A Multi-Criteria Decision Support System for Selecting Cell Phone Services

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INTRODUCTION

Cell phones have achieved high levels of market penetration in a relatively short time. According to the Canadian Wireless Telecommunications Association (CWTA, 2006), more than half of all Canadians are cell phone customers and 47% of all phone connections in Canada are wireless. For many organizations, equipping their employees with cell phones is an accepted operational cost. The industry-analyst firm Yankee Group estimates that businesses now spend a quarter of their telecommunications budgets on cell phone expenses (Allianceone, 2006). In Massachusetts, over 10% of cell phone bills are paid by employers (Cummings & Smith, 2005).

Most areas have multiple cell phone service providers, and each typically provides a wide variety of plans with different cost structures. One Canadian company claims that most companies are actually spending 20-50% more than they need to (Allianceone, 2006). There are several reasons for this. First, finding the most cost-effective plan from among so many choices is complex and time-consuming. Second, each employee can have a different calling pattern in terms of total minutes, where the calls are originating from or going to, and when the calls are placed. Often there is no single plan that is best for everyone. Third, cost is not the only factor to consider; service quality varies as well. Moreover, plan costs, calling patterns and service quality are constantly changing. While larger organizations can use specialized consulting companies and have the volume to get special discounts, smaller businesses are often very much on their own to determine which plan(s) is best for them.

The goal of this research is to develop a Multi-Criteria Decision Support System (MCDSS) to help organizations, particularly small businesses, determine the best cell phone plans for their employees. Finding the lowest cost plan is relatively straightforward using a computer-based system; each calling pattern can be compared over all plan cost structures. To incorporate non-cost factors, a survey was conducted among small businesses to determine which they considered to be most important. These factors were then integrated into the MCDSS using the Analytic Hierarchy Process (AHP). The system allows decision makers to have different preferences for the importance of non-cost factors, different rankings for how each service provider performs on these factors, and different weightings between cost and non-cost factors overall.

CELL PHONE INDUSTRY

This research was conducted in a small city (population under 100,000) in Canada in 2006. At that time, there were four major cell phone providers, two owned by the same company, offering a total of ninety business plans with different rates. The rates have a similar structure across different plans. The main elements are a fixed monthly cost, per minute rates and additional options. The fixed monthly cost covers service fees (including system access and 911 emergency services) and often includes an allotment of "free" minutes. Once these have been exhausted, per minute rates come into effect.

Per minute rates are based on when the call is placed and its origin and destination. Canadian cell phone service providers usually divide location into three categories: local, long distance within Canada and from Canada to the U.S., and long distance from the U.S. to Canada. Within each category, the minutes can be classified by time as weekday, evening, and weekend. Each plan can provide different free minute allotments and different per minute rates for each of the nine combinations of location and time. However, each provider currently has identical weekend and evening rates so there are actually only seven call types to consider.

Some plans offer additional options that customers can select according to their needs and usage patterns (e.g., caller ID). Some affect costs, such as special rates when calling other cell phones from the same provider and business pooling plans that allow a group to share unused free minutes.

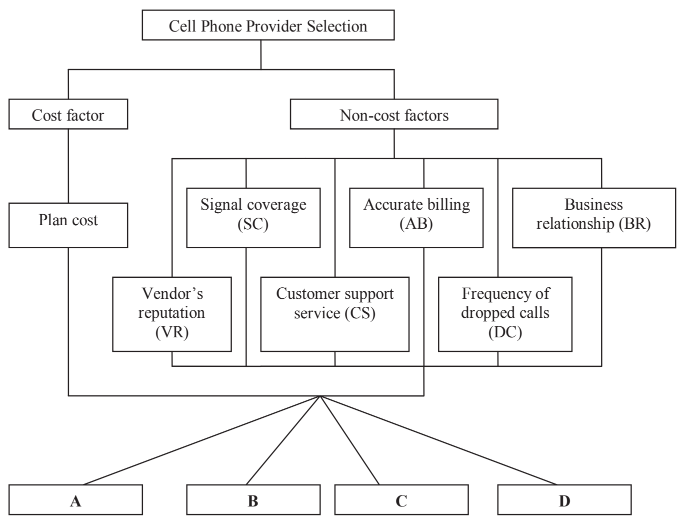
CUSTOMER SURVEY

Finding the best provider of a product or service is a common task that typically involves multiple criteria. The lowest cost plan is not necessarily the best plan. Non-cost factors can significantly affect a user's experience with any supplier, and cell phone service customers are starting to focus more on factors such as billing accuracy, provider reputation, and service quality (Cummings & Smith, 2005; Mao, Srite, Thatcher, & Yaprak, 2005; Navarro, 2005; Totten, Lipscomb, Cook, & Lesch, 2005; Woo & Fock, 1999). We selected 13 of these criteria (Table 1) for consideration.

A survey was constructed using a five-point Likert scale to measure the importance of each criterion. In addition, some demographic data were collected to help understand the characteristics of local business cell phone use. After constructing the questions, 10 academic researchers with backgrounds in the cell phone industry examined the clarity of the questions, the accuracy of the language, and the structure of the questionnaire. The questionnaire was refined and finalized after incorporating their feedback.

The survey was mailed to a random sample of 140 businesses, identified using the local Yellow Pages telephone directory. Most of them were in construction,

Figure 1. A four-level AHP hierarchy for selecting cell phone service vendors



transportation, and automotive retailing. Two response methods (regular mail or Web-based) were provided. A 29.2% response rate was obtained within four weeks. The six most important non-cost criteria (with 5.0 being the highest possible rating) were signal coverage (4.53), customer support service (4.53), accurate billing (4.47), frequency of dropped calls (4.45), provider's attitude and willingness to maintain the business relationship (4.37), and vendor's reputation 4.26. The two most important cost factors, ranked fifth and seventh, were the fixed cost of the plan(s) (4.37) and the per minute rate (4.21). Respondents were given the opportunity to include additional factors not included in the survey. Contract handling and warranty coverage were among them, but none of the entries occurred frequently enough to be included in the system.

Most respondents reported that their cell phone bills are less than $2,000, and none were responsible for cell phone bills for over 50 employees. The average monthly cost for each user is estimated at $64.71.

SYSTEM DESIGN

The goal of this research was to build a Decision Support System (DSS) to help small businesses find the right cell phone plan for their needs. The system was designed using a standard framework (Sprague, 1980), where the key component parts are a database, model base, and dialogue generator (or user interface).

Database

The database typically requires external and internal data. In this case, the external data are the cost structures for each plan. These were retrieved from provider web sites on February 2, 2006. The internal data is based on 500 different simulated employee calling patterns, which are generally consistent with local calling patterns. The database was stored using Microsoft Access.

Model Base

The model base has three main parts, which analyze cost and non-cost factors and then integrate them to provide a final decision (Figure 1). The Analytic Hierarchy Process (Saaty, 1980), a multi-criteria decision making technique which permits the inclusion of subjective factors in arriving at a recommendation, was used to assess the criteria because it can handle both quantitative and qualitative criteria. For that reason, a large number of DSS covering many types of products and services have been developed using the AHP (Vaidya & Kumar, 2006; Vargas, 1990).

The AHP facilitates decision making among a number of alternatives and criteria by formulating priorities. The process requires that the decision maker provide judgments about the relative importance of each criterion (e.g., signal coverage, customer service support, etc.) and then specify preferences for each decision alternative (cell phone provider) on each criterion. The output of AHP is a prioritized ranking, indicating the overall preference for each of the decision alternatives (Saaty, 1980, 1990). Expert Choice™, a commonly used software package to perform AHP computations, is used in this system.

Non-Cost Factors

Non-cost criteria are attributes of the four cell phone service providers, not the 90 individual plans. In order to determine the weight of each of the top six non-cost criteria (Figure 1), 15 entries are required for the pairwise comparison matrix. Table 1 provides an arbitrary set of example ratio judgments. These would normally vary among decision makers. Similarly, the ratio preferences of alternatives (providers) with respect to each criterion were entered into pairwise comparison matrices. Based on an example set of ratio preferences, the relative priorities of the providers with respect to the set of criteria are computed by Expert Choice™ (Table 2). The missing entries, excluding the main diagonal of the matrix, can be determined using the reciprocal. For example, if Signal Coverage (SC) has a priority of 2 over Customer Support (CS), then CS has a priority of 0.5 over SC.

Finally, the aggregate relative priorities (combining the criteria weights in Table 1 with the relative priorities of the providers in Table 2) were generated using Expert Choice. These priorities (p_i^{NC}) range from 0.323 (A), the best choice when cost is not a consideration, to 0.269 (B), 0.215 (C), and 0.193 (D).

Cost Factors

The lowest cost cell phone plan for an employee can be found by simply computing the cost of every plan for that employee's calling pattern (i.e., number of minutes for each of the seven calling types) and selecting the minimum. For this system, a Search Decision Rule (SDR) approach was used based on Taubert (1968) who proposed this method for the aggregate scheduling problem.

The search algorithm for this system seeks the minimum cost with respect to different calling patterns. In the search loop phase, the minimum cost for the seven different call types (based on call time and locations) for a calling pattern are obtained within the inner search loops, and the total minimum cost is determined through an outer search loop. In both loops, comparisons are made between the

Table 1. Pairwise comparisons of criteria

Criteria	SC	CS	DC	AB	BR	VR	Weights
SC			3.0			2.0	0.136
CS	2.0		4.0	1.0	2.0	2.0	0.258
DC							0.065
AB	3.0		3.0		2.0	2.0	0.270
BR	2.0		2.0			2.0	0.168
VR			2.0				0.105

Note. SC: Signal coverage; CS: Customer support service; DC: Frequency of dropped calls; AB: Accurate billing; BR: Provider's attitude and willingness for business relationship; VR: Vendor's reputation

Table 2. Relative priorities of providers with respect to each criterion

	Criteria					
Providers	SC	CS	DC	AB	BR	VR
A	0.232	0.200	0.205	0.167	0.167	0.232
B	0.140	0.200	0.169	0.333	0.333	0.395
C	0.232	0.400	0.288	0.333	0.333	0.232
D	0.395	0.200	0.338	0.167	0.167	0.140

currently achieved cost and its previous optimal cost. If the current cost is less than previous optimal one, minimum cost becomes the current cost. Otherwise, the existing minimum cost is retained.

This can be expressed more clearly as follows. Let U_{ik} be the projected usage time for calling type k (below) for the i^{th} employee. Based on plans offered by local cell phone providers, seven different calling types are included:

- Local daytime usage (k = 1)
- Local weekend usage (k = 2)
- Local evening time usage (k = 3)
- Long distance daytime usage within Canada or from Canada to the U.S. (k = 4)
- Long distance weekend/evening usage within Canada or from Canada to the U.S. (k = 5)
- Long distance daytime usage within the U.S. or from the U.S. to Canada (k = 6)
- Long distance weekend/evening usage within the U.S. or from the U.S. to Canada (k = 7)

A particular cell phone service provider P may have N_P plans available. Every provider has different costs for each calling type for each service plan. Each plan has a basic service charge and allots a maximum amount of free time (which could be 0) for each calling type. When an employee's usage exceeds these amounts, the organization is charged for additional use at various rates. Even for the same provider, these rates vary from plan to plan and this cost is denoted by $C_{ik}^{\ j}$ and will be calculated whenever applicable by the function $f^j(U_{ik})$ for a particular vendor as follows:

$$C_{ik}^{\ j} = f^j(U_{ik}) \quad (j = 1, .., N_p)$$

where $C_{ik}^{\ j}$ is cost of the k^{th} calling type under the j^{th} service plan for the i^{th} employee. Note that $f^j(U_{ik})$ calculates the cost for additional time beyond the free allotment and therefore $C_{ik}^{\ j}$ is equal to zero if the time used is at or below that free allotment.

The total cost for the i^{th} employee under a given plan j is given by

$$C_i^j = B_i^j + \sum_{k=1}^{T} C_k^j \quad (j = 1, .., N_p)$$

where:

C_i^j = the total cost for the i^{th} employee under the j^{th} plan

B_i^j = the basic service (fixed) cost for the i^{th} employee under the j^{th} plan

T = number of calling types (T=7)

$C_i^{j_i^*}$ is the minimum of all plan costs for the i^{th} employee for the plan j_i^* among all N_P plans, where:

$$C_i^{j_i^*} = \min\left\{C_i^j, j \in N_P\right\}$$

For a group of N employees, the total minimum cost is:

$$C^* = \sum_{i=1}^{N} C_i^{j_i^*}$$

Using the simulated user calling patterns, the minimum cost when using a single provider is the sum of these minimum costs, which are \$29,058.69 (D), \$36,869.57 (B), \$47,377.18 (A) and \$52,466.97 (C).

To determine the relative priorities of the providers with respect to cost, a pairwise comparison matrix was generated. The lower the cost, the more preferred it is. For example, selecting B is 1.423 (52,466.97/36,869.57) times preferred compared to C. As for non-cost factors, the preference of C compared to B can be determined using reciprocity (i.e., $a_{ji} = 1/a_{ij}$ for i^{th} and j^{th} providers). The relative priorities of each provider with respect to cost (p_i^C), generated using Expert Choice™, are 0.208 (A), 0.267 (B), 0.187 (C), and 0.338 (D).

Integrating Cost and Non-Cost Priorities

Finally, both cost and non-cost priorities for the providers need to be integrated to produce the overall final ranking (Sarker & Zahir, 2006). Let p_i^C and p_i^{NC} be the relative priorities of i_{th} provider for cost and non-cost factors, and w_1 and w_2 be weights of the factors, respectively (subject to $w_1 + w_2 = 1$). The overall aggregate relative priority A_i for the i_{th} provider is:

$$A_i = w_1 \times p_i^C + w_2 \times p_i^{NC}.$$

The decision maker can choose different weights in accordance with the goal of the organization, and finally determine which provider, and associated minimum cost plans, is optimal for an organization.

As shown in Table 3, A outperforms the rest of the providers when the cost weight is less than 46% while D is the best choice for higher cost weightings.

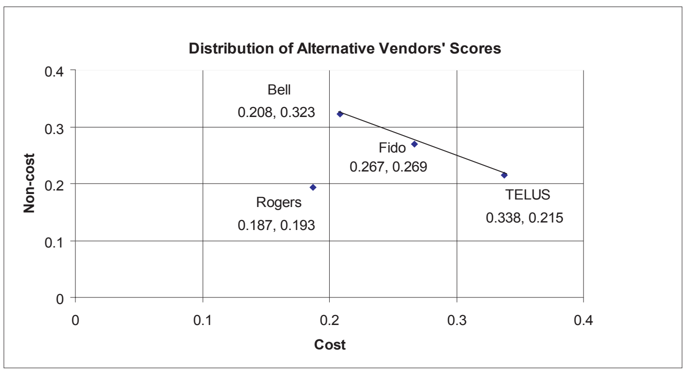
Figure 2 provides a graphical view showing that only A or D can be the optimal solution.

Table 3. Aggregate relative priorities of providers for different cost and non-cost weights

Cost Weight (w_1)	A	B	C	D
0%	**0.323**	0.269	0.193	0.215
10%	**0.312**	0.269	0.192	0.227
20%	**0.300**	0.269	0.192	0.240
30%	**0.289**	0.268	0.191	0.252
40%	**0.277**	0.268	0.191	0.264
46%	**0.270**	0.268	0.190	**0.272**
50%	0.266	0.268	0.190	**0.277**
60%	0.254	0.268	0.189	**0.289**
70%	0.243	0.268	0.189	**0.301**
80%	0.231	0.267	0.188	**0.313**
90%	0.220	0.267	0.188	**0.326**
100%	0.208	0.267	0.187	**0.338**

Note. $w_1 + w_2 = 1$ (w_2 is non-cost weight)

Figure 2. Providers' relative priorities with respect to cost and non-cost factors



CONCLUSIONS

Selection of cell phone service providers can be solved as multi-criteria problem involving both quantitative and qualitative factors. An integrated DSS was constructed to help organizations select the best cell phone provider(s). The method is a significant improvement compared with existing methods that are cost-oriented only. Both the literature review and the results of the survey indicate that several non-cost criteria play important roles in determining the optimal cell phone service provider. Signal coverage was considered most critical, and this may be particularly important to organizations that not only serve the city they are in but also a large surrounding rural area.

The AHP-based analysis of potential providers makes it possible to include multiple non-cost criteria. The factors relevant to the cell phone provider selection can be manipulated in accordance with the user's preferences. Moreover, not only are non-cost factors included but the results of the analysis can be used to demonstrate how and why these factors are influencing a decision.

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