point scale (0: very likely, Δ: neutral, and ×: very unlikely). For scoring, O, Δ, and × given for the advantage items meant +1, 0, and -1 respectively, and vice versa for the disadvantage items (-1, 0, +1 respectively). The line for each flexible display concept on the strategy canvas was drawn by connecting the means of five evaluations for each evaluation item.

2.3 Screen Size and Folding Method Preference

Participants

Thirty right-handed individuals (15 males and 15 females) were recruited for the experiment with their mean (SD) age of 21.6 (2.19) years old. All participants had used smartphones for at least the past two years, the mean (SD) smartphone usage experience of the participants was 4.6 (1.5) years. All participants have reported that they were healthy with no musculoskeletal diseases.

Design of experiment

The experiment was designed with two different sessions to evaluate screen size preference and folding methods preference separately. Both sessions were carried out using 3D printed mock-ups.

Session 1

A 3 (hand length) × 5 (task) × 3 (screen size) mixed factorial design was used for the first session to evaluate the appropriate screen size of the foldable smartphone for each task. The first independent variable was the hand length (between-subjects); the level of the hand length was classified based on the hand data of South Koreans aged between 20–50 years (Size Korea, 2010), the 3 levels of hand length were small (≤169.9mm; 10th percentile), medium (174.9–177.3mm; 40th–60th percentile), and large (≥182.2mm; 90th percentile).

The second independent variable was the tasks. The tasks were determined by the rank of smartphone application usage in Korea (Korea Internet & Security Agency, 2014). Top 5 applications used for the experiments were Kakao Talk (79.4%), Call (70.7%), Internet Search (44.0%), SMS (40.0%), and Games (29.6%). The last independent variable, screen size, was determined by the multiplying the sum of the average size of the existing smartphones (120×60mm) and the bezel thickness between bodies (5 mm) by the number of screens. The size of existing smartphone was calculated by subtracting bezel from the optimized size (140×65mm) considering the grasp evaluated by Lee (2016), and there were 3 levels: small screen (120×60mm), medium screen (120×130mm), and the large screen (120×200 mm) as shown in Figure 1.

The first session was proceeded after each participant used each size mockup freely while sitting on a height adjustable seat with both hands on the table. Suitability of screen size was rated on a 100mm VAS (0: Too small, 100: Too big) as a dependent variable.

![Figure 1. Screen sizes considered in the experiment](image)

Session 2

The second session was to determine appropriate folding methods. A 3 (hand length) × 14 (mock-up type) mixed factorial design was used. The first independent variable, hand length, was defined as in the first session. The second independent variable was the mock-up type. There were 5 types of folding methods, two of them had a double screen (middle screen) and the remaining three had a triple screen (large screen). All the folding methods had the different versions depending on the direction they were unfolded.

Two dependent variables were used in the second session. The first dependent variable was satisfaction level of folding/unfolding method of each mock-up type, and was rated on a 100mm VAS scale (0: very uncomfortable, 100: very comfortable). The second dependent variable was the ranked score for the folding methods of double-screen concepts, triple-screen concepts, and then of all concepts. For ranking all screen size concepts, the price, weight, and thickness of all concepts were assumed to be equal. In addition, participants were asked to determine the maximum price...
of the triple screen smartphone that they would pay to buy the phone, while assuming the price of double screen smartphone to be 1 million won.

**Procedure**

Both sessions were carried out on the same day in a series after a 5-minute break. The duration of the first and second sessions was 20 min and 40 min, respectively. Before each session began, participants were introduced about the session for 5 min. After the second session was finished, 2 min was given to evaluate the ranking of foldable smartphone concepts and the agreeable price of the triple screen concept.

### 3. Results

#### 3.1 Strategy Canvas

The overall score of each flexible smartphone concept based on the advantages and disadvantages listed in Table 1 of all five evaluators were cumulated by their classes and subclasses and plotted on Figure 2. The overall cumulative score of classes are shown on Table 1.

#### 3.2 Screen Size and Folding Method Preference

**Session 1**

According to 3-way ANOVA of three independent variables, the screen size and task both showed significant effects (p-value: <0.0001). For the interaction effect, the interaction between screen size and task showed a significant effect (p-value < 0.0001). Tukey’s HSD was done on screen size, task, and their interaction effect for post-hoc analysis. The post-hoc analysis result showed that the medium screen size was the closest to the appropriate screen size, and the small screen size was appropriate for the call task.

**Session 2**

According to 2-way ANOVA, only the mock-up type showed significant result (p-value < 0.001). Tukey’s HSD was done on the mock-up folding type for post-hoc analysis. The post-hoc analysis result showed the most comfortable folding method to be the dual screen infold followed by z-type. The outfold concept won over the infold concept in the ranking of double screen concept. Twenty one participants have chosen outfold over infold concept. In the triple screen concept, 17 participants have chosen z-type over e-outfold (7) and e-infold (6). In the overall screen size concept ranking, the z-type scored the first rank with 14 participants’ choice, followed by e-outfold (5), dual screen outfold (4), dual screen infold (4), and e-infold (3). As for the agreeable price of the triple screen concepts, the mean price was 1.22 million won with SD of 0.33.

### 4. Conclusion

According to the strategy canvas, the foldable smartphone concepts showed the highest score among the other flexible smartphone concepts. The reasons behind this result seem to be the rigidness and the familiarity of shape that foldable smartphone concepts have. In contrary, the rollable smartphone concept scored the lowest mark in strategy canvas, and participants had hard time imagining the concept when they marked the score. The folding method rank supported the findings of the strategy canvas. The z-type mock-up scored the first rank in overall comparison, and it was the only concept that had the same form as the existing smartphones when folded (accessible screen in front and no screen on the back).

The post-hoc analysis results indicated that the most suitable screen size to be the medium size from both the screen size preference evaluation and the folding method evaluation. However, when the medium and large screen
size mock-ups were compared together to be ranked, the large screen mock-ups took the first and second places.

In conclusion, the foldable smartphone concepts are the most preferable flexible smartphone concept due to its resemblance of existing smartphones' shape and rigidness. For the appropriate screen size and folding method preference, the medium screen outfold concept was the most appropriate concept in terms of size and comfort. However, when evaluated through relative comparison of ranking, the large-size double fold concept (Z-type) were the most preferred one.

References


