ANALYTIC HIERARCHY PROCESS AND ITS APPLICATION TO GRADE OF TRAFFIC SERVICE FOR CELLULAR NETWORK

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Abstract: In a cellular network, several traffic control services are previously provided. Above all, when the network becomes congested e.g. world-cup ticket-reservation, THREE traffic control scenarios are proposed. In this paper, applying an AHP (Analytic Hierarchy Process) approach enables us to obtain a solution which scenario is best/worst among these traffic control scenarios, from user's view point. Firstly, we construct a web site on which cellular network users can simply answer a questionnaire regarding grade of traffic services via internet. We then formulate a pair-wise comparison matrix (p.c.m.) through this questionnaire result for an individual respondent. We next calculate the maximum eigenvalue of the p.c.m., which leads to CI (consistency index). Via this CI value, we can see how well the respondent answers logically. Through this process, we obtain all CI values for all questionnaire respondents. We propose a decision making technique for questionnaire respondents group through these individual CI values. Taking the geometric mean of p.c.m. elements we obtain the weighted eigenvector for the maximum eigenvalue of this geometric mean p.c.m., namely priority (users' dissatisfaction) vector. From the priority vector, we can see how well/badly these traffic control scenarios operate.

1 INTRODUCTION

In a Cellular Network, several traffic control services are previously provided. Above all, when the network becomes congested e.g. world-cup ticket-reservation, THREE traffic control scenarios are proposed and becoming important (Akinaga, Kaneda, 2005); *spatial distribution*, *time distribution*, and *traffic reduction*. By *spatial distribution*, we mean that users are recommended to move in an area where communication channels are not so busy. Traffic can be spatially distributed. By *time distribution* we mean that users are recommended to wait for a while so that users can access the network with a higher probability. Traffic can be distributed over a period of time. By *traffic reduction* we mean that users are recommended to change from voice service into data (e-mail or web) service. Traffic can be reduced since data service (channel holding) time is much shorter than voice service time (channel holding). The main purpose of this paper is to evaluate these traffic control scenarios by using an *AHP (Analytic Hierarchy Process)* approach.

The AHP approach is applied to obtain a solution which scenario is best/worst among these traffic control scenarios, from user's view point. Firstly, we construct a web site on which cellular network users can simply answer a questionnaire (a set of questions) regarding grade of traffic control scenarios via internet. There are very few literatures on AHP questionnaires systems at web site in Japan.

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The secondary purpose this paper is to provide an idea and philosophy for making a web-site AHP questionnaire system. At the beginning of our AHP analysis, we formulate a *pair-wise comparison matrix (p.c.m.)* through this questionnaire result for an individual respondent. We next calculate the maximum eigenvalue of the p.c.m., which leads to *CI (consistency index)*. Via this CI value, we can see how well the respondent answers logically. When CI value is smaller, the more the questionnaire respondent answers consistently (The questionnaire answer result with a high CI value is not reliable).
Through this process, we obtain all CI values for all questionnaire respondents. Taking the geometric mean of p.c.m. elements we obtain the weighted *eigenvector* for the maximum eigenvalue of this geometric mean p.c.m., namely priority (users' dissatisfaction) vector. From the priority vector, we can see how well/badly the traffic control scenarios operate.
The rest of this paper is organized as follows. Section 2 describes our hierarchy structure and the necessary linear algebra mechanism. Section 3 constructs our web-site AHP questionnaire engine, enabling one to obtain our solution. Here, we propose a decision making technique for questionnaire respondents group through individual CI values. Section 4 summarizes our result and mentions reaming our research topics.

2 AHP APPROACH

2.1 Hierarchical Structure and Analytic Procedure

AHP is a mathematical approach for multicriteria decision making (Saaty, 1980). In the AHP approach, we have to start expressing a hierarchical structure by dividing our problem into the several layers. Each layer is assumed to consist of some elements. Here, the number of layers and that of elements are not constant, in other words, we have to decide how many layers there are in the hierarchical structure and elements in the individual layers. AHP is a very flexible approach.
Though, the top layer of the hierarchical structure is assumed to consist of only one element called a goal (problem target). The bottom layer is called the solution layer that may consist of some elements where each element corresponds to a solution to the goal. The middle layer(s) are (is) called the criteria layer(s). Each element in the criteria layer will be also called as criteria element; See Figure 1.
We have to subsequently compute the weights between a pair of the elements in an individual layer.

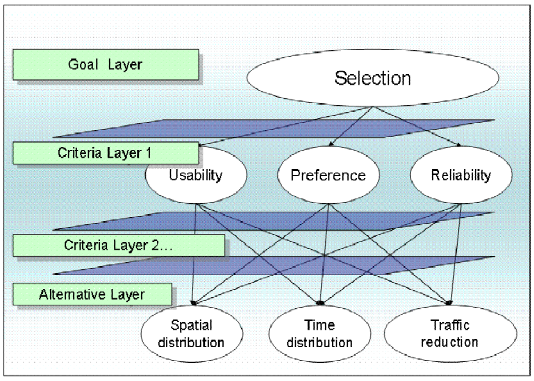


Figure 1: Analytic hierarchy process.

If we denote by n the number of pair-wise comparisons, we have to compare $n(n-1)/2$ times, since our pair-wise comparison should have a special reciprocal form, i.e. $a_{ij} \times a_{ji} = 1$.We finally calculates the weights of the overall layers. Based on the calculated weights, we can evaluate priority to the goal of an individual solution. For our analytical process see Figure 1. We will describe the details of CI (as seen in the figure) in the next section.

2.2 Linear Algebra Structure

We calculate weight $w_1, w_2, \cdots, w_n$ on the element layer $A_1, A_2, \cdots, A_n$. At this time, if we assume importance occasion to a_j of a_i that is a_{ij}, element $A_1, A_2, \cdots, A_n$ p.c.m. becomes $A = [a_i]$. When provided $w_1, w_2, \cdots; w_n$ is well-known, $A = [a_i]$ becomes (1)

Note that, for any *i*, *j* and *k* holds $a_{ij} \times a_{jk} = a_{ik}$. The evaluation illustrates completely consistent.
To multiply a weight column vector ***w*** by this p.c.m.

$$A = \left[a_{ij}\right] = \begin{matrix} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{matrix} \begin{matrix} A_1 & A_2 & & A_n \\ \left[\begin{matrix} w_1/w_1 \\ w_2/w_1 \\ \vdots \\ w_n/w_1 \end{matrix}\right. & \begin{matrix} w_1/w_2 \\ w_2/w_2 \\ \vdots \\ w_n/w_2 \end{matrix} & \begin{matrix} \cdots \\ \cdots \\ \\ \cdots \end{matrix} & \left.\begin{matrix} w_1/w_n \\ w_1/w_n \\ \vdots \\ w_n/w_n \end{matrix}\right] \end{matrix}$$

$$a_{ij} = w_i / w_j, \quad a_{ij} = 1/a_{ji}, \qquad w = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} \tag{1}$$

$i, j = 1, 2 \cdots n$

$A \bullet w = nw$ ***A*** give a vector ***nw***.
This expression is able to change an eigenvalue.

$$(A - n1) \bullet w = 0 \tag{2}$$

I is an identity matrix. The following (2), if $\boldsymbol{w} \neq 0$ is hold, *n* must become the eigenvalue ***A***. Then ***w*** becomes the eigenvalue vector ***A***. Because rank ***A*** is 1, the eigenvalue $\lambda_i (i = 1,\ 2,\ \cdots\ n)$ becomes one is non-zero, others are zero. Moreover, when the sum total of the main opposite angle element ***A*** is *n,* and λ_{max} is λ_i which is not zero,

$$\lambda_i = 0, \lambda_{\max} = n(\lambda_i \neq \lambda_{\max}) \quad (3)$$

Therefore, a weight vector $\boldsymbol{w}$ to $A_1,\ A_2,\ \cdots,\ A_n$ becomes a eigenvalue vector in $(\sum w_i = 1)$ normalized to the maximum eigenvalue λ_{max} of ***A***. When it is actually applied to the questionnaire analysis, $\boldsymbol{w}$ is unknown, we then must calculate $\boldsymbol{w}'$. We can evaluate $\boldsymbol{w}'$ from the p.c.m. $\boldsymbol{A}'$ given questionnaire answer.

$$A' w' = \lambda'_{\max} w'$$

$\lambda'_{\max}$ is the maximum eigenvalue of A'. It gives unknown $\boldsymbol{w}'$. As conditions become more complicated, it is in the tendency the results of the questionnaire answer are not consistent more. We know as $\boldsymbol{A}'$ does not become consistent, λ_{max} grows bigger than *n* (Saaty, 1984).

$$\lambda'_{\max} = n + \sum_{i=1}^{n} \sum_{j=i+1}^{n} \frac{(w'_j a_{ij} - w'_i)^2}{w'_i w'_j a_{ij} n} \quad (4)$$

Following (4), always hold $\lambda'_{max} \geqq n$. If $\lambda'_{max} = n$, provided satisfy consistency. We can denote consistency index by (5).

$$C.I. = \frac{\lambda'_{\max} - n}{n-1} \quad (5)$$

CI (Consistency Index) denotes whether pair comparison is properly. Saaty who is the advocate of AHP is proposed from experience when CI is less than 0.15 or 0.1, we should do pair comparison again because pair comparison can not be done properly. When CI is 0, called perfect consistency, and effective is value less than 0.15 or 0.1.

3 WEB AHP QUESTIONNAIRE ENGINE

3.1 Quality Evaluation

THREE traffic control scenarios are proposed and becoming important (Akinaga, Kaneda, 2005); *spatial distribution*, *time distribution*, and *traffic reduction*. By *spatial distribution*, we mean that users are recommended to move in an area where communication channels are not so busy. Traffic can be spatially distributed. By *time distribution* we mean that users are recommended to wait for a while so that users can access the network with a higher probability. Traffic can be distributed over a period of time. By *traffic reduction* we mean that users are recommended to change from voice service into data (e-mail or web) service. Traffic can be reduced since data service (channel holding) time is much shorter than voice service time (channel holding). Let evaluate a quantity about user dissatisfaction by using an *AHP*.

Define,
- Goal: selection
- Criteria: usability, preference, reliability
- Solution: spatial distribution, time distribution, traffic reduction (Figure 1).

A terrible earthquake: Situation in which user calls terrible earthquake to know safety of important person.
A large fireworks: Situation in which user who gets lost to friend in a large fireworks calls.
Ticketing reservation: Situation in which user calls for ticketing early reservation of event

We construct hierarchical structure (Figure1).When among solution is taken in criteria layer, element 'usability' imply whether to take much time, element 'preference' implies whether to be poor, element 'reliability' implies whether a worry is left. Elements of Solution layer, 'spatial distribution' imply user movement. 'time distribution' implies time shift. 'traffic reduction' implies other media recommendation.
We must decide a number of layers with AHP, however if one layer is increased, pair comparative items increase by the element, and so questionnaire despondence takes labour too much. In this paper, criteria layer is only three, because avoid the AHP questionnaire being repeated concerning.

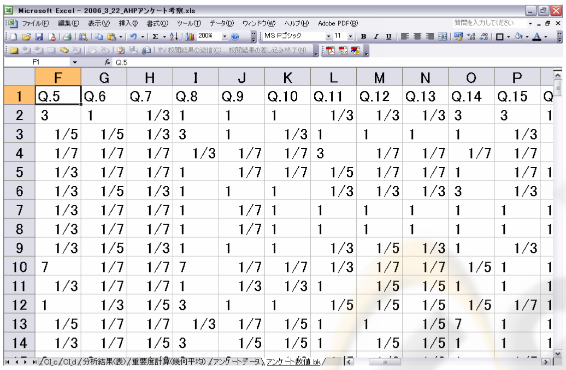
3.2 Questionnaire Engine Construct

As for the questionnaire, although there are various things of the paper base, exit polls, telephone surveys and mailing investigations in principle, it is the most suitable for the questionnaire via an internet how to collect it to count data economically in a short time.
Here, we construct Questionnaire Engine on web presumed questionnaire answer via the internet for questionnaire survey, collective and analysis.

As a preparation for set up on Web, we rent the free server which can use CGI, and registers for DDNS (Dynamic Domain Name Server) for reducing URL because improve access easily (URL, 2006).
As a preparation for questionnaire counting, we construct the engine that is able to input to the spreadsheet software automatically by programming it in HTML, and able to analyze by preparing a calculation program. Moreover, we presume the problem which is not input to the spreadsheet software properly in the un answer and so on, take measure to prepare dummy answer.
Importance measure for generate p.c.m. define as follow Table 1.

Table 1: Intensity of the dissatisfaction and definition.

Intensity of relative importance	Definition
1	Equal dissatisfaction
3	Weak dissatisfaction
5	Strong dissatisfaction
7	Absolute dissatisfaction



	F	G	H	I	J	K	L	M	N	O	P	Q
1	Q.5	Q.6	Q.7	Q.8	Q.9	Q.10	Q.11	Q.12	Q.13	Q.14	Q.15	Q
2	3	1	1/3	1	1	1	1/3	1/3	1/3	3	3	1
3	1/5	1/5	1/3	3	1	1/3	1	1	1	1	1/3	
4	1/7	1/7	1/7	1/3	1/7	1/7	3	1/7	1/7	1/7	1/7	
5	1/3	1/7	1/7	1	1/7	1/7	1/5	1/7	1/7	1	1/7	1
6	1/3	1/5	1/3	1	1	1	1/3	1/3	1/3	3	1/3	
7	1/3	1/7	1/7	1	1/7	1	1	1	1	1	1	1
8	1/3	1/7	1/7	1	1/7	1	1	1	1	1	1	1
9	1/3	1/5	1/3	1	1	1	1/3	1/5	1/3	1	1/3	
10	7	1/7	1/7	7	1/7	1/7	1/3	1/7	1/7	1/5	1	1
11	1/3	1/7	1/7	1	1/3	1/3	1	1/5	1/5	1	1	1
12	1	1/3	1/5	3	1	1	1/5	1/5	1/5	1/5	1/7	1
13	1/5	1/7	1/7	1/3	1/7	1/5	1	1	1/5	7	1	1
14	1/3	1/7	1/5	3	1/5	1/5	1	1/5	1/5	1	1	1

Figure 2: Spreadsheet software input screen.

When an answer clicks on ‘absolute reliability’ on the ‘spatial distribution’ side, input “7” to spreadsheet software, and when clicks on ‘strong reliability’ on the ‘traffic reduction’ side, input it “1/5” (Figure 2).
We putted the engine to the test which included movement confirmation before the questionnaire survey actual take. Consequently, a wrong point did not occur in the counting processing of the data which it was afraid of, though respondent to a questionnaire did not recognize hardly the difference in valuation item which server constructing side intends, rather than their contents of answer got confusion (Consistency index was strangely high) .
Therefore, we use much visual information in the part of the question so that a respondent can understand obvious (Figure 3). We made Waseda university students as well as Fukagawa high school

$$w_1' \frac{v_1'}{v_1' + v_2' + v_3'} w' = \begin{pmatrix} w' \\ w_2' \\ w_3' \end{pmatrix}, (i = 1, 2, 3) \qquad (6)$$

students reply to the questionnaire from December, 2005 to February, 2006 via the Internet. They can fully utilize cellular communication system and used to internet. We received a response rate of 95% (valid response).

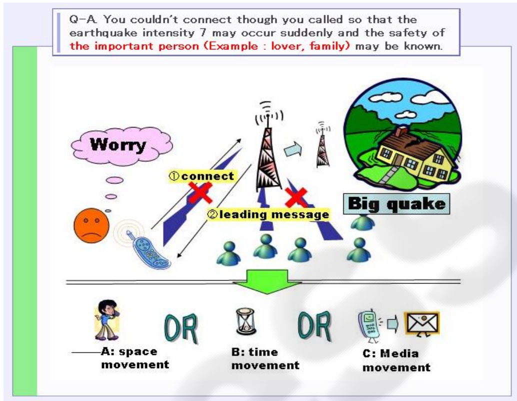


Figure 3: Visual information.

3.3 Individual User Analysis

It is noted if λ'_{max} of preceding section 2.2 is n=3, we are able to get λ'_{max} to evaluate geometry mean of element constituent $\boldsymbol{A}'$ (Oguchi, 2006).A result of a questionnaire applies in the Table 2.

Table 2: Respondent to a questionnaire example.

Criteria	Usability	Preference	Reliability
Usability	1	7	3
Preference	1/7	1	1/3
Reliability	1/3	3	1
Usability	Spatial	Time	Traffic
Spatial distribution	1	1/5	1/3
Time distribution	5	1	3
Traffic reduction	3	1/3	1
Preference	Spatial	Time	Traffic
Spatial distribution	1	1/3	1/3
Time distribution	3	1	3
Traffic reduction	3	1/3	1
Reliability	Spatial	Time	Traffic
Spatial distribution	1	1/3	3
Time distribution	3	1	5
Traffic reduction	1/3	1/5	1

We calculated weight for solution of each criteria.We applies weights of other criteria was evaluated in the same way (Table 3).

$$v'_1 = \sqrt[3]{a'_{11} \times a'_{12} \times a'_{13}} = \sqrt[3]{1 \times 7 \times 3} = 2.759$$

$$v'_2 = \sqrt[3]{a'_{21} \times a'_{22} \times a'_{23}} = \sqrt[3]{1/7 \times 1 \times 1/3} = 0.362$$

$$v'_3 = \sqrt[3]{a'_{31} \times a'_{32} \times a'_{33}} = \sqrt[3]{1/3 \times 3 \times 1} = 1.000$$

$$w' = (0.669,\ 0.088,\ 0.243)^T$$

Table 3: Result of evaluated each weight.

Criteria	Solution	Spatial	Time	Reduction	CI
Usability	0.669	0.105	0.637	0.258	0.019
Preference	0.088	0.135	0.584	0.281	0.068
Reliability	0.243	0.258	0.637	0.105	0.019

As in Table 3, this respondent to a questionnaire feels weight with ‘usability’ in solutions, and feels weight with ‘time distribution’ in each criteria. At this time, maximum eigenvalue λ'_{max} is given (4), and CI is given (5). Result of evaluated CI illustrate Table 4, regard this answer is consistency because CI in each pair comparison is less than 0.1,Multiply weight in the whole by in the weight to each criteria, we find the priority of the solution finally. Multiply 0.105 which is weight of ‘usability’ for ‘spatial distribution’ by 0.669 which is weight of criteria, we find that 0.105 x 0.669=0.07. Result of evaluated all elements, we find that upper 4 rows (Table 4). The priority of the solution is given sum cols. Consequently, we find this user feels most dissatisfaction to waiting for the time.

Table 4: Priority.

	Spatial distribution	Time distribution	Traffic reduction
Usability	0.070	0.426	0.173
Preference	0.012	0.051	0.025
Reliability	0.063	0.155	0.026
Priority	0.145	0.632	0.223

3.4 Group Users Analysis

This section, we evaluate priority vector whole of the user group in terms of result of an analysis user individual. We use *Gm*. We consider about the priority of the individual solution as follow preceding section. It knows result of an analysis user individual is selected by the CI with an AHP analysis technique. Though, the group analysis algorithm is not set up with AHP. Here, a CI is taken with the threshold, and we propose in accordance with the computational algorithm of the Figure 6.

Here that a change in that threshold, how influences a priority vector.

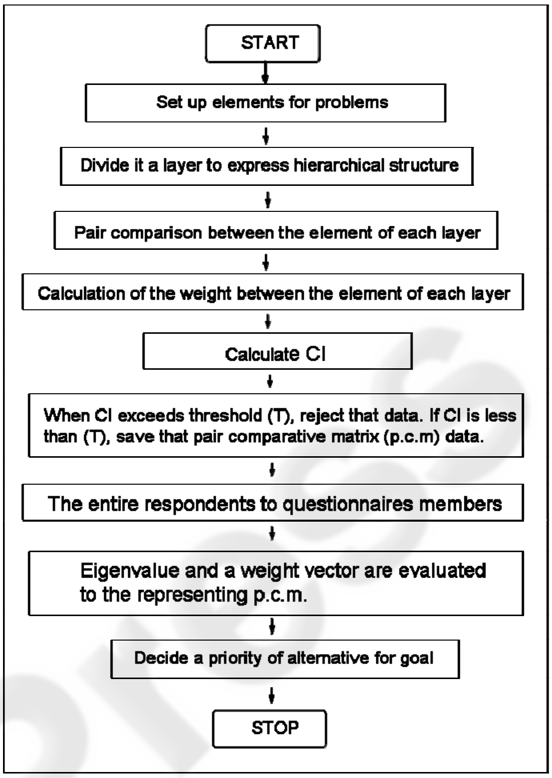


Figure 4: Group decision making algorithm.

Step1: If it is not consistent with the questionnaire, this CI is used as a threshold (T) though an adjustment occasion CI grows big. In other words, evaluate CI from the p.c.m. of the respondent to a questionnaire, and when CI exceeds (T), reject that data. If CI is less than (T), save that pair comparative matrix data.

Step2: The entire respondents to questionnaires members do a step 1.

Step3: a_{ij} element of the representing p.c.m. to

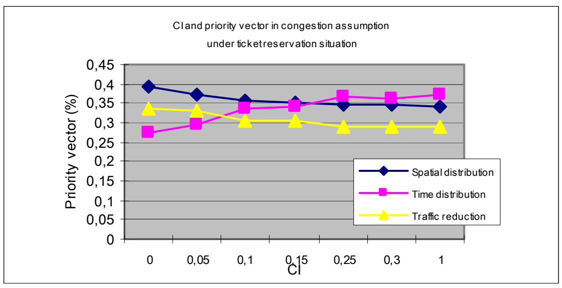


Figure 5: CI and priority vector in congestion assumption under a ticket reservation situation.

express the will of the group is given to it in the *Gm* of the p.c.m. a_{ij} element of (is not reject) save in the step 1-2. For example, when there are forty people are not rejected, it is the *Gm* which consists of forty elements.

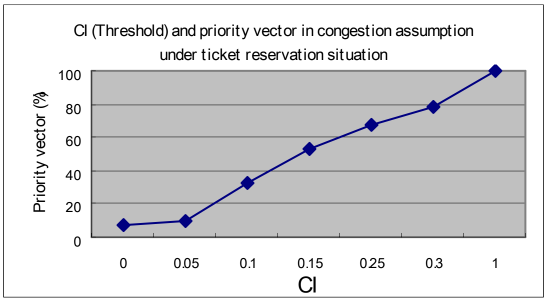


Figure 6: CI (Threshold) and priority vector in congestion assumption under a ticket reservation situation.

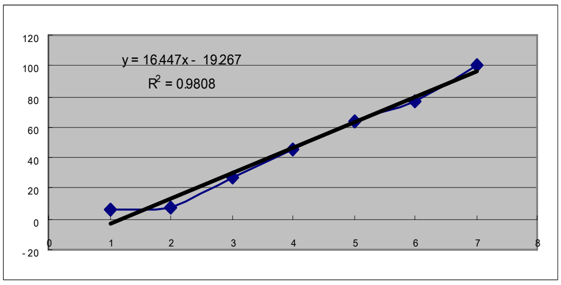


Figure 7: CI and priority vector in congestion assumption under ticket reservation situation.

Step4: Eigenvalue and a weight vector are evaluated to the representing p.c.m. which it could get in the step 3; we evaluate a priority vector as well as CI.
Here, CI of the horizontal shaft of each figure illustrates a threshold. In other words, data exceed threshold are rejected (We restrict group to the user of under the threshold).
When an approximate straight line by the regression line of the least squares was calculated, Y-intercept became a minus at the case of this questionnaire (Figure 7). In other words, when the threshold of CI is made very small, it devotes that the population which satisfies disappears. CI had better be big from the viewpoint of the group. On the other hand, CI had better be low from individual viewpoint (The existence of the trade-off). From the above, we propose that CI what took the priority of 0.1 ~ 0.15 (about 50% of the whole) is effective in group decision making. When it tried how to control traffic by the spatial distribution (spatial movement), time distribution (time shift), and traffic reduction (other media recommendation), many students feel dissatisfaction with the spatial movement most, and feel dissatisfaction few with the changing other media recommendation traffic control, in this case.

4 CONCLUSION

We have set up a problem how a user thinks of traffic control scenarios in cellular networks. We have solved this problem applying the AHP approach. We have firstly presented a visual questionnaire on the web site by using the hyper text mark-up language (HTML) so that the respondents can answer easily and quickly. We have then formulated a pair-wise comparison matrix (p.c.m.) through this questionnaire result for an individual respondent. We have subsequently calculated the maximum eigenvalue of the p.c.m.. Through this process, we have obtained all *CI* (consistency index) values for all questionnaire respondents. We have proposed a decision making technique for questionnaire respondents group through these individual *CI* values. Taking the geometric mean of p.c.m. elements we have obtained the weighted eigenvector for the maximum eigenvalue of this geometric mean p.c.m., namely priority (user's dissatisfaction) vector. From the priority vector, we have been able to see how well/badly these traffic control scenarios operate. It is left as a future research topic to analyze not only our traffic control scenarios (*spatial distribution*, *time distribution* and *traffic reduction*) but also other control scenarios in cellular networks. It is also left as a future research topic to investigate another decision making technique since group decision is not yet unique in the AHP approach (We have adapted the geometric mean of p.c.m. elements for the questionnaire respondents whose CI values are less than our threshold).

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