# A hybrid fuzzy goal programming for smart phones and rate plan selection

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### Abstract

Smartphones are essential personal belongings today. However, smartphone buyers (SBs) are often hesitant in deciding what the best smartphone and rate plan to choose offered by telecom providers. Among many new smartphones, it is often difficult for users to choose the most suitable one in consideration of reaching the salient success aspiration level (SSAL) as close as possible, e.g., large battery capacity, and avoiding falling below the survival aspiration level (SAL) as far as possible, e.g., budget limitation, simultaneously. A novel hybrid weighted SSAL-SAL fuzzy goal programming (FGP) is proposed to assist SBs in finding satisfactory smartphones of their preferences with suitable rate plans. To meet different preferences, SBs can easily set different weights for each smartphone selection goal with linguistic terms, such as high, average, and low. In addition, these linguistic terms can easily be transformed into trapezoidal fuzzy numbers. The weights are then attached to goals in the objective function in the weighted SSAL-SAL-FGP model for choosing the most suitable smartphone. Moreover, this study also allows SBs to set the goal satisfaction levels as a preemptive priority for each goal in the FGP to find the most suitable rate plan option for the selected smartphone.

The proposed approach allows SBs to select the best smartphones with suitable rate plans considering their priority preferences. In addition, SBs can save costs and precious time in finding their ideal smartphones and rate plan options. Finally, various examples are used to demonstrate the usefulness of the proposed weighted SSAL-SAL-FGP model, which allows SBs to set different weights for each goal with the intuitive method such as linguistic terms or preemptive priority to select appropriate smartphones with suitable rate plans to match their habits and budgets. Besides, this study distributed an online questionnaire to investigate smartphone owners and found that female smartphone owners consider the battery capacity and the weight of the smartphone more crucial than the other criteria, while male smartphone owners prefer a smartphone with bigger screen size.

Keyword: Aspiration level, Smartphone selection, Fuzzy goal programming, Rate plan selection

## 1. Introduction

Smartphone users have their preferences and criteria in the selection of smartphones and rate plans. For male users, battery capacity is the most important feature, followed by hardware quality, ease of use, price, and size of the display (Haverila, 2011). Haverila (2013) found that females in high school and undergraduate students in Finland seem to put more emphasis on price, design, parts used, local language support, and ringtones, while male respondents appreciate the use of business services. Seva and Helander (2009) found that in Singapore, pre-purchase is affected by functional attributes such as display size, weight, and thickness, while purchase intention is influenced by the aesthetic attributes of the body color in the Philippines. Rau et al. (2015) indicated that Chinese customers pay much attention to brand reputation than German customers do. Chinese customers pay much attention to price, brand reputation, screen size of smartphones for showing good social status. Germans customers are also important to German customers. The perspective on the selection of smartphones in different preferences in the selection of smartphones in the selection the sele

different countries. However, we can find the price, display size, battery life, and the design of smartphones are essential criteria in the selection of smartphones.

Table 1 The perspective on the selection of smartphones in different countries						
Country	The perspective on smartphones	Sources				
Singapore	Pre-purchase is affected by functional attributes such	Seva and Helander				

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	as display size, weight, and thickness.	(2009)
Philippines	Purchase intention is influenced by the aesthetic	Seva and Helander
	attributes of the body color	(2009)
China	Chinese customers pay much attention to price, brand	Rau et al. (2015)
	reputation, large screen for showing a good social	
	status.	
German	Germans customers concern the longer battery life,	Rau et al. (2015)
	bigger screen sizes, and faster devices.	
Finland	Females in high school and undergraduate students in	Haverila (2013)
	Finland put more emphasis on price, design, parts	
	used, local language support, and ringtones.	
	Male respondents appreciate more about the use of	
	business services.	

With the rapid and widespread growth of new smartphones and rate plan options offered by various telecom companies, it is challenging for users to choose the best smartphone and the appropriate rate plan to match their daily usage and habits. Facing many new smartphones emerged in the market, it is often difficult for users to choose the most suitable ones to reach their salient success aspiration level (SSAL) as close as possible, e.g., large battery capacity, and to avoid falling below their survival aspiration level (SAL) as far as possible, e.g., budget

limitation, simultaneously. As a good strategy, companies take risks by both approaching the SSAL and moving away from the SAL at the same time (Greve, 1998). The SSAL-SAL method is proposed to help firms to solve multiple criteria/objective decision-making problems (Chang, 2018). The drawbacks of the SSAL-SAL method are as follows: (1) it has not been used to solve practical problems; (2) it does not allow decision-makers (**DMs**) to set different weights for each goal with the intuitive method, and (3) it does not allow DMs to express their fuzzy preference relations between goals. Therefore, the contributions of the proposed weighted SSAL-SAL-FGP method are (1) it is the first time to apply SSAL-SAL method to a practical problem, (2) it is the first time to provide the weight setting mechanism for the SSAL-SAL method, and (3) it discusses the fuzzy preference relations among goals for the SSAL-SAL method as well. Facing lots of potential smartphone alternatives, smartphone buyers (**SBs**) need a more scientific and intuitive method to choose the most suitable ones. In addition, the proposed weighted SSAL-SAL-FGP method also contributes to the field of decision-making.

Moreover, choosing from many potential rate plan alternatives is also challenging for SBs. Nowadays, a SB usually needs to choose an appropriate rate plan while choosing a suitable smartphone. However, telecom companies usually provide many rate plans, such as unlimited cellular access and talk options. In general, SBs have too many rate plan options to choose from telecom companies, especially when they have been perplexed over ambiguous advertising. When SBs consider multiple goals of a rate plan selection, setting preemptive priority among goals is essential. Thus, a purely scientific and feasible method is required to help SBs find out the most suitable smartphone and its matching rate plan.

Meanwhile, the fuzzy decision-making method has been widely applied to solve real-world problems, especially in order to aid human judgments and linguistic evaluations in the decision-making process. Liu et al. (2018) presented a multiple criteria decision-making method

with interval-valued Pythagorean fuzzy information based on the developed distance measures. Meng et al. (2019) presented an approach of linguistic intuitionistic fuzzy preference relations for multi-criteria decision making and adopted it as a tool in evaluating mobile phones. However, their approach requires the DMs to compare two objects at one time and does not support group decision-making. Feng et al. (2020) established an integrated multi-criteria decision model based on a morphological matrix and intuitionistic fuzzy preference relations in solving the group decision-making problem in the product conceptual stage. Javed et al. (2020) proposes a grey absolute decision analysis method to deal with the problem of uncertainty and incomplete data for multiple criteria group decision-making. Wu et al. (2020) combined triangular intuitionistic fuzzy numbers (TIFNs), analytic network process (ANP), and preference ranking organization method for enrichment evaluations (PROMETHEE) in site selection of offshore wind power stations.

Nevertheless, sometimes it is not easy for DMs to make a comparison between criteria. Hsu (2015) integrated the fuzzy ANP, the fuzzy VIKOR, and the importance performance analysis (IPA) to diagnose managerial strategies and analyze customer gaps in service quality. Çolak and Kaya (2020) integrated Delphi, Analytic Hierarchy Process (AHP), and VIsekriterijumska Optimizcija I Kompromisno Resenje (VIKOR) methods to evaluate alternative energy storage technologies for Turkey under hesitant fuzzy environment. To the best of our knowledge, there are few present works on fuzzy preference relations between the selection goals of smartphones and the rate plan selection.

In the real world, many decision-making problems are vague and uncertain, especially in setting preference relations among goals. With some of the previous methods, DMs are asked to express their preference with numerical values. When DMs cannot give precise numerical values to express their priority, linguistic terms come in handy to assist them in setting priorities and

make a reasonable decision (Liu et al., 2020). Although the SSAL-SAL method can be used to solve the decision-making problem of multiple criteria/objectives, it does not allow DMs to set the weight for each goal with an intuitive method in solving the decision-making problem. In order to solve this problem, the weighted SSAL-SAL-FGP method is proposed to allow DMs to solve the real problem using linguistic terms in weight setting among goals.

Some studies focused on the issue of smartphone addiction. Chang et al. (2019) studied smartphone addiction by interviewing 2621 fifth-grade students and 2468 parents in Taiwan. They found the fifth-grade students spent 11 hours per week using either smartphones or tablets, and children who had poor academic performance, depression, were more likely to experience smartphone addiction. Park (2019) examined smartphone users' perception and evaluation of their dependent behavior with 70 smartphone users in South Korea. He found that functionally dependent users were more willing to change their dependent behavior than existentially dependent users.

Some studies discussed smartphone purchasing behavior in different counties. Gordon et al. (2017) surveyed 393 college students and discussed the relationship between smartphones and users' identities in three different cultures, Oman, Ukraine, and the U.S. Anand et al. (2018) adopted the conjoint analysis method to study the purchasing behavior of the youth for mobile phones in Delhi to know what attributes of mobile phones affect their decisions. Ahmad et al. (2019) collected price data of mobile phones in two major cities of Pakistan from 2016 to 2017 and found the brand, battery capacity, weight, operating system, random access memory (RAM) and storage memory size, and display size positively correlated with the pricing.

However, few studies have investigated the choices of smartphones and rate plans. Some studies have only focused on the remanufacturing and environmental impact of mobile phones. Ouariguasi-Frota-Neto and Bloemhof (2012) studied the effectiveness and eco-efficiency of remanufacturing in personal computer and mobile phone industries. Potoglou et al. (2020) used two-choice experiments in Germany, India, Japan, Sweden, UK, and the US to examine the extent people value sustainably-resourced materials for cars and mobile phones. They found that price and functional attributes (e.g., sustainable materials) dominated the product choice. However, the discussion of the selection problem of rate plans is also lacking. In short, the present works focusing on smartphones and rate plans selection are limited even though it is a fundamental issue.

In this paper, the method of weighted SSAL-SAL-FGP is proposed to resolve the selection problem of smartphones and rate plans in consideration of individual users' preferences. The qualitative and quantitative issues are also considered at the same time in one decision model. This improves the usefulness of mathematical programming in management science. The study integrates several approaches to solving real problems. The weighted SSAL-SAL-FGP method is proposed to solve the smartphone and rate plan selection problem in which the solution approaches the SSAL as close as possible and avoids falling below SAL as far as possible, simultaneously. FGP allows decision-makers to set a fuzzy aspiration level for each goal in multiple objective problems. That is, FGP can easily be used to minimize the deviation between goal target and fuzzy aspiration level to obtain satisfactory solutions. To meet different preferences, SBs can set different weights in the weighted SSAL-SAL model for each smartphone selection goal with linguistic terms, such as high, average, and low. Then the weights are attached to goals in the objective function in choosing the most suitable smartphone. Moreover, this study also allows SBs to set the goal satisfaction levels as preemptive priority for each goal in the FGP to find the most suitable rate plan options from the selected smartphone. For example, the weighted SSAL-SAL method is used to find the smartphones with large battery capacities (i.e., to approach SSAL) and low-price (i.e., to move away from SAL), and thus

determines the most satisfactory smartphone. Then, the FGP is used to select the best rate plan with respect to the SB's fuzzy preferences.

The rest of this paper is organized as follows. Section 2 reviews the previous research on smartphone selection criteria. The solution procedure of the proposed weighted SSAL-SAL-FGP method is also described in this section. Section 3 presents a real case selection of smartphones and rate plans provided by three major telecom companies in Taiwan. Section 4 provides the empirical discussion about weight settings in the weighted SSAL-SAL method and preemptive priority goal setting in the FGP method. Section 5 provides conclusions and suggestions for future work.

## 2. The Proposed weighted SSAL-SAL-FGP Method

2.1 Smartphone Selection Criteria

Most smartphone users would prefer to buy a smartphone with better functionality but at a relatively lower price. However, they are bombarded with many options and various features from retailers. From pricing, branding, hardware specifications to functionality are of the crucial elements in the process of smartphone selection. This study combs through the literature and conducts interviews among ten SBs and five senior smartphone retailers in Taiwan to obtain the smartphone selection criteria, as shown in Table 2.

Smartphone selection criteria	Sub Smartpho	items ne selection	of	Sources
Price and Brand	Price		Işık Hav Ana	lar and Büyüközkan, 2007; Chen et al., 2010; rerila, 2011; Haverila, 2013; Aggarwal et al., 2018; and et al., 2018
	Brand		Işık Hav	lar and Büyüközkan, 2007; Chen et al., 2010; rerila, 2011; Haverila, 2013

Table 2. Smartphone selection criteria

Hardware	Style/Design	Işıklar and Büyüközkan, 2007; Chen et al., 2010; Haverila, 2011; Haverila, 2013; Mobilecon 2019;
	Weight	Işıklar and Büyüközkan, 2007; Seva and Helander, 2009; Chen et al., 2010; Aggarwal et al., 2018
	Color	Chen et al., 2010
	Battery capacity	Işıklar and Büyüközkan, 2007; Chen et al., 2010;
		Haverila, 2011; Haverila, 2013; Aggarwal et al., 2018;
		Mobilecon 2019
	Size of the display	Kurniawan, 2008, Seva and Helander, 2009; Haverila,
		2011; Haverila, 2013; Aggarwal et al., 2018;
		Mobilecon 2019
	Memory	Haverila, 2011; Aggarwal et al., 2018; Mobilecon
		2019
	Thickness of the phone	Seva and Helander, 2009;
	Processor	Mobilecon 2019;
	Camera	Mobilecon 2019
Technical build	Phone book capability	Chen et al., 2010
in functions	Schedule	Chen et al., 2010
	Digital camera	Chen et al., 2010
	Flash disk capability	Chen et al., 2010
	Games	Işıklar and Büyüközkan, 2007

## 2.2 Smartphone Ranking with weighted SSAL-SAL Method

As seen in Table 2, there are numerous criteria used for selecting smartphones; some of them should be approaching the SSAL as close as possible (e.g., battery capacity, the higher, the better), while the others are moving away from the SAL as far as possible (e.g., price, the lower, the better), simultaneously. Many marketing and management issues are handled by the approach of these two aspiration levels, SSAL and SAL, in the real world (Mezias, et al., 2002; Miller and Chen, 2004). In real life, DMs try to find the best strategies to increase their market share as much as possible while maintaining organizational performance to avoid increasing the expense as far as possible, simultaneously. The weighted SSAL-SAL method can help SBs to find the

best smartphone from the ranking of the alternatives by approaching the salient success aspiration level (e.g., high battery capacity) as close as possible and moving away from the survival aspiration level (e.g., high price) as far as possible. The description of the weighted SSAL-SAL model is detailed in appendix A.

Furthermore, SBs can define each linguistic term with trapezoidal fuzzy numbers and use linguistic terms such as high, average, and low for each goal to express their weights concerning each goal. This study transforms these linguistic terms for each goal into weights  $w_i$  and these weights are attached to the objective function in the weighted SSAL-SAL model. The linguistic terms can then be transformed into trapezoidal fuzzy numbers with the method proposed by Cheng and Lin (2002), as shown in Table 3.

Linguistic Terms	Trapezoidal Fuzzy Numbers
Very Low (VL)	(0,0.1,0.1,0.2)
Low (L)	(0.1,0.2,0.2,0.3)
Medium Low (ML)	(0.2,0.3,0.3,0.5)
Medium (M)	(0.4,0.5,0.5,0.6)
Medium High (MH)	(0.5,0.7,0.7,0.8)
High (H)	(0.7,0.8,0.8,0.9)
Very High (VH)	(0.8,0.9,0.9,1)

Table 3. Linguistic terms and trapezoidal fuzzy numbers

The *k*th SB can define the linguistic terms with the trapezoidal fuzzy numbers  $\tilde{A}_{ki}$ , for the *i*th goal according to their preference (Cheng and Lin 2002), as shown in Appendix B.

A trapezoidal fuzzy number,  $\tilde{A} = (a_1, b_1, c_1, d_1)$ ,  $a_1 \le b_1 \le c_1 \le d_1$ , and its membership function is expressed as follows:

$$\mu_{\tilde{A}}(x) = \begin{cases}
0, & x < a., \\
\frac{(x-a_1)}{(b_1-a_1)}, & a. \leq x \leq b., \\
1, & b_1 \leq x \leq c_1, \\
\frac{(x-d_1)}{(c_1-d_1)}, & c_1 \leq x \leq d_1, \\
0, & y = d
\end{cases}$$
(2.1)

When  $b_1 = c_1$ ,  $\mu_{\tilde{A}}(x)$  b angular fuzzy numbers, in order to be more realistic, we modified the Eq. (11) in Appendix B with Eq. (2.2)  $(0 \le a_{ki} \le b_{ki} = c_{ki} \le d_{ki} \le 1)$  which make  $\mu_{\tilde{A}}(x)$  become triangular fuzzy numbers in this study.

$$\widetilde{A}_{ki} = (a_{ki}, b_{ki}, c_{ki}, d_{ki}), \ 0 \le a_{ki} \le b_{ki} = c_{ki} \le d_{ki} \le 1, \ k = 1, \dots, q, \ i = 1, \dots, l$$

$$(2.2)$$

For example, an SB can define the linguistic term "High" with the trapezoidal fuzzy numbers (0.7,0.8,0.8,0.9), as shown in Table 3.

The weight  $w_i$  is obtained from the linguistic terms provided by SBs considering a smartphone buyer's opinion or the group decision-making result. The SBs can use linguistic terms to access the importance of the goals. Moreover, the triangular fuzzy numbers,  $0 \le a_{ki} \le b_{ki} = c_{ki} \le d_{ki} \le 1$ , (k = 1,...,q, i = 1,...,l) can be defined by the *k*th SB for the *i*th goal according to their preference. For the group decision-making situation, different linguistic terms from several SBs can be merged according to Cheng and Lin (2002) with Eq. (13), as shown in Appendix B.

After SBs set the selection goal for each smartphone with linguistic terms, they will be transformed into weight  $w_i$ . For example, let the trapezoidal fuzzy numbers  $W_1$ ,  $W_2$  and  $W_3$  be the weights of the goals G1, G2 and G3, respectively, where  $W_1 = (a_1, b_1, c_1, d_1)$ ,  $W_2 = (a_2, b_2, c_2, d_2)$ ,  $W_3 = (a_3, b_3, c_3, d_3)$ . The normalized weights  $\overline{W}_1$ ,  $\overline{W}_2$  and  $\overline{W}_3$  of  $W_1$ ,  $W_2$  and  $W_3$ , respectively, can be obtained according to Cheng and Lin (2002) with Eq. (14),

as shown in Appendix B. The weights  $w_1 = \overline{W}_1$ ,  $w_2 = \overline{W}_2$ ,  $w_3 = \overline{W}_3$ , are then attached to the goals in the objective function (Eq. (1) of Appendix A) in the weighted SSAL-SAL model.

In order to find a suitable smartphone to meet different buyers' preferences, the objective function (Eq. (1) of Appendix A) should be modified as follows.

$$\begin{array}{l}
\text{Minimize} \\ w_1^* ((\frac{s_1^+ + s_1^-}{1}) + k_1^-) + w_2^* ((\frac{d_2^+ + d_2^-}{1}) + f_2^-) + w_3^* ((\frac{d_3^+ + d_3^-}{1}) + f_3^-) \\ + w_4^* ((\frac{s_4^+ + s_4^-}{1}) + k_4^-) \\ \end{array}, \tag{2.3}$$

where  $w_1$ ,  $w_2$ ,  $w_3$ , and  $w_4$  represent the weights of "the price of the chosen smartphone not bundled with any rate plan" (G1 as SAL), "the rate of buyer satisfaction about the battery capacity of the smartphone" (G2 as SSAL), "the rate of buyer satisfaction about the screen size of the smartphone" (G3 as SSAL), and "the weight of the chosen smartphone" (G4 as SAL),  $\sum_{i=1}^{4} w_i = 1$ . With the weights,  $w_1$ ,  $w_2$ ,  $w_3$ , and  $w_4$  attached to G1-G4, the preemptive achievement rates of the goals can be determined by DMs. As for  $(\frac{s_1^+ + s_1^-}{1}) + k_1^-$  in Eq. (2.3), which means the deviational variables of G1 must be minimized. With the higher value of  $w_i$ (i = 1, 2, ..4), the relative goal is satisfied given a higher priority.

### 2.3 Fuzzy Goal Programming (FGP) on Internet Product Classification

Mohanty and Bhasker (2005) proposed a fuzzy approach to solve production classification problems on the Internet. In their model, a DM searches for the best satisfactory product that fulfills "most" of the attributes rather than all the attributes according to his preference level. Chang (2014) extended the model of Mohanty and Bhasker (2005) to fit the context of the classification problem on the Internet. In addition, the S-shaped membership function and binary classification technique are also addressed (see Appendix C).

There are *n* goals given to SB to decide and *m* alternatives where each one has *t* attributes.

 $y_{i,j}$  indicates the *j*-th alternative for the *i*-th goal. The alternatives can be classified using FGP method (in Appendix C) according to the predefined user satisfaction level  $r_i$ . With Eqs. (22)-(23), the proposed model can find qualified alternatives. The qualified alternatives are selected sequentially according to user satisfaction level for the *i*-th goal.

It seems difficult for SBs to select a suitable rate plan since there are so many alternatives, and each one contains multiple attributes. The FGP method (Chang, 2014) can easily be used to compare the rate plan options offered by various telecom companies considering SBs' preferences for it can deal with multiple objectives and allow SBs to set a fuzzy aspiration level for each goal.

Moreover, SBs can set their preemptive priority values for each goal in the FGP. The procedure of the preemptive priority setting is summarized as follows.

1. Normalize the original features of the rate plans into a ratio scale.

2. SBs set a goal satisfaction level as a preemptive priority for the selection problem.

3. Determine the preemptive priority values for goals G5-G8 in FGP.

2.4 Solution procedure

In choosing a smartphone, many SBs would like to consider the smartphone features first, and the rate plans later. According to POLLS market research consultancy (2018), 58.7% of the smartphone users living in Taiwan choose their smartphones based on brand preference, followed by 41.6% on memory size, 39.8% on screen size, 33.4% on camera function, 23.4% on pricing, and 21.8% on battery capacity.

This study integrates the SSAL-SAL method (Chang, 2018) and the FGP method (Chang, 2014) by adding a weighted mechanism to be a new method, called the weighted SSAL-SAL-FGP method, to aid SBs in resolving the real selection problem of smartphones and

rate plans in Taiwan. The weighted SSAL-SAL method is first ranking the smartphone alternatives for SBs. Under this approach, SBs' goals reach the SSAL as close as possible (e.g., battery capacity, the higher, the better) and avoid falling below the SAL as far as possible (e.g., price, the lower, the better). To meet different preferences, SBs can set different weights  $w_i$  for each goal with linguistic terms, such as high, average, and low, which can be transformed into trapezoidal fuzzy numbers. Then, the weights are attached to goals in the objective function in the weighted SSAL-SAL model in choosing the most suitable smartphone.

Subsequently, the FGP method (Chang, 2014) is used to compare the various rate plans considering SBs' preferences and needs. In general, SBs have many rate plan options with ambiguous information to choose from, and that leads to confusion. In order to clarify this ambiguity, FGP can act as an aid to distinguish the rate plans that fit the goals of buyers. Moreover, this study also allows SBs to set the goal satisfaction levels as a preemptive priority for each goal in the FGP to find the most suitable rate plan options for the selected smartphone.

Fig. 1 illustrates the procedure of the proposed weighted SSAL-SAL-FGP method for the smartphone selection problem.



Fig. 1. An integrated weighted SSAL-SAL-FGP procedure for smartphone selection

## **3.** An illustrative case

A real case (a female user called Clare) is presented to illustrate how SBs can use the proposed method to select their ideal smartphone and rate plan provided by various telecom providers. First, Clare would like to buy a smartphone to replace her old one, considering her smartphone usage habits, she prefers a smartphone that is light, low cost, and has a big screen. In addition, the price is her first concern, so Clare chooses this criterion to select an appropriate smartphone from telecom providers. However, she is frustrated and confused by excessive information about smartphones and rate plans offered by them. In this situation, she must spend plenty of time searching through many alternatives on the internet, but there is no suitable tool to help her resolve the problem of buying a smartphone bound with an ideal rate plan on account of her usage habits. Moreover, most of the telecom companies offer and change their already many rate plan bundles from time to time. This makes it even harder for Clare to determine an appropriate smartphone with the desired rate plan within a reasonable amount of time.

The proposed method can solve the above-mentioned problems and exclude most of the unacceptable alternatives to save Clare's time. Furthermore, it also creates a personalized list according to the scoring attributes of her fuzzy preferences. In order to help Clare estimate her preferences more accurately, the S-shape utility functions are introduced to formulate her fuzzy preferences in smartphone selection. Clare defines four smartphone goals (G1, G2, G3, and G4) to find the smartphone closest to her preference that includes attributes such as the price, battery capacity, screen size, and weight. Considering the four goals simultaneously, we collected data from the telecom company websites (Chunghwa Telecom, 2020) and listed five smartphone

alternatives with various features in Table 4. The price of a smartphone (G1) without any affiliated rate plan from telecom companies should be the lesser, the better; the battery capacity of a smartphone (G2) should be the higher, the better; the screen size of a smartphone (G3) should be the larger, the better; the weight of a smartphone (G4) should be the lesser, the better. Table 4. Smartphone features of five alternatives

Smartphones	HTC ONE M9	LG G3	Samsung GALAXY S6	Sony Xperia Z3	iphone6
Smartphones variables	<i>x</i> <sub>1</sub>	<i>x</i> <sub>2</sub>	<i>x</i> <sub>3</sub>	<i>x</i> <sub>4</sub>	<i>x</i> <sub>5</sub>
Price (NT dollars)	21900	22400	21654	20900	22500
Battery capacity (mAh)	2840	3000	2550	3100	1810
Screen size (inch)	5.2	5.5	5.1	5.2	4.7
Weight (g)	157	153	138	152	129

In order to avoid the effects from different measurement scales of different goals when using the weighted SSAL-SAL method, this study normalized the original features of the five smartphone alternatives in Table 4 into a ratio scale, as shown in Table 5. In each goal, a smartphone alternative with the highest feature value gets the ratio scale of 1, while one with the lowest feature value gets the ratio scale of 0.

Table 5. Ratio scale of five smartphone alternatives

Smartphones	HTC ONE M9	LG G3	Samsung GALAXY S6	Sony Xperia Z3	iphone6
Price (NT dollars)	0.63	0.94	0.47	0.00	1.00
Battery capacity (mAh)	0.80	0.92	0.57	1.00	0.00

Screen size (inch)	0.63	1.00	0.50	0.63	0.00
Weight (g)	1.00	0.86	0.32	0.82	0.00

Based on the weighted SSAL-SAL method, Clare's requirement can be formulated as a decision model partly shown in Appendix D. This problem is solved using LINGO (Schrage, 2002) to obtain the optimal solution as  $(x_1, x_2, x_3, x_4, x_5) = (0,0,0,1,0)$ , which indicates that the best choice of smartphones is  $x_4$ : Sony Xperia Z3. The achievement values of goals G1-G4 are  $(\eta_1, \lambda_2, \lambda_3, \eta_4) = (0,1,0.63,0.82)$ , meaning that the smartphone not bound to any rate plan with the lowest price (G1) is the Sony Xperia Z3. First, since the price goal (G1) is an SAL goal moving away from  $h_{1,\text{max}} = 1$  as far as possible, the achievement value of G1,  $\eta_1 = 0$ , is 100% fully achieved. Second, since the battery capacity goal (G2) is an SSAL goal approaching SSAL,  $g_2 = 1$ , as close as possible, the battery capacity goal (G2) is 100% achieved ( $\lambda_2 = 1$ ). The battery capacity of Sony Xperia Z3 performs the best among the choices. Third, since the screen size goal (G3) is an SSAL goal approaching SSAL,  $g_3 = 1$ , as close as possible, the screen size goal (G3) is 63% achieved ( $\lambda_3 = 0.63$ ). The screen size of the Sony Xperia Z3 is relatively bigger than some of the others. Finally, since the phone weight goal (G4) is an SAL goal moving away from  $h_{4,\text{max}} = 1$  as far as possible, the phone weight goal (G4) is 18% achieved  $(\eta_4 = 0.82)$ . The weight of the chosen smartphone is lighter than some of the others.

In order to find the ranking list of the recommended smartphones, we remove the  $x_4$  temporarily in the selection process and run the LINGO (Schrage, 2002) program to solve the problem again. As a result, besides the best recommended smartphone, Sony Xperia Z3 ( $x_4$ ), the other recommended smartphones are LG G3 ( $x_2$ ), Samsung GALAXY S6 ( $x_3$ ), HTC ONE M9

 $(x_1)$ , and iPhone 6  $(x_5)$ .

According to the interview with Clare, we found that she considers the price (G1) and the battery capacity (G2) of a smartphone more important than the other criteria. Her biggest concern is the price of a smartphone without any affiliated rate plan from telecom companies. Clare sets different weights on each goal, as shown in Table 6. The detailed information of the trapezoidal fuzzy numbers and the calculated weights can be seen in Appendix B.

Table 6. Importance of each goal- Clare

Goals	Linguistic Terms	Trapezoidal Fuzzy Numbers	Weights (%)
G1: Price	Medium High	(0.5,0.7,0.7,0.8)	39
G2: Battery capacity	High	(0.7,0.8,0.8,0.9)	46
G3: Screen size	Low	(0.1,0.2,0.2,0.3)	10
G4: Weight	Very Low	(0,0.1,0.1,0.2)	5

In Table 6, the weight assignments for G1-G4 are 39%, 46%, 10%, and 5%, respectively. Thus, the weights of G1-G4 are added for Clare as in Eq. (3.1).

Minimize  

$$\begin{array}{l}
0.39^{*}\left(\left(\frac{s_{1}^{+}+s_{1}^{-}}{1}\right)+k_{1}^{-}\right)+0.46^{*}\left(\left(\frac{d_{2}^{+}+d_{2}^{-}}{1}\right)+f_{2}^{-}\right)\\
+0.10^{*}\left(\left(\frac{d_{3}^{+}+d_{3}^{-}}{1}\right)+f_{3}^{-}\right)+0.05^{*}\left(\left(\frac{s_{4}^{+}+s_{4}^{-}}{1}\right)+k_{4}^{-}\right)
\end{array}$$
(3.1)

The recommended smartphone is Sony Xperia Z3  $(x_4)$ , which has the largest battery capacity with the lowest phone price among all alternatives. The ranking list of the recommended smartphones is Sony Xperia Z3  $(x_4)$ , LG G3  $(x_2)$ , HTC ONE M9  $(x_1)$ , Samsung GALAXY S6  $(x_3)$ , and iPhone 6  $(x_5)$ . Compared with the result from the one without Clare's weight setting with linguistic terms, the ranking of HTC ONE M9  $(x_1)$  moves slightly forward becoming the third recommended smartphone, which has relatively large battery capacity (G2).

Considering the four goals simultaneously, we collected data from the telecom company websites (Chunghwa Telecom, 2020) and listed five smartphone alternatives with various features in Table 4.

Since the proposed method has recommended Sony Xperia Z3, we also collected data from the telecom company websites (Chunghwa Telecom, 2020) and listed 20 rate plan options for the Sony Xperia Z3 from three major telecom providers (Chunghwa Telecom, Taiwan Mobile CO., and Far EasTone Telecom Co.) in Taiwan, as presented in Table 7.

	Rate	Price with two-		Monthly free	Monthly
	plans	years contract	wontiny can	inter-network talk	cellular data
		(NT \$)	charge (INT 5)	time (minutes)	(GB)
Chunghwa	A1	12800	639	20	1.6
Telecom	A2	9900	936	35	6
	A3	8400	1136	50	9
	A4	3900	1336	65	unlimited
	A5	0	1736	100	unlimited
	A6	0	2636	200	unlimited
Taiwan Mobile	B1	13900	599	30	1.5
	B2	12400	799	40	3
	B3	9990	999	50	6
	B4	5400	1299	70	10
	B5	3990	1399	80	unlimited
	B6	1990	1599	100	unlimited

Table 7. The 20 rate plan options of the major telecom companies

	B7	0	1899	140	unlimited
	B8	0	2599	200	unlimited
Far EasTone	C1	11490	799	40	3.5
Telecom	C2	9990	999	100	6.5
	C3	7990	1199	130	9.5
	C4	3990	1399	170	unlimited
	C5	0	1799	210	unlimited
	C6	0	2699	400	unlimited

Then, based on the selected Sony Xperia Z3, Clare determines another four goals, G5, G6, G7, and G8, for the rate plan option selection. The objective is to find an appropriate rate plan closest to her preferences for the contract phone price, monthly call charge, monthly free inter-network talk time, and monthly cellular data.

(G5) The price of the smartphone with a two-year contract should be the lower, the better.

(G6) The monthly call charge should be the lower, the better.

(G7) The monthly free inter-network talk time should be the higher, the better.

(G8) The monthly cellular data should be the higher, the better.

We also normalized the original features of the rate plans of major telecom providers in Table 7 into a ratio scale, as shown in Table 8.

Table 8. The satisfaction level of the rate plans of the major telecom companies

Rate plans variables	Rate plans	Price (NT dollars)	Monthly call charge (NT \$)	Monthly free inter-network talk time (minutes)	Monthly cellular data (GB)
y11	A5	1.00	0.46	0.21	1.00

_						
	y12	A6	1.00	0.03	0.47	1.00
	y13	B7	1.00	0.38	0.32	1.00
	y14	B8	1.00	0.05	0.47	1.00
	y15	C5	1.00	0.43	0.50	1.00
	y16	C6	1.00	0.00	1.00	1.00
	y17	B6	0.86	0.52	0.21	1.00
	y18	A4	0.72	0.65	0.12	1.00
	y19	B5	0.71	0.62	0.16	1.00
	y110	C4	0.71	0.62	0.39	1.00
	y111	B4	0.61	0.67	0.13	0.81
	y112	C3	0.43	0.71	0.29	0.76
	y113	A3	0.40	0.74	0.08	0.71
	y114	A2	0.29	0.84	0.04	0.43
	y115	B3	0.28	0.81	0.08	0.43
	y116	C2	0.28	0.81	0.21	0.48
	y117	C1	0.17	0.90	0.05	0.19
	y118	B2	0.11	0.90	0.05	0.14
	y119	A1	0.08	0.98	0.00	0.01
	y120	B1	0.00	1.00	0.03	0.00

The rate plan selection decision-model is formulated using the FGP method (Chang, 2014) and is partly listed in Appendix E. This problem is also solved by using LINGO (Schrage, 2002) to obtain the selected set as {y7, y10, y12} shown in Tables 9-10.

The recommended rate plans are Taiwan Mobile B6 (y7), and Far EasTone Telecom C4 (y10), and C3 (y12). The selected rate plans provide better performance for the four goals, and

they all provide higher cellular data with a medium-cost. Overall, we recommend Clare to buy Sony Xperia Z3 bundled with Taiwan Mobile's B6 rate plan or Far EasTone Telecom Co.'s C3 or C4 rate plan. The rate plans B6 and C4 provide unlimited Internet access. However, for the goal of the price with a two-year contract, rate plan B6 is much better than the others, and for the goal of monthly call charge, the C3 rate plan is slightly better than the others. Overall, the C4 rate plan shows the best performance, followed by B6, and then C3. The comparison of 20 rate plans of major telecom companies is shown in Fig. 2.

As seen in Fig. 2, the rising of the price of the smartphone with a two-year contract (G5) follows the lowering of the monthly call charge (G6); the intersection point of the two goals is about y7-y12. Meanwhile, the higher monthly call charge per month (G6), the higher the monthly cellular data (G8) would be. The intersection point of the two goals is about y10-y13.



Fig 2. The comparison of 20 rate plans of major telecom companies

Table 9. The solution to the rate plans of major telecom companies

| Rate plans    | The solution |
|---------------|--------------|---------------|--------------|---------------|--------------|---------------|--------------|
| variables for | value        |

G5		G6		G7		G8	
y11	1	y21	0	y31	1	y41	1
y12	1	y22	0	y32	1	y42	1
y13	1	y23	0	y33	1	y43	1
y14	1	y24	0	y34	1	y44	1
y15	1	y25	0	y35	1	y45	1
y16	1	y26	0	y36	1	y46	1
y17	1	y27	1	y37	1	y47	1
y18	1	y28	1	y38	0	y48	1
y19	1	y29	1	y39	0	y49	1
y110	1	y210	1	y310	1	y410	1
y111	1	y211	1	y311	0	y411	1
y112	1	y212	1	y312	1	y412	1
y113	0	y213	1	y313	0	y413	1
y114	0	y214	1	y314	0	y414	0
y115	0	y215	1	y315	0	y415	0
y116	0	y216	1	y316	1	y416	0
y117	0	y217	1	y317	0	y417	0
y118	0	y218	1	y318	0	y418	0
y119	0	y219	1	y319	0	y419	0
y120	0	y220	1	y320	0	y420	0

Table 10. The selected rate plans of major telecom companies

Alt	ernatives of rate [	plans	Price (NT dollars)	Monthly call charge (NT \$)	Monthly free inter-network talk time (minutes)	Monthly cellular data (GB)
y71	Taiwan Mobile	B6	1990	1599	100	unlimited
y121	Far EasTone	C3	7990	1199	130	9.5
y101		C4	3990	1399	170	unlimited

## 4. Discussion

#### 4.1 Weight Setting for the weighted SSAL-SAL Method

To understand the usage habits of smartphone owners, this study distributed an online questionnaire to interview smartphone owners in April 2018, in Taiwan. The questionnaire is given in Appendix F. The subjects are 1583 workers, aged 16-55, with smartphone buying experience in central Taiwan. They have used the Internet to search for smartphone information and buy smartphones. This study conducted an online questionnaire to collect data about the usage habits of smartphone owners. The result of the online questionnaire is listed in Table 11. This study found that male and female subjects have different preferences in the selection of smartphones. Male smartphone owners usually use their smartphones as a map (34.5%) or game console (26.1%), while female subjects usually use their smartphones for social networks (34.3%) or photo shootings (30.6%). Female smartphone owners consider the battery capacity and the weight of the smartphone to be the most important criteria, while male owners tend to need a smartphone with bigger screen size.

Table 11. The results of the online questionn	aire
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Category	Item	Male	Female
Sex	Sample number	962	621
Vocation	Public servant	144	138

	Service industry	168	164
	Manufacturing industry	360	114
	Medical	43	21
	Finance	85	45
	Student	162	63
	Housekeeping	0	76
Age	16-20	25	47
	21-25	149	23
	26-30	122	108
	31-35	170	101
	36-40	82	73
	41-45	152	90
	46-50	144	81
	51-55	118	98
	56-60	0	0
	Above 61	0	0
Brand	Apple	299	173
	hTC	184	80
	Xiaomi	9	2
	Samsung	318	185
	Sony Ericsson	132	117
	LG	20	64
Function	Мар	332	89
	Digital camera	118	190
	Checking social network	133	213
	Schedule	128	77
	Games	251	52

According to the survey, we found that female smartphone owners consider the battery capacity and the weight of the smartphone more than other criteria, and they set different weights on each goal, as shown in Table 12. The detailed information of the trapezoidal fuzzy numbers and the calculated weights can be seen in Section 2.3.

Table 12. Importance of each goal- female smartphone owners

Goals	Linguistic Terms	Trapezoidal Fuzzy Numbers	Weights (%)
G1	Low	(0.1,0.2,0.2,0.3)	10
G2	High	(0.7,0.8,0.8,0.9)	40
G3	Low	(0.1,0.2,0.2,0.3)	10
G4	High	(0.7,0.8,0.8,0.9)	40

In Table 12, the weight assignments for G1-G4 are 10%, 40%, 10%, and 40%, respectively. Thus, the weights of G1-G4 are added for female SBs as in Eq. (4.1).

Minimize  

$$\begin{array}{l}
0.1^{*}\left(\left(\frac{s_{1}^{+}+s_{1}^{-}}{1}\right)+k_{1}^{-}\right)+0.4^{*}\left(\left(\frac{d_{2}^{+}+d_{2}^{-}}{1}\right)+f_{2}^{-}\right)\\
+0.1^{*}\left(\left(\frac{d_{3}^{+}+d_{3}^{-}}{1}\right)+f_{3}^{-}\right)+0.4^{*}\left(\left(\frac{s_{4}^{+}+s_{4}^{-}}{1}\right)+k_{4}^{-}\right)
\end{array}$$
(4.1)

The recommended smartphone is Sony Xperia Z3  $(x_4)$ , which has the largest battery capacity and relatively lighter weight. Meanwhile, we found that male smartphone owners prefer a smartphone with bigger screen size, and they set different weights on each goal, as shown in Tables 13.

Goals	Linguistic terms	Trapezoidal Fuzzy Numbers	Weights (%)
G1	Medium	(0.4,0.5,0.5,0.6)	29
G2	Low	(0.1,0.2,0.2,0.3)	12
G3	High	(0.7,0.8,0.8,0.9)	47
G4	Low	(0.1,0.2,0.2,0.3)	12

Table 13. Importance of each goal- male smartphone owners

In Table 13, the weight assignments for G1-G4 are 29%, 12%, 47%, and 12%, respectively. Thus, the weights of G1-G4 are added for male SBs as in Eq. (4.2). After the computation, the recommended smartphone is LG G3 ( $x_2$ ), which has the largest screen size and slightly lower price.

Minimize  

$$\begin{array}{l}
0.29*\left(\left(\frac{s_{1}^{+}+s_{1}^{-}}{1}\right)+k_{1}^{-}\right)+0.12*\left(\left(\frac{d_{2}^{+}+d_{2}^{-}}{1}\right)+f_{2}^{-}\right)\\
+0.47*\left(\left(\frac{d_{3}^{+}+d_{3}^{-}}{1}\right)+f_{3}^{-}\right)+0.12*\left(\left(\frac{s_{4}^{+}+s_{4}^{-}}{1}\right)+k_{4}^{-}\right)
\end{array}$$
(4.2)

4.2 Preemptive Priority Setting of Goals for the FGP Method

After determined the smartphone, the New HTC ONE, from the weighted SSAL-SAL method, this study adopts the FGP method (Chang, 2014) to select an appropriate rate plan offered by various telecom providers according to SB preference.

Sometimes, SBs need to find an appropriate rate plan according to their priorities among goals. For example, they would like to set goals such as budget limits and usage habits in the rate plan selection. Also, if the relationship between goals is determined, the probability of finding a satisfactory rate plan increases. The preemptive priority structure of goals can be achieved by setting the satisfaction level of each goal in Eq. (4.3).

$$\sum_{i=1}^{m} r_i \ge B,\tag{4.3}$$

where *B* is the achievement rate of the goals that is bound to the utility value  $r_i$ . It means that the summation of some evaluation goals should achieve at least the value of *B*. With Eq. (4.3), SBs can set a preemptive priority for each goal to obtain the most suitable rate plan. Eq. (4.3) can make one or more goals achieve at least some degree of summation achievement as a preemptive priority structure of goals. For example, if we set  $r_1$ = 0.64,  $r_2$ = 0.8,  $r_3$ = 0.001, and  $r_4$ = 0.001 in Eq. (4.3), it means the achievement rate of G1 and G2 must be higher than the others. The modified FGP can determine the most appropriate achievement among goals and recommend a suitable rate plan.

Let us consider four cases with preemptive priorities to demonstrate the above-mentioned idea.

(Case 1) The price of the smartphone bundled with a rate plan from telecom companies (G5) should be under 4000 NT dollars. Also, the amount of the monthly call charge (G6) should be the less, the better. (Case 2) The amount of the smartphone price bundled with a rate plan from telecom companies (G5) and the monthly call charge for a two-year contract (G6) should be under 20000 NT dollars. (Case 3) The monthly cellular data (G8) should not be unlimited, and the monthly call charge (G6) should be the less, the better. (Case 4) The monthly free inter-network talk time (G7) should be at least 120 minutes, and the monthly call charge (G6) should be the less, the better. These cases can be formulated as the preemptive priority constraints for goals G5-G8. These problems are also solved using LINGO (Schrage, 2002). The satisfaction levels of goals in four cases are shown in Table 14, and the selected rate plans sets are shown in Table 15.

Goals	Goal 5: Price	Goal 6:	Goal 7: Monthly	Goal 8:	The best rate
		Monthly	free inter-network	Monthly	plans
		call charge	talk time	cellular data	
Case 1	$r_1 = 0.72$	$r_2 = 0.62$	$r_3 = 0.1$	<i>r</i> <sub>4</sub> = 0.1	y8
Case 2	$r_{1} = 0.08$	$r_{2>}=0.92$	$r_3 = 0.1$	$r_4 = 0.1$	y19, y20
Case 3	$r_1 = 0.1$	$r_2 = 0.6$	$r_3 = 0.1$	<i>r</i> <sub>4</sub> = 1	y8, y9, y10
Case 4	$r_1 = 0.1$	$r_2 = 0.5$	<i>r</i> <sub>3&gt;</sub> = 0.21	$r_4 = 0.1$	y10

Table 14. The satisfaction levels of goals in four cases

Ta	ble	: 1.	5. '	Tł	ıe	se	lec	tec	l ra	te	pl	ans	s c	of	tł	ıe	m	aiı	n t	tel	ec	co	m	co	m	pa	ni	es	in	f	our	C	as	ses
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	Alternativas	Talacom	Price	Monthly call	Monthly free	Monthly
Case	Alternatives	Telecom	(NT	charge (NT	inter-network talk	cellular data
	of rate plans	is companies	dollars)	dollars)	time (minutes)	(GB)

Case 1	y8	Chunghwa A	4 3900	1336	65	unlimited
		Telecom				
Case 2	y19	Chunghwa A	1 12800	639	20	1.6
		Telecom				
	y20	Taiwan B	1 13900	599	20	1.5
		Mobile			50	
Case 3	y8	Chunghwa A	4 3900	1336	65	unlimited
		Telecom				
	y9	Taiwan B	5 3990	1399	90	unlimited
		Mobile			80	
	y10	Far EasTone C	4 3990	1399	170	unlimited
Case 4	y10	Far EasTone C	4 3990	1399	170	unlimited

In Case 1, the recommended rate plan is Chunghwa Telecom A4 (y8), which has a phone price of 3900 NT dollars (under 4000 NT dollars) and a relatively low monthly call charge. In Case 2, the recommended rate plans are Chunghwa Telecom A1 (y19) and Taiwan Mobile B1 (y20), which have a good performance in G6 but poor in G5. The amount of price the smartphone bundled with a rate plan from telecom companies (G5) and the monthly call charge for a two-year contract (G6) of the recommended rate plans of A1 and B1 are 15975 and 14975 NT dollars, respectively. Overall, we found that the bundled rate plans with higher phone prices and lower monthly call charges are better than the ones with lower phone prices and higher monthly call charges. In Case 3, the recommended rate plans are Chunghwa Telecom A4 (y8), Taiwan Mobile B5 (y9), and Far EasTone Telecom C4 (y10). The monthly cellular data are all unlimited. Also, the monthly call charges are lower than the others. In Case 4, the recommended rate plan is Far EasTone Telecom C4 (y10), which has 170 minutes of monthly free inter-network talk time

(above 120 minutes) and a relatively lower monthly call charge. We listed the details of the selected rate plans of the major telecom companies for the four cases in Table 15. We then found that Chunghwa Telecom provides the most appropriately selected rate plans.

## **5.** Conclusions

The main contributions of the study are as followed. (1) This study proposed a weighted SSAL-SAL-FGP method to assist SBs in finding satisfactory smartphones with suitable rate plans according to their budget and usage habits. SBs can determine the best smartphones from many alternatives using the weighted SSAL-SAL method and select the best matching rate plans from various telecom companies using the FGP method. (2) SBs can set different weights for each smartphone selection goal with linguistic terms, such as high, average, and low, which can be transformed into trapezoidal fuzzy numbers. The weights are attached to the objective function in the weighted SSAL-SAL model in choosing the most suitable smartphone. (3) With different weight settings among goals in the weighted SSAL-SAL method, SBs can easily select ideal smartphones without consuming too much time. (4) Moreover, considering different usage habits or budget limits, SBs can also set the satisfaction level of goals as a preemptive priority in the FGP method. (5) In addition, to avoid the effects from different measurement scales of different goals in the weighted SSAL-SAL model, this study normalized the original features of the smartphone alternatives and the original features of the rate plans of major telecom providers into a ratio scale. The proposed integrated weighted SSAL-SAL-FGP method provides a better match for SB and increases the probability of making the right decision when searching for smartphones and rate plans.

Moreover, the proposed method can be used to solve not only the problem of smartphone selection but also in general selection decision problems in the field of decision making. Facing an excess of information about smartphone and rate plan offerings from various telecom providers, SBs can determine their own selection goals of smartphone and rate plan and can get the most suitable smartphones matching decent rate plans under their budget limits in a short period.

The traditional GP model allows DMs to set only one aspiration level for each goal. This study proposed an integrated weighted SSAL-SAL-FGP method to deal with a multi-aspiration level problem. The weighted SSAL-SAL method is used to solve the problem of reaching the SSAL as close as possible and avoid falling below the SAL as far as possible, simultaneously. Meanwhile, the FGP can be used to deal with multiple objectives and allows an SB to set a fuzzy aspiration level for each goal. The purpose of the weighted SSAL-SAL-FGP method is to minimize the deviations between the achievement of goals and aspiration levels while dealing with conflicting goals concurrently. The proposed weighted SSAL-SAL-FGP method can be formulated as linear programming, which can be easily solved using standard linear programming packages. With the proposed weighted SSAL-SAL-FGP method, SBs can solve the problem of selecting smartphones and rate plans of user preference.

The proposed weighted SSAL-SAL-FGP method, as a smartphone purchase decision aid, makes the following contributions: (1) it helps SBs find satisfactory phones according to their needs in light of usage habits subject to budget limits; (2) it helps SBs to find suitable rate plans; and (3) with different weight settings among goals, SBs can save money and precious time to find their ideal smartphones and rate plans.

Providing an evaluation search tool for smartphone searches is the key success factor for winning consumers' trust and preference. Nevertheless, current online agents cannot provide search tools powerful enough to meet conflicting goals and heterogeneous preferences of SBs. This study presented an integrated approach to support SBs in their evaluation process. The proposed approach determines the best smartphone from many alternatives, according to user preference. That way, the proposed approach maximizes the sum of satisfaction levels given weighted goals.

The proposed approach transforms SBs' fuzzy preference levels into fixed weights, and then the personal ranking results of smartphones can be obtained. SBs can adjust their preemptive priorities on each goal with ease to obtain different rankings. This helps buyers clarify their thoughts about their ideal smartphones that a good ranking can drastically reduce search time and increase the matching rate.

In a competitive market of smartphone manufacturers, it is vital to provide a useful aid for customers to procure rankings based on their preferences. With the online questionnaire, this study also found smartphone preferences of Asian customers in evaluating and selecting new smartphones. According to the findings, male smartphone owners usually use their smartphones as a map (34.5%) or game console (26.1%), while female ones usually use their smartphones for social networks (34.3%) or photo shootings (30.6%). This information is useful for smartphone manufacturers to design new smartphones for consumers. In addition, according to the survey, we found that female smartphone owners consider the battery capacity and the weight of the smartphone more important than other criteria, while male smartphone owners prefer a smartphone with bigger screen size. Smartphone manufacturers can also know what SBs most concerned about and then design better products that suit customers more.

Besides, this study provides useful information about SBs' rate plan preferences for telecom companies. Accordingly, telecom companies can provide better rate plans to match SBs' needs, hence increases the market share. Also, SBs can adjust their goal priorities by setting different preemptive priorities on each goal to obtain different rate plan options. We use various examples to show that the proposed weighted SSAL-SAL-FGP model allows SBs to select satisfactory smartphones with suitable rate plans to match their usage habits and budgets quicker than the

existing methods.

There are some limitations in this study; however, only Taiwanese customers' smartphone preference is considered in this study. In the future, the proposed method can also be applied to other countries. Moreover, smartphone manufacturers can analyze customers' smartphone preferences in different countries to devise better business strategies. Also, the proposed method can be adopted in solving not only smartphone selection problems but also in general decision problems. With the weighted SSAL-SAL, DMs can solve their multiple-goal problems to reach their predefined salient success aspiration level (SSAL) as close as possible, e.g., higher market share, and to avoid falling below the survival aspiration level (SAL) as far as possible, e.g., budget limits, simultaneously. They can also set a goal satisfaction level as a preemptive priority in the FGP method to evaluate the alternatives and get their rankings to solve more selection problems. The promising results motivate the need for further study on fuzzy multi-objective decision making problems considering qualitative and quantitative issues (Chang, 2007; Zheng and Chang, 2020).

Appendix A

(SSAL-SAL model)	
Minimize $\sum_{i=1}^{4} w_i(e_i + d_i^+)$	(1)
Subject to	
$\mu_1 + e_1 = 1$ ,	(2)
$\mathbf{f}(\mathbf{x}) + (\mathbf{D}^{\mathbf{u}} - \mathbf{g})\mu_1 + d_1^+ = \mathbf{D}^{\mathbf{u}},$	(3)
$\mu_2 + e_2 = 1$ ,	(4)
$\mathbf{f}(\mathbf{x}) - \mathbf{g}\boldsymbol{\mu}_2 - \boldsymbol{d}_2^+ = 0,$	(5)
$\mu_3 + e_3 = 1$ ,	(6)
$\mathbf{e}(\mathbf{x}) - (\mathbf{N}^{\mathbf{u}} - \mathbf{h})\boldsymbol{\mu}_{\delta} + \boldsymbol{d}_{3}^{+} = \mathbf{h},$	(7)

$$\mu_4 + e_4 = 1, \tag{8}$$

$$\mathbf{e}(\mathbf{x}) + \mathbf{h}\boldsymbol{\mu}_{\delta} - \boldsymbol{d}_{4}^{+} = \mathbf{h}\,,\tag{9}$$

 $\mathbf{x} \in \mathbf{F}$  (**F** is a feasible set)

where  $\mu_1$ ,  $\mu_2$ ,  $\mu_3$ ,  $\mu_4$  are the fuzzy scores;  $e_1$ ,  $e_2$ ,  $e_3$ ,  $e_4$  are the deviational variables that attach to  $1 - \mu_1$ ,  $1 - \mu_2$ ,  $1 - \mu_3$ , and  $1 - \mu_4$ .  $\mathbf{f}(\mathbf{x}) = \{f_1(\mathbf{x}), f_2(\mathbf{x}), \dots, f_n(\mathbf{x})\}$  is an n-vector of the object functions, defined as  $f_i(\mathbf{x}) = \mathbf{c}^i \mathbf{x}, j = 1, 2, \dots n$ , where  $\mathbf{c}^j$  is the n-vector of coefficients for the j-th objective,  $\mathbf{g} = (g_1, g_2, \dots, g_n) \in \mathbb{R}^n$  is the vector of the SSAL, and  $\mathbf{h} = (h_1, h_2, \dots, h_n) \in \mathbb{R}^n$  is the vector of the SAL.  $\mathbf{e}(\mathbf{x}) = \{e_1(\mathbf{x})ef_2(\mathbf{x}), \dots e_n(\mathbf{x})\}$  is an n-vector of the object functions, defined as  $e_i(\mathbf{x}) = \mathbf{c}^i \mathbf{x}, i = 1, 2, \dots n$ , where  $\mathbf{c}^i$  is the n-vector of coefficients for the *i*-th objective.  $\mathbf{e}(\mathbf{x})$  and  $\mathbf{f}(\mathbf{x})$  can be either the same or different functions, depending on real situations or DM needs.

 $d_1^+$  is the deviational variable that is attached to  $\mathbf{D}^{\mathbf{u}} - (\mathbf{f}(\mathbf{x}) + (\mathbf{D}^{\mathbf{u}} - \mathbf{g})\mu_1)$ .  $d_2^+$  is the deviational variable that is attached to  $\mathbf{f}(\mathbf{x}) - \mathbf{g}\mu_2$ .  $d_3^+$  is the deviational variable that is attached to  $\mathbf{h} - \mathbf{e}(\mathbf{x}) + (\mathbf{N}^{\mathbf{u}} - \mathbf{h})\mu_{\delta}$ .  $d_4^+$  is the deviational variable that is attached to  $\mathbf{e}(\mathbf{x}) + \mathbf{h}\mu_{\delta} - \mathbf{h}$ .

#### Appendix B

A trapezoidal fuzzy number,  $\tilde{A} = (a_1, b_1, c_1, d_1)$ ,  $a_1 \le b_1 \le c_1 \le d_1$ , and its membership functions are expressed as follows:

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x < a. \\ \frac{(x-a_1)}{(b_1-a_1)}, & a \le x \le h. \\ 1, & b_1 \le x \le c_1, \\ \frac{(x-d_1)}{(c_1-d_1)}, & c_1 \le x \le d_1, \\ 0, & x > d_1, \end{cases}$$
(10)  
When  $b_1 = c_1, \quad \mu_{\tilde{A}}(x)$  b ungular fuzzy numbers.

There are q SBs and l goals. The kth SB can define the trapezoidal fuzzy number  $\widetilde{A}_{ki}$  by

linguistic terms for the *i*th goal according to their preference as Eq. (11)

$$\widetilde{A}_{ki} = (a_{ki}, b_{ki}, c_{ki}, d_{ki}), \ 0 \le a_{ki} \le b_{ki} \le c_{ki} \le d_{ki} \le 1, \ k = 1, \dots, q, \ i = 1, \dots, l$$

$$(11)$$

For the goal 1, the *k*th DM can define the trapezoidal fuzzy number,  $\tilde{A}_{k1}$  for the *i*th goal according to their preference as Eq. (12).

$$\widetilde{A}_{k1} = (a_{k1}, b_{k1}, c_{k1}, d_{k1}), \quad k = 1, \dots, q$$
(12)

In solving the group decision making problem, the different trapezoidal fuzzy numbers from *m* SBs for goal 1 can be merged with Eq. (13). The average  $\tilde{A}_{mean1}$  of all  $\tilde{A}_{k1}$  is computed by Eq. (13).

$$\widetilde{A}_{mean1} = (a_{mean1}, b_{mean1}, c_{mean1}, d_{mean1}) = (\frac{1}{q} \sum_{k=1}^{q} a_{k1}, \frac{1}{q} \sum_{k=1}^{q} b_{k1}, \frac{1}{q} \sum_{k=1}^{q} c_{k1}, \frac{1}{q} \sum_{k=1}^{q} d_{k1})$$
(13)

For an SB, assume that the trapezoidal fuzzy numbers  $W_1$ ,  $W_2$  and  $W_3$  are the weights of the goals G1, G2 and G3, respectively, where  $W_1 = (a_1, b_1, c_1, d_1)$ ,  $W_2 = (a_2, b_2, c_2, d_2)$ ,  $W_3 = (a_3, b_3, c_3, d_3)$ . The normalized weights  $\overline{W}_1$ ,  $\overline{W}_2$  and  $\overline{W}_3$  of  $W_1$ ,  $W_2$  and  $W_3$ , respectively, can be obtained from Eq. (14).

$$\overline{W}_{1} = W_{1} \oslash (W_{1} \oplus W_{2} \oplus W_{3}) = (a_{1}, b_{1}, c_{1}, d_{1}) \oslash (a_{1} + a_{2} + a_{3}, b_{1} + b_{2} + b_{3}, c_{1} + c_{2} + c_{3}, d_{1} + d_{2} + d_{3})$$

$$= (\frac{a_{1}}{d_{1} + d_{2} + d_{3}}, \frac{b_{1}}{c_{1} + c_{2} + c_{3}}, \frac{c_{1}}{b_{1} + b_{2} + b_{3}}, \frac{d_{1}}{a_{1} + a_{2} + a_{3}}), \qquad (14)$$

where  $a_1$ ,  $b_1$ ,  $c_1$  and  $d_1$  are individual trapezoidal fuzzy numbers of W<sub>1</sub>;  $a_2$ ,  $b_2$ ,  $c_2$ , and  $d_2$  are individual trapezoidal fuzzy numbers of W<sub>2</sub>;  $a_3$ ,  $b_3$ ,  $c_3$  and  $d_3$  are individual trapezoidal fuzzy numbers of W<sub>3</sub>.

Appendix C

(FGP)

Minimize 
$$\sum_{i=1}^{n} (p_i + n_i) + a_i^+ + a_i^-)$$
 (15)

Subject to

$$r_{i} \leq \left(\frac{g_{i,\max} - y_{i}}{g_{i,\max} - g_{i,\min}}\right) b_{i}, \quad i = 1, 2, \dots, n,$$
(16)

$$z_i(\mathbf{x}) - p_i + n_i = y_i, \quad i = 1, 2, ..., n,$$
(17)

$$r_i - a_i^+ + a_i^- = 1, \quad i = 1, 2, ..., n,$$
 (18)

$$g_{i,\min} \le y_i \le g_{i,\max}, \quad i = 1, 2, \dots, n$$
, (19)

$$p_i, n_i, a_i^+, a_i^-, r_i \ge 0, \quad i = 1, 2, ..., n,$$
 (20)

$$b_i \in R_i(\mathbf{x}), \ i = 1, 2, ..., n,$$
 (21)

$$1 - r_i \le \sum_{j=1}^{m-1} (\mu_{attribute}(P_j) - \mu_{attribute}(P_{j+1})) y_{i,j} - k,$$
(22)

$$y_{i,j} \ge y_{i,j+1}, \quad j = 1, 2, ..., m - 1,$$
(23)

where  $p_i$  and  $n_i$  are positive and negative deviational variables from the *i*-th target value  $y_i$ ;  $a_i^+$  and  $a_i^-$  are deviational variables attached to  $|r_i - 1|$ ;  $r_i$  is the value of the utility function;  $b_i$  is the binary decision variable that is restricted by the resource constraint function  $R_i(\mathbf{x})$ . The target value  $y_i \in [g_{i,\min}, g_{i,\max}]$  of  $z_i(\mathbf{x})$  is a continuous variable, where  $g_{i,\max}$  and  $g_{i,\min}$  are the upper and lower bound values; k is a small positive value. The binary variables,  $y_{i,j}$ , are used to indicate which alternatives are selected. For example, if  $\prod_{j=1}^{m-1} y_{i,j} = 1$ , it indicates that alternative,  $P_j$ , is selected; otherwise  $P_j$  is not selected.  $\mu_{attribute}(P_j)$  represents the average satisfaction level for the attributes of the *j*-th alternative will be forced to achieve a level, the higher, the better. Meanwhile,  $y_{i,j}$  will be selected in sequence, and hence  $y_{i,j}$  will be selected before  $y_{i,j+1}$  with Eq. (23).

Appendix D

 $\begin{array}{ll} \text{Minimize} & (\frac{s_1^+ + s_1^-}{1}) + k_1^- + (\frac{d_2^+ + d_2^-}{1}) + f_2^- + (\frac{d_3^+ + d_3^-}{1}) + f_3^- + (\frac{s_4^+ + s_4^-}{1}) + k_4^- \\ \text{!G1 : Price} \\ & s_1^+ = 1 - n_1^+, \ s_1^- = 1 - n_1^-, \ \ 0.63x_1 + 0.94x_2 + 0.47x_3 + 0x_4 + 1x_5 - n_1^+ + n_1^- = 1, (h_{1,\max} = 1) \\ & n_1^+ \le b_1, \ n_1^- \le (1 - b_1), \ \eta_1 \le (0.63x_1 + 0.94x_2 + 0.47x_3 + 0x_4 + 1x_5), \\ & \eta_1 + k_1^- = 0, \ x_1 + x_2 + x_3 + x_4 + x_5 = 1, \\ & \text{@BIN}(x_i); \ & \text{@BIN}(b_1); \ & \text{@BIN}(b_4); \ i = 1, 2, \dots, 5 \\ & \text{For example, by referring to the price data in Table 5, we have} \ & e_i(\mathbf{x}) = 0.63x_1 + 0.94x_2 + 0.47x_3 + 0.47x_4 + 1x_5 \\ & \text{in price goal (G1). Since G1 is an SAL goal, the equations of G1 will find the alternatives from } e_i(\mathbf{x}), \text{ which are moving away from } h_{i,\max} = 1 \\ & \text{(the highest price of all).} \end{array}$ 

### Appendix E

Minimize

$$\sum_{j=1}^{12} (p_{1j} + n_{1j}) + \sum_{j=1}^{16} (p_{2j} + n_{2j}) + \sum_{j=1}^{14} (p_{3j} + n_{3j}) + \sum_{j=1}^{9} (p_{4j} + n_{4j}) + \sum_{k=1}^{4} (a_k^+ + a_k^-) + \sum_{j=1}^{20} (y_{1j} + y_{2j} + y_{3j} + y_{4j})$$
  
Subject to

G5: The price of the smartphone with two-years contract

$$\begin{split} r_{1} &= \frac{0.08(n_{11} - n_{12})}{1990} + \frac{0.03(n_{12} - n_{13})}{1910} + \frac{0.07(n_{13} - n_{14})}{90} + \frac{0.11(n_{14} - n_{15})}{1410} + \frac{0.1(n_{15} - n_{16})}{2590} + \frac{0.1(n_{16} - n_{17})}{410} \\ &+ \frac{0.03(n_{17} - n_{18})}{1500} + \frac{0.19(n_{18} - n_{19})}{90} + \frac{0.1(n_{19} - n_{110})}{1500} + \frac{0.01(n_{110} - n_{111})}{910} + \frac{0.14(n_{111} - n_{112})}{40} + \frac{0.14(n_{111} - n_{112})}{40} \\ r_{1} - a_{1}^{+} + a_{1}^{-} = 1, z_{1} - p_{11} + n_{11} = 13990, z_{1} - p_{12} + n_{12} = 12800, z_{1} - p_{13} + n_{13} = 12400, \\ z_{1} - p_{14} + n_{14} = 1490, z_{1} - p_{15} + n_{15} = 9990, z_{1} - p_{16} + n_{16} = 9990, z_{1} - p_{17} + n_{17} = 8400, \\ z_{1} - p_{18} + n_{18} = 7990, z_{1} - p_{19} + n_{19} = 5400, z_{1} - p_{110} + n_{110} = 3990, z_{1} - p_{111} + n_{111} = 3990, \\ z_{1} - p_{112} + n_{112} = 1990, \\ 1 - r_{1} = 0.08y_{120} + 0.03y_{119} + 0.07y_{118} + 0.11y_{117} + 0.01y_{115} + 0.11y_{114} + 0.03y_{113} \\ + 0.19y_{112} + 0.1y_{111} + 0.01y_{19} + 0.14y_{18} + 0.14y_{17} - 0.00001, \\ y_{11} \ge y_{17}, y_{11} = y_{12} = y_{13} = y_{14} = y_{15} = y_{16}, y_{17} \ge y_{18}, y_{18} \ge y_{19}, y_{19} = y_{110}, y_{110} \ge y_{111}, y_{111} \ge y_{112}, \\ y_{112} \ge y_{113}, y_{113} \ge y_{114}, y_{114} \ge y_{115}, y_{115} = y_{116}, y_{116} \ge y_{117}, y_{117} \ge y_{118}, y_{118} \ge y_{119}, y_{119} \ge y_{120}, \\ y_{120} = 0, r_{1} = 0.5, r_{2} = 0.5, r_{3} = 0.2, r_{4} = 0.5, !$$
 Assume lambda 1=0.5, lambda 2=0.5, lambda 3=0.2, and lambda 4=0.5; @BIN(y\_{ij}); i = 1,2,...4; j = 1,2,...20;

Appendix F

The Smartphone Usage Questionnaire

- 1. Your gender:  $\bigcirc$  Male  $\bigcirc$  Female
- 2. Which best describes the industry or business of your primary workplace?
  O Public servant O Service industry O Manufacturing industry O Medical
  O Finance O Student O Housekeeping O Other (please specify)
- 3. What is your age range?

 $\bigcirc 16\text{-}20 \quad \bigcirc 21\text{-}25 \quad \bigcirc 26\text{-}30 \quad \bigcirc 31\text{-}35 \quad \bigcirc 36\text{-}40 \quad \bigcirc 41\text{-}45 \quad \bigcirc 46\text{-}50$ 

○ 51-55 ○ 56-60 ○ Above 61

- 5. What are the main tasks that you usually perform in your smartphone?
  O Map O Digital camera O Checking social network O Schedule
  O Games
- 6. How importance would you set for the price of a smartphone when you consider buying one?
   Very Low Low Medium Low Medium Medium High
   High Very High
- 7. How importance would you set for the battery capacity of a smartphone when you consider buying one?

 $\bigcirc$  Very Low  $\bigcirc$  Low  $\bigcirc$  Medium Low  $\bigcirc$  Medium  $\bigcirc$  Medium High

 $\bigcirc$  High  $\bigcirc$  Very High

8. How importance would you set for the screen size of a smartphone when you consider buying one?

 $\bigcirc$  Very Low  $\bigcirc$  Low  $\bigcirc$  Medium Low  $\bigcirc$  Medium  $\bigcirc$  Medium High

```
\bigcirc High \bigcirc Very High
```

9. How importance would you set for the weight of a smartphone when you consider buying one?

 $\bigcirc$  Very Low  $\bigcirc$  Low  $\bigcirc$  Medium Low  $\bigcirc$  Medium  $\bigcirc$  Medium High

 $\bigcirc$  High  $\bigcirc$  Very High

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