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Multi-criteria ranking of voice transmission carriers of a telecommunication company using PROMETHEE

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Abstract

This paper ranks the voice transmission carriers as used by mobile telecommunication companies. The versatility of the PROMETHEE method made it a useful tool for this ranking process. However, in our approach, the logistic preference function which is a recently proposed preference function was adopted in the ranking procedure as opposed to the Gaussian preference function. The results obtained by the logistic preference function yield a similar effect as that of the Gaussian preference function with both reaching an optimal ranking at the complete ranking stage.

Keywords: Complete ranking, Logistic preference function, Mobile telecommunication, Multi-criteria decision making, PROMETHEE method

Introduction

Telecommunication carrier is by definition companies that are authorized by a regulatory agency to operate a telecommunications system. In the work of Ching-Ter et al. (2011), the problem of routing management still stands to confuse many telecommunication-related companies among which are: equipment manufacturers, platform vendors, service operators, and billing system. Through their study, they observed that routing control is dependent not only on equipment but also on the operational flow of the company. Unlike Internet Service Provider (ISP) where its providers often control the entire network topology; the same is not of telecommunication operators. A full range of service is only possible to the reach of its customers by contracting partners such as service carriers. In the case of customer calls or user calls, these operators provide service according to an internal and pre-deployed routing logic to its service providers or carriers depending upon the destination or the service traffic to available routes. That is, a clear guide is instituted for the engineering staff on path deploying for the next period (or billing cycle) to come while achieving multiple pre-defined goals automatically. In this instance, decision-making which is the science of recognizing and determining choices based on the values and partialities of the decision maker becomes necessary (Diaz et al. 2015; Caron and Daniels 2013; Anderson and Mansingh 2014). Making a choice implies that there are alternatives to be considered, and in such a case we do not only distinguish as many of these choices but also take the one that best fits with the objectives, values, goals, and desires. This process starts with the classification of the decision makers and stakeholders in the resolution and reducing the possible misunderstanding about problem definition, requirements, criteria, and goals (Majumder and Ghosh 2013; Al-Tarawneh 2012). According to Ignaccolo et al. (2017), Moffett and Sarkar (2006), to make a decision, one needs to understand the problem, the urgency, the scope of the decision, the criteria for the choice, their sub-criteria, stakeholders, and groups affected and the alternative steps to take. In the case of resource allocation, one requires the needed priorities to determine the best alternative to allocate the appropriate share of the resources. They also recommended that the decision-making process must distinguish causes, limiting assumptions, policy and organizational barriers and interfaces, and any stakeholder concerns. The aim is to reveal the issue in a fair and precise problem statement that represents both the first circumstances and the desired circumstances. The problem statement must nevertheless be a brief and unambiguous written material agreed upon by all decision-makers and stakeholders.

Related works

In Triantaphyllou and Mann (1995), Nemhauser et al. (1989), it was explained that decision-making suggests many criteria and sub-criteria employed to order the options of choice. Not solely does one need to generate preferences for the options about the requirements for which they must be estimated, but also regarding essential goals. The works of Steuer (1986), Steuer and Na (2003), Hirschberger et al. (2013) also stipulated that the case where we have a finite number of criteria but the number of feasible alternatives are infinite belongs to the field of multiple criteria optimization. Contrary to that, decision-making problems where the number of the criteria and alternatives is finite with an explicit definition of alternatives are called multi-attribute decision-making problems. Again, Kuhn and Tucker (1951) considered problems with multiple objectives while formulating optimality conditions for nonlinear programming. The Multiple Objective Programming (MOP) problem seeks to optimize a set of incommensurable and conflicting objectives under some constraints simultaneously and this was brought to bear in Charnes et al. (1955), Charnes and Cooper (1961), Contini and Zionts (1968). In Saaty (1977, 1986, 1990, 2003), Analytic Hierarchy Process (AHP) which is a multi-criteria decision-making approach was introduced with tools that can be used to solve complex decision problems. These have captivated the curiosity of many researchers due to their critical mathematical properties and the requirement that the input data are easy to get. According to Merkin (1979) AHP is based on the well-defined mathematical structure of uniform matrices with correlated eigenvector's to generate real or approximate weights. The method examines the models and alternatives concerning a criterion in a consistent and pairwise mode. The AHP uses a necessary scale of absolute numbers that have been proven and validated experimentally to capture individual preferences concerning quantitative and qualitative attributes (Saaty 1980, 1990). The study of Kumar et al. (2009) explores the analytical hierarchy process as applied to vendor selection in the following categories: small-, medium- and large-scale industries. Their work investigates the problem associated with the use of AHP as a vendor selection tool under different criteria (Singh et al. 2003, 2005). For large companies, a formal approach is adopted in selecting suppliers as opposed to small- and medium-sized industries (Pearson and Ellram 1995). The AHP method is also adopted by Tam and Tummala (2001) in vendor selection of a telecommunications system. In their article, they formulated an AHP-based model to examine the feasibility of selecting a vendor for a telecommunications system as a case study. The proposed model shows an improvement in the group decision-making in vendor selection that matches with customer specifications. This model gives a systematic process with the reduced time taken in vendor selection. These articles (Figueira et al. 2009, 2013) also developed ELECTRE which is a family of multi-criteria decision analysis methods with the concept of constructing a directed network of preferences. With this approach, a set of outranking decisions which is considered as best is constructed. In the work of Brans and Vincke (1985), PROMETHEE I also know as partial ranking, and PROMETHEE II that is complete ranking was developed. Some years later, PROMETHEE III which is a ranking strategy based on the intervals, and PROMETHEE IV the continuous case was proposed by Brans and Mareschal (1994), Brans et al. (1986). The same authors proposed the interactive visual module GAIA, a graphical representation to support their methodology (Deshmukh 2013), while the work of Brans and Mareschal (1992) further suggest PROMETHEE V as an extension with the inclusion of the segmentation constraints. With the representation of the human brain, the work of Brans and Mareschal (1995) proposed PROMETHEE VI. The decision table which serves as the starting point of the PROMETHEE method was proposed by Brans and Vincke (1985). In the decision table is a score defined of which for simplicity sake do not require normalization or transformation to a dimensionless scale. It is, therefore, assumed that a higher score value implies better performance, while the weights of the criteria are determined by an appropriate method other than the PROMETHEE method. In the work of Anagnostopolous et al. (2005), the PROMETHEE method with the AHP was adopted in the study of water resource planning. Their scope of the study was the management of the Nestos river in relation to the operation of two dams constructed. The management of the water supply is required to create a balance in the needs for irrigation, the public electrical corporation for hydropower generation, as well as environmental requirements in the presence of valuable natural ecosystems in the area. The study of Athawale and Chakraborty (2010) adopted the PROMETHEE II method in facility location selection. This method becomes relevant to decision makers in the citation of a new organization or the expansion of existing facility. The association of cost to the acquisition of land and the construction of facility makes facility location problem a long-term investment decision. In the UK police force, the analysis of improvement of rank performance was carried out in the work of Barton and Beynon (2006a, b) using the PROMETHEE method. Their study took twofolds, where the first exploits the PROMETHEE-based uncertainty analysis in rank improvement while the second phase makes use of the result from the first phase to aid in the performance strategies. Finally, the survey of Velasquez and Hester (2013) indicated the strengths and the weaknesses of the various multicriteria methods including AHP, PROMETHEE, MAUT, and ELECTRE. In this paper, we use the logistic preference function (Amponsah et al. 2012) in the PROMETHEE method to rank voice transmission carriers of a mobile telecommunication company.

Methods

The problem of Decision Optimization is stated as follows: Let the set $A = \{A_j\}, j = 1, \ldots, m$, be a finite set of alternatives. Let the set $C = \{C_i\}, i = 1, \ldots, n$ be a weighted finite set of criteria with w_i being the weights Let X_{ij} be real-valued performance index of the alternative j on criterion i, determine alternative A_j with index j as the best choice alternative satisfying the criteria The Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) I and II were developed by Brans and Vincke (1985) to provide a ranking from best to worst of a finite set of alternatives. Ranking of alternatives based on PROMETHEE methodology requires the following steps:

Step 1: Input data of decision table: the data show in quantitative terms the performance of each alternative A_j on each criterion, C_i for all the criteria C. Cost and profit criteria are labeled as minimizing and maximizing criteria, respectively. The performance is denoted by the X_{ij} in the decision table.

Step 2: Calculate deviations of various criteria values: for all maximizing criteria we use the equation

$$d_i(A_k, A_l) = X_{ik} - X_{il} \tag{1}$$

While for minimizing criteria we use the equation

$$d_i(A_k, A_l) = -(X_{ik} - X_{il}) \tag{2}$$

Step 3: Select a generalized preference function: Podvezko and Podviezko (2010) put forward eight generalized preference functions. These generalized preference functions include

1. The u-shape preference function,
2. The level preference function,
3. The multistage preference function,
4. The v-shape preference function,
5. The v-shape with indifference preference function,
6. The c-shape preference function and
7. The Gaussian preference function.

Gaussian function is best suited for continous criteria. However, Amponsah et al. (2012) proposed new continuous generalized preference function which they called Logistic preference function. It is defined by

$$P(d) = \begin{cases} 0 & d \leq 0 \\ \frac{1-e^{\frac{-d^2}{\sigma^2}}}{1+e^{\frac{-d^2}{\sigma^2}}} & d > 0 \end{cases} \tag{3}$$

where σ is the standard deviation. The logistic preference function is used for the computations in this paper.

Step 4: Calculate the preference (criterion) value denoted by $P_i(d_i(A_k, A_i))$. Using the logistic preference function, we have:

$$P_i(d_i(A_k, A_l)) = \begin{cases} 0 & d \leq 0 \\ \frac{1-e^{\frac{-d^2}{\sigma^2}}}{1+e^{\frac{-d^2}{\sigma^2}}} & d > 0 \end{cases} \tag{4}$$

The calculated value $P_i(d_i(A_k, A_l))$ measures the intensity of the decision maker's preference for the alternative A_k over A_i on the same criterion C_i for $i = 1, \ldots, n$.

Step 5: Calculate the preference index: we calculate the preference index for each alternative A_k over another alternative A_i for all criteria C_i by using the relation

$$\pi(A_k, A_i) = \sum_{i=1}^{n} w_i p_i(A_k, A_i) \quad \text{for } k, l = 1, \ldots, m \tag{5}$$

where w_i is the weight of criterion i.

Step 6: Rank the alternatives: ranking a finite set of alternatives in PROMETHEE may involve two main stages namely,

1 Partial ranking: this is known as PROMETHEE I and it establishes the outranking relation existing between various alternatives via the leaving (positive) and the entering (negative) flows $(\phi^+(A_k)), (\phi^-(A_k))$ respectively.

(a) Positive outranking flow for A_j is the preference of the alternative A_j over all other alternatives A_k and $A_k \neq A_j$. The flow is denoted by

$$\phi^+(A_j) = \frac{1}{m-1} \sum_{k=1}^{m} \pi(A_j, A_k), \quad j = 1, \ldots, m \tag{6}$$

(b) Negative outranking flow for A_j is the preference of all other alternatives A_k over $A_j \in A$ and $A_k \neq A_j$

$$\phi^-(A_j) = \frac{1}{m-1} \sum_{k=1}^{m} \pi(A_k, A_j), \quad j = 1, \ldots, m \tag{7}$$

The set of relations of pairs of alternatives in partial ranking scheme are mediated by the symbols P, I and R placed between two alternatives. The relation $A_k P A_l$ signifies the preference of the alternative A_k over A_l considering all the criteria, $A_k I A_l$ signifies the indifference between alternatives A_k and A_l and $A_k R A_l$ indicates the incomparability of the two alternatives A_k and A_l. These three (3) cases are identified using in Table 1. The arrowed relation in column three of Table 1 indicate graph network branch from vertex A_k to vertex A_l. A ranking procedure fails if the total count of branches on any node is less than the number of alternatives minus one where the partial ranking stage above fails

Table 1 Relations between alternatives in PROMETHEE partial preorder ranking

Preference relation	Cases	Graphical representation
$A_k P A_l$	$\phi^+(A_k) > \phi^+(A_l)$ and $\phi^-(A_k) < \phi^-(A_l)$	$A_k \rightarrow A_l$
	$\phi^+(A_k) > \phi^+(A_l)$ and $\phi^-(A_k) = \phi^-(A_l)$	
	$\phi^+(A_k) = \phi^+(A_l)$ and $\phi^-(A_k) < \phi^-(A_l)$	
$A_k I A_l$	$\phi^+(A_k) = \phi^+(A_l)$ and $\phi^-(A_k) = \phi^-(A_l)$	–
$A_k R A_l$	$\phi^+(A_k) > \phi^+(A_l)$ and $\phi^-(A_k) > \phi^-(A_l)$	–
	$\phi^+(A_l) > \phi^+(A_k)$ and $\phi^-(A_l) > \phi^-(A_k)$	

Table 2 The two existing relations between alternatives in complete ranking

Preference relation	Cases	Graphical representation
$A_k P A_l$	$\phi(A_k) > \phi(A_l)$	$A_k \rightarrow A_l$
$A_k I A_l$	$\phi(A_k) = \phi(A_l)$	–

to determine the best alternative we conclude the process with the complete ranking step below.

2 Complete ranking (PROMETHEE II): at this stage, it is the PROMETHEE II (preorder complete ranking) which completes the whole ranking process, establishing a relation that links all alternatives, be they comparable or incomparable and placing them in their right perspective, in a hierarchy from best to worst. Therefore, if after partial ranking, some alternatives are found to be incomparable, then we apply PROMETHEE II method to finish the ranking process for an optimal decision to be made. In fact, it makes use of only the p and I (preference and indifference respectively). This approach makes use of what is called the net outranking flow symbolically represented by $\phi(A_k)$ for the alternative A_k such that

$$\phi(A_k) = \phi^+(A_k) - \phi^-(A_k) \tag{8}$$

the alternative A_l in terms of the net outranking flow becomes:

$$\phi(A_l) = \phi^+(A_l) - \phi^-(A_l) \quad \forall A_l \in A \tag{9}$$

So, the higher the net flow the better the alternative.

- (i) The alternative A_k is preferable to A_l if and only if $\phi(A_k) > \phi(A_l)$
- (ii) The alternative A_k is indifferent to A_l if and only if $\phi(A_k) = \phi(A_l)$

Table 2 shows the two (2) existing relations between alternatives in complete ranking

Data

Mobile telecommunication companies route their international and local calls through multiple telecommunication carriers. To select the most efficient carriers to use a telecommunication companies, use a myriad of performance criteria to assess the carriers to choose the most suitable. Such exercise is important so as to avoid subscriber complaints of failed calls, misdirection of calls and noise. A Ghanaian company wants to evaluate six carriers (alternatives) against six performance criteria. The list of alternatives and criteria are provided below: the codes of the six international mobile carriers (alternatives) considered are presented as: $VTC-1(A_1)$, $VTC-2(A_2)$, $VTC-3(A_3)$, $VTC-4(A_4)$, $VTC-5(A_5)$, $VTC-6(A_6)$. The criteria identified by the Network Performance team of the mobile telecommunication company for measuring performance are:

1 Route availability (C_1): The logical (trunk line) connection between two switch or exchange nodes define route of calls. Route availability is defined as:

$$\text{Route availability}[\%] = \frac{\text{NTO}}{\text{TNT}} \times 100 \tag{10}$$

where NTO is the number of trunk outage, TNT is the total number of trunks. Route availability should not be less than 100%, hence it is a maximizing criterion

2 Busy hour traffic (C_2): In a day, the 60 min interval in which the traffic is highest is called busy hour (BH). If the average number of calls to and from a terminal during a period of T second in traffic hour is 'n' and the average holding time before personal calls end is 'h' seconds, the average occupancy of the terminal is given by:

$$A = \frac{nh}{T} \tag{11}$$

The busy hour traffic should be high and, therefore, it is a maximizing criterion.

3 Capacity (C_3): The capacity of a given carrier is measured in terms of the subscribers or the traffic load that it can handle. The Erlang B formula is the most commonly used figure in any telecommunication capacity calculation, (Chromy 2011). The capacity of the carrier should be high and thus it is a maximizing criterion.

4 Utilization (C_4): The utilization of the trunk is calculated as a ratio of the total traffic to the capacity expressed as a percentage:

$$\text{Utilization}[\%] = \frac{\text{Total traffic}}{\text{Capacity}} \times 100 \tag{12}$$

The utilization should not exceed 80%, it is, therefore, a minimizing criterion

5 Congestion (C_5): It is the condition in a switching center when a caller cannot obtain a connection to the wanted end user immediately. It is expressed as:

$$\text{Congestion}[\%] = \frac{\text{NCFC}}{\text{TNCA}} \times 100, \tag{13}$$

where NCFC is the no. of connected failed calls, TNCA is the total No. of call attempts. Congestion should be less than or equal to 1%, it is a minimizing criterion.

Table 3 Performance matrix table of carriers (alternatives) against respective criteria

Criteria	Type	Alternatives						Mean	Standard deviation
		A_1	A_2	A_3	A_4	A_5	A_6		
C_1	Max	100	100	100	87.87	100	100	97.9783	4.952052
C_2	Max	26.92	97.61	181.42	183.94	112.39	86.14	114.737	60.1068
C_3	Max	22.83	110.35	387.89	311.71	229.85	229.85	215.413	132.3365
C_4	Min	117.93	88.45	46.77	59.01	48.9	37.48	66.4233	30.73794
C_5	Min	11.9	0.15	0	0	0	0	2.00833	4.846279
C_6	Min	31.51	35.36	51.05	45.45	36.4	35.46	39.205	7.418816

6 Answer to seizure ratio (C_6): The answer/seizure ratio (ASR) is a measurement of network quality and call success rate in telecommunications. It is the percentage of answered telephone calls with respect to the total call volume. This value must not be < 40%, it is a maximizing criterion. The carrier linkage problem is modeled using a performance matrix data of Table 3. Table 3 shows the performance of carriers, by a mobile operator in Ghana. The first column, labeled criteria ($C_1, \cdots, C_6$) is the column for the six criteria. The second column lists the type of criteria as being a maximizing or minimizing criterion. The alternatives ($A_1, \cdots, A_6$) are listed in the row below the header. The rest of the table are the performance measures X_{ij} which are the scores of the various alternatives under the criteria.

Model formulation and computation

Decision problem statement is stated as follows: given a finite set of alternatives $A = A_j, j = 1, \ldots, m$ against a set of criteria, $C = C_j$ and weights $w_i, i = 1, \ldots, n$ what alternative A_j is the best alternative? We state our model instance of the Decision Optimization problem as follows: Let $A = \{A_j\}, j = 1, \ldots, 6$ be the set of carrier alternatives of the telecommunication company Let $C = \{C_i\}, i = 1, \ldots, 6$ be the set of equally weighted criteria with $w_i = 1/6$ being the weights Let X_{ij} be real-valued performance index of the carrier alternative j on criterion i, determine carrier alternative A_j with index j as the best choice carrier satisfying the criteria. The PROMETHEE algorithm for ranking the carrier alternatives is used in the following steps of calculations:

1 Calculation of deviations: The deviations $d_i(A_k, A_l)$ are obtained through a pair-wise comparison of the values of the alternatives on each criterion over all the criteria. It should be noted that the deviations are obtained as below:

- $d_i(A_k, A_l) = \{X_{ik} - X_{il}\}$—maximizing criteria
- $d_i(A_k, A_l) = \{-(X_{ik} - X_{il})\}$—minimizing criteria,

Table 4 Deviations $d_1(A_k, A_l)$ on criterion C_1

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	0	0	0	12.13	0	0
A_2	0	0	0	12.13	0	0
A_3	0	0	0	12.13	0	0
A_4	− 12.13	− 12.13	− 12.13	0	− 12.13	− 12.13
A_5	0	0	0	12.13	0	0
A_6	0	0	0	12.13	0	0

Table 5 Deviations $d_2(A_k, A_l)$ on criterion C_2

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	0	− 70.69	− 154.5	− 157.02	− 85.47	− 59.22
A_2	70.69	0	− 83.81	− 86.33	− 14.78	11.47
A_3	154.5	83.81	0	− 2.52	69.03	95.28
A_4	157.02	86.33	2.52	0	71.55	26.25
A_5	84.47	14.78	− 69.03	− 71.55	0	26.25
A_6	59.22	− 11.47	− 95.28	− 97.8	− 26.25	0

Table 6 Deviations $d_3(A_k, A_l)$ on criterion C_3

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	0	− 87.52	− 365.06	− 288.88	− 207.02	− 207.02
A_2	87.52	0	− 277.54	− 201.36	− 11.95	− 11.95
A_3	365.06	227.54	0	76.18	158.04	158.04
A_4	288.88	201.36	− 76.18	0	81.86	81.86
A_5	207.02	119.5	− 158.04	− 81.86	0	0
A_6	207.02	119.5	− 158.04	− 81.86	0	0

Table 7 Deviations $d_4(A_k, A_l)$ on criterion C_4

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	0	− 29.48	− 71.16	− 58.92	− 69.03	− 80.45
A_2	29.48	0	− 41.68	− 29.44	− 39.55	− 50.97
A_3	71.16	41.68	0	12.24	2.13	− 9.29
A_4	58.92	29.44	− 12.24	0	− 10.11	− 21.53
A_5	69.03	39.55	− 2.13	10.11	0	− 11.42
A_6	80.45	50.97	9.29	21.53	11.42	0

where X_{ik} and X_{il} correspond to performance values of two alternatives A_k and A_l on a criterion C_i. Tables 4, 5, 6, 7, 8 and 9 presents all possible deviations $d_i(A_k, A_l)$ from the pair-wise comparison of the alternatives on all the criteria.

2 Preference evaluation: We now calculate the intensity measure $P_i(A_k, A_l)$ of the decision maker's preference of A_k over A_l using the deviations $d_i(A_k, A_l)$. The preference function to be used is the logistic preference function (Amponsah et al. 2012):

Table 8 Deviations $d_5(A_k, A_l)$ on criterion C_5

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	0	− 11.75	− 11.9	− 11.9	− 11.9	− 11.9
A_2	11.75	0	− 0.15	− 0.15	− 0.15	− 0.15
A_3	11.9	0.15	0	0	0	0
A_4	11.9	0.15	0	0	0	0
A_5	11.9	0.15	0	0	0	0
A_6	11.9	0.15	0	0	0	0

Table 9 Deviations $d_6(A_k, A_l)$ on criterion C_6

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	0	− 3.85	− 19.54	− 13.94	− 4.89	− 3.95
A_2	3.85	0	− 15.69	− 10.09	− 1.04	− 0.1
A_3	19.54	15.69	0	5.6	14.65	15.59
A_4	13.94	10.09	− 5.6	0	9.05	9.99
A_5	4.89	1.04	0	− 9.05	0	0.94
A_6	3.95	0.1	− 15.59	− 9.99	− 0.94	0

$$P(d) = \begin{cases} 0 & d \leq 0 \\ \frac{1-exp\left(\frac{-2d^2}{\sigma^2}\right)}{1+exp\left(\frac{-2d^2}{\sigma^2}\right)} & d > 0 \end{cases} \tag{14}$$

where d = deviation, σ = standard deviation, $d = d_i(A_k, A_l)$ and $\sigma^2 = \sigma^2(i)$ Tables 10, 11, 12, 13, 14 and 15 summarizes the values of $P_i(A_k, A_l)$ for each criterion C_i.

3 Aggregate Preference Index: The result to be used in further analysis is obtained by the computation of the aggregate preference index. The aggregate preference index is given by:

$$\pi(A_k, A_l) = \sum_{i=1}^{n} (w_i P_i(A_k, A_l)) \tag{15}$$

Table 16 shows the values of $(\pi(A_k, A_l))$ for all six carrier alternatives.

4 Partial ranking: From the aggregate preference indices, the Positive Outranking flow for the carrier alternative A_j is:

$$\phi^+(A_j) = \frac{1}{n-1} \sum_{k=1}^{n} \pi(A_j, A_k) \tag{16}$$

and the Negative Outranking flow for the carrier alternative

$$\phi^-(A_j) = \frac{1}{n-1} \sum_{k=1}^{n} \pi(A_k, A_j) \tag{17}$$

Table 10 Values of $P_1(A_k, A_l)$ for criterion C_1

	$l=1$	$l=2$	$l=3$	$l=4$	$l=5$	$l=6$
$k=1$	0	0	0	0.9051	0	0
$k=2$	0	0	0	0.9051	0	0
$k=3$	0	0	0	0.9051	0	0
$k=4$	0	0	0	0	0	0
$k=5$	0	0	0	0.9051	0	0
$k=6$	0	0	0	0.9051	0	0

Table 11 Values of $P_2(A_k, A_l)$ for criterion C_2

	$l=1$	$l=2$	$l=3$	$l=4$	$l=5$	$l=6$
$k=1$	0	0	0	0	0	0
$k=2$	7	0.3326 0	0	0	0	0.0908
$k=3$	0.929	0.4045	0	0 0.3183	0.5568	
$k=4$	0.9361	0.4744	0.0004	0	0.3401	0.0477
$k=5$	0.4572	0.0151	0	0	0	0.0477
$k=6$	0.238	0	0	0	0	0

Table 12 Values of $P_3(A_k, A_l)$ for criterion C_3

	$l=1$	$l=2$	$l=3$	$l=4$	$l=5$	$l=6$
$k=1$	0	0	0	0	0	0
$k=2$	0.1089	0	0	0	0	0
$k=3$	0.9565	0.6287	0	0.0827	0.3422	0.3422
$k=4$	0.831	0.5218	0	0	0.0954	0.0954
$k=5$	0.5454	0.2011	0	0	0	0
$k=6$	0.5454	0.2011	0	0	0	0

Table 13 Values of $P_4(A_k, A_l)$ for criterion C_4

	$l=1$	$l=2$	$l=3$	$l=4$	$l=5$	$l=6$
$k=1$	0	0	0	0	0	0
$k=2$	0.226	0	0	0	0	0
$k=3$	0.8716	0.4298	0	0.0396	0.0012	0
$k=4$	0.7252	0.2254	0	0	0	0
$k=5$	0.8513	0.3918	0	0.0271	0	0
$k=6$	0.9369	0.5963	0.0229	0.122	0.0345	0

The values of the positive and negative outranking flows are tabulated in Table 17 In the partial ranking step, the following conditions below should be well noted. A_k is preferred to A_l if and only if one of the following three conditions is satisfied:

Table 14 Values of $P_5(A_k, A_l)$ for criterion C_5

	$l=1$	$l=2$	$l=3$	$l=4$	$l=5$	$l=6$
$k=1$	0	0	0	0	0	0
$k=2$	0.8995	0	0	0	0	0
$k=3$	0.9064	0.0002	0	0	0	0
$k=4$	0.9064	0.0002	0	0	0	0
$k=5$	0.9064	0.0002	0	0	0	0
$k=6$	0.9064	0.0002	0	0	0	0

Table 15 Values of $P_6(A_k, A_l)$ for criterion C_6

	$l=1$	$l=2$	$l=3$	$l=4$	$l=5$	$l=6$
$k=1$	0	0	0	0	0	0
$k=2$	0.0672	0	0	0	0	0
$k=3$	0.9396	0.8069	0	0.1398	0.7509	0.802
$k=4$	0.7078	0.432	0	0	0.3557	0.4246
$k=5$	0.1082	0.0049	0	0	0	0.004
$k=6$	0.0707	0.0004	0	0	0	0

Table 16 Aggregate Preference Indices ($\pi(A_k, A_l)$)

	$l=1$	$l=2$	$l=3$	$l=4$	$l=5$	$l=6$
$k=1$	0	0	0	0.1509	0	0
$k=2$	0.2724	0	0	0.1509	0	0.0151
$k=3$	0.7673	0.3784	0	0.1946	0.2355	0.2836
$k=4$	0.6846	0.2757	0.00007	0	0.1319	0.0946
$k=5$	0.4782	0.1022	0	0.1554	0	0.0086
$k=6$	0.4497	0.133	0.0038	0.1712	0.0058	0

Table 17 Values of the positive and negative outranking flows

A_j	$\phi^+(A_j)$	$\phi^-(A_j)$
A_1	0.03018	0.53044
A_2	0.08768	0.17786
A_3	0.37188	0.00077
A_4	0.23737	0.1646
A_5	0.14888	0.07464
A_6	0.1527	0.08038

(a) $\phi^+(A_k) > \phi^+(A_l)$ and $\phi^-(A_k) < \phi^-(A_l)$
(b) $\phi^+(A_k) > \phi^+(A_l)$ and $\phi^-(A_k) = \phi^-(A_l)$
(c) $\phi^+(A_k) = \phi^+(A_l)$ and $\phi^-(A_k) < \phi^-(A_l)$

From the above relations, the table of partial ranking flow is shown in Table 18. The flow is from a row carrier alternative to a column carrier alternative. A dash

Table 18 Partial ranking flow linkages of carrier alternatives

	A_1	A_2	A_3	A_4	A_5	A_6	Outarrows
A_1	–	1	1	1	1	1	5
A_2	–	–	1	1	1	1	4
A_3	–	–	–	–	–	–	0
A_4	–	–	1	–	–	–	1
A_5	–	–	1	–	–	–	1
A_6	–	–	1	–	–	–	1
InArrows	0	1	5	2	2	2	12

Table 19 Partial ranking flow linkages of carrier alternatives

	Inarrows	Outarrows	Total
A_1	0	5	5
A_2	1	4	5
A_3	5	0	5
A_4	2	1	3
A_5	2	1	3
A_6	2	1	3

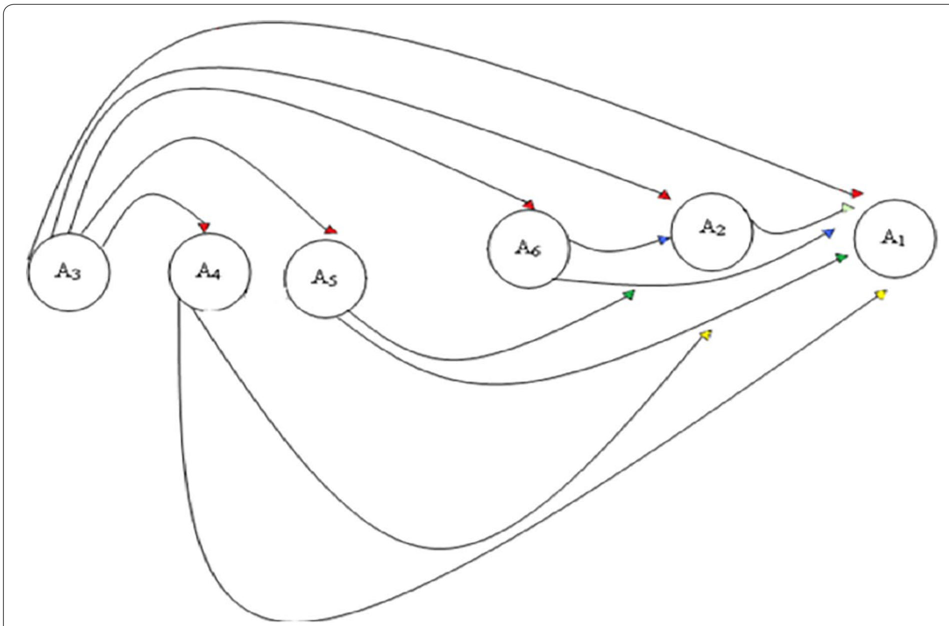

Fig. 1 Incomplete graph of partial ranking

represents no flow link (arrow) and a '1' represents a flow link (arrow). The total outarrows and inarrows listed respectively at the last column and row of the table. Table 19 lists the total inarrows and outarrows as well as providing ranking for the alternatives. The carrier alternative with higher outarrows is better than one with lower outarrows. Alternatives A_4, A_5, A_6 have total arrows less than the maximum

Table 20 Values of the net flow for all six alternatives

A_k	$\phi^+(A_k)$	$\phi^-(A_k)$	$\phi(A_k)$
A_1	0.03018	0.53044	− 0.50026
A_2	0.08768	0.17786	− 0.09018
A_3	0.37188	0.00077	0.371106
A_4	0.23737	0.1646	0.072774
A_5	0.14888	0.07464	0.07424
A_6	0.1527	0.08038	0.07232

Table 21 Complete ranking flow linkages of carrier alternatives

	A_1	A_2	A_3	A_4	A_5	A_6	Outarrows
A_1	–	1	1	1	1	1	5
A_2	–	–	1	1	1	1	4
A_3	–	–	–	–	–	–	0
A_4	–	–	1	–	–	–	1
A_5	–	–	1	1	–	–	2
A_6	–	–	1	1	1	–	3
InArrows	0	1	5	4	3	2	12

Table 22 Complete ranking InArrow and OutArrow linkages on carrier alternative nodes

	Inarrows	Outarrows	Total
A_1	0	5	5
A_2	1	4	5
A_3	5	0	5
A_4	4	1	5
A_5	3	2	5
A_6	2	3	5

Table 23 Ranking of six alternatives using PROMETHEE

Alternatives	Number of out-directed arcs	Ranking position
A_1	5	1st
A_2	4	2nd
A_3	0	6th
A_4	1	5th
A_5	2	4th
A_6	3	3rd

of 5 required. Thus the optimal ranking cannot be obtained at this stage of partial ranking. From the graph of partial ranking of Fig. 1, it is realized that there are no linkages between the carrier alternatives A_4, A_5 and A_6. Thus, the three alternatives are incomparabl; therefore, optimal ranking cannot be obtained.

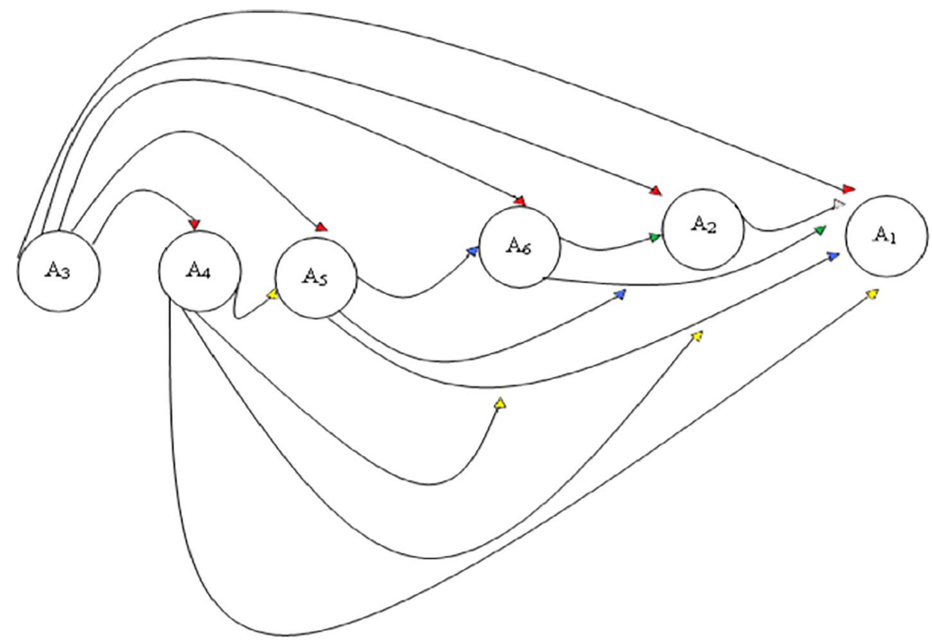

Fig. 2 The graph of the complete ranking

5 Complete ranking: Values of the net flow are calculated as

$$\phi(A_k) = \phi^{+}(A_k) - \phi^{-}(A_k) \tag{18}$$

Table 20 presents the calculated values of $\phi(A_k)$ Preference exists between a pair of alternatives (A_k, A_l) if $\phi(A_k) \neq \phi(A_l)$ Considering the alternatives A_k, and A_l, alternative A_k is preferred to alternative A_l if and only if $\phi(A_k) > \phi(A_l)$ otherwise A_k is not preferred to alternative A_l. From the above relations, the table of complete ranking flow is shown in Table 21. Tables 22 and 23 list the total inarrows and outarrows as well as providing ranking for the alternatives. The total number of arrows on each carrier alternative node is counted to be five. Optimal ranking is now achieved since all the carrier alternatives have the required maximum of 5 total arrows. From the graph of complete ranking of Fig. 2, it is observed that all carrier alternate nodes are mutually pair-wise linked either through an inarrow or outarrow ave the maximum five linkages which is one less than the total number of nodes. Thus, we have complete ranking with the confirmed order being A_1, A_2 and A_6 A_5 , A_4 and A_3.

Discussion

There was situation of incomparability illustrated by no linkages between the carrier alternatives A_4, A_5 and A_6 in the partial raking step of the PROMETHEE method; therefore, the alternatives could not be ranked. The complete ranking step satisfied all the conditions of ranking optimality and all carrier alternatives were appropriately ranked from best to worst in the order, A_1, A_2 and A_6 A_5, A_4 and A_3. Amponsah et al. (2012) who first used the logistic preference function reported general comparability with the performance of the Gaussian preference function even though the logistic preference function performed better than the Gaussian preference function in the test case they used. Using the Gaussian preference function to check our results, it was determined that the complete ranking stage was reached by both preference functions with the ranking order being the same.

Conclusion

This paper is the first test of the logistic preference function introduced in the literature by Amponsah et al. (2012), where the performance of five telecommunication companies were ranked based on data from the National Communication Authority in Ghana. On the other hand, this paper uses PROMETHEE methodology to rank communication carrier alternatives of a telecommunication company. The optimal solution was obtained at the complete ranking stage and carrier alternative VTC-1 was the best ranking communication carrier choice. The results of this study will have economic impact with the selection of the best communication transmission carrier. This will introduce efficiency, real-time savings and customer satisfaction. Comparison with results using the Gaussian preference function showed that both approaches reached the same optimal solution at the complete ranking stage.

Authors' contributions

BB, JKA and KFD designed the study. JKA and KFD gave technical support and conceptual advice. BB set up the experiment for performance evaluation. All authors prepared the manuscript. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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