Some Applications of AHP to the Urban Traffic System

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Abstract

AHP can be used as a powerful tool in planning, decision making, and evaluating urban traffic systems. We have applied it to solve four problems and the results of these applications were satisfactory. The problems were the following: (a) Analysis of the problems and causes of the poor situation of urban transit in Tianjin, (b) Evaluation of the urban transportation planning, (c) Model split analysis, and (d) Synthetic evaluation of the urban traffic system. In this paper, we have reviewed problems (a,b,c); given the hierarchical structure and provided the results of these applications. Problem d is detailed, a numerical example is given, and the structure of a system with interdependence on this problem is considered.

1. Introduction

Because AHP has many advantages, such as simplicity, practicability, and flexibility, it has been applied to solve the problems of planning, evaluating, optimization and decision making on a wide-range of fields [1]. AHP is also a powerful tool in the research of urban traffic system. The key tasks of the applications of AHP on the different fields are the same, i.e. setting priorities, but how to use it on different fields is the important problem.

In recent years the author has engaged in urban traffic engineering. We have researched into theoretic problems of forecasting, planning, modeling and simulation of urban traffic system. In addition, we have attempted the work of tackling the urban traffic in a comprehensive way in Tianjin, improving the urban public transit system in Tianjin and examining the urban transportation planning also in Tiajin. In these applications we have dealt with such problems as the Fuzzy-AHP and AHP for the system with feedback.

In this paper we explain the following problems from an applied point of view:

a) Analysis of the problems and causes of the poor situations of the urban public transit in Tianjin.

b) Evaluation of the urban transportation planning.

c) Model split analysis.

d) Synthetic evaluation of the urban traffic system.

2. Problem a

To improve the poor situation of urban transit in Tianjin in 1988, we used AHP to analyze the problems and the causes for this situation. We constructed a hierarchy of this problem.

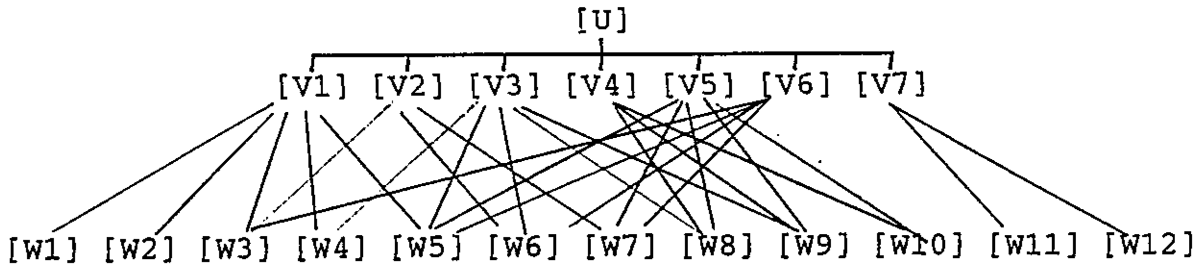

Figure 1. Hierarchy of Problem a

where

U : Level 1, focus, by this problem it is the final result from level 2.

V : Level 2, criteria, by this problem it is the phenomenon of U.

V1 : Crowded by buses.

V2 : Inconvenient transfer, transfer times too much.

V3 : Wait time is too long.

V4 : Speed of buses is too slow.

V5 : Buses are not on time.

V6 : Short of stations.

V7 : Inconvenient ride.

W : Level 3, alternatives, the causes of U.

W1 : Trips temporal distribution is intensive.

W2 : Trips spatial distribution is intensive.

W3 : Service area of buses network is too small.

W4 : Short of buses.

W5 : Poor dispatches of buses.

W6 : Not reasonable of bus routes.

W7 : Poor management.

W8 : Roads jammed with traffic.

W9 : Traffic flow is not in order.

W10: Poor quality of buses.

W11: Poor bus services.

W12: Short of the employees in the public transit company.

The judgement matrices were provided by 9 experts. Mu, Mv1, Mv2, Mv3, Mv4 and the priority vectors are W2, V31, V32, V33, V34, V35, V36, V37 and W3 respectively.

Level 2

$$\text{Mu} \quad \begin{bmatrix} 1 & 1 & 2 & 2 & 3 & 2 & 5 \\ 1 & 1 & 2 & 2 & 3 & 2 & 5 \\ .5 & .5 & 1 & 1 & 2 & 1 & 3 \\ .5 & .5 & 1 & 1 & 2 & 1 & 3 \\ .3333 & .3333 & .5 & .5 & 1 & .5 & 2 \\ .5 & .5 & 1 & 1 & 2 & 1 & 3 \\ .2 & .2 & .3333 & .3333 & .5 & .3333 & 1 \end{bmatrix}$$

C.R. = 0.003 λ_{max} = 7.0207

the priority vector of Level 2

W2 = (.2447 .2447 .1308 .1308 .0740 .1308 .04441)

Level 3

$$\text{Mv1} \quad \begin{bmatrix} 1 & 3 & 3 & .3333 & 1 \\ .3333 & 1 & 1 & .2 & .3333 \\ .3333 & 1 & 1 & .2 & .3333 \\ 3 & 5 & 5 & 1 & 3 \\ 1 & 3 & 3 & .3333 & 1 \end{bmatrix}$$

C.R. = 0.012 λ_{max} = 5.0555

V31 = (.1953 0.732 .0732 .4631 .1953)

$$\text{Mv2} \quad \begin{bmatrix} 1 & .3333 & 3 \\ 3 & 1 & 5 \\ .3333 & .2 & 1 \end{bmatrix}$$

C.R. = 0.033 λ_{max} = 3.0385

V32 = (.2583 .6370 .1047)

$$\text{MV3} \quad \begin{bmatrix} 1 & 3 & 5 & 7 & 7 \\ .3333 & 1 & 3 & 5 & 5 \\ .2 & .3333 & 1 & 3 & 3 \\ .1429 & .2 & .3333 & 1 & 1 \\ .1429 & .2 & .3333 & 1 & 1 \end{bmatrix}$$

C.R. = 0.030 λ_{max} = 5.1357

V33 = (.5101 .2594 .1230 .0537 .0537)

$$\text{Mv4} \quad \begin{bmatrix} 1 & 3 & 3 \\ .3333 & 1 & 1 \\ .3333 & 1 & 1 \end{bmatrix}$$

C.R. = 0.000 λ_{max} = 3.0000

V34 = (.6000 .2000 .2000)

$$Mv5 \quad \begin{bmatrix} 1 & 3 & 5 & 5 & 1 \\ .3333 & 1 & 3 & 3 & .3333 \\ .2 & .3333 & 1 & 1 & .2 \\ .2 & .3333 & 1 & 1 & .2 \\ 1 & 3 & 5 & 5 & 1 \end{bmatrix}$$

$$C.R. = 0.033 \qquad \lambda_{max} = 3.0385$$

$$V36 = (.1047 \quad .2583 \quad .6370)$$

$$Mv7 \quad \begin{bmatrix} 1 & 3 & .3333 \\ .3333 & 1 & .2 \\ 3 & 5 & 1 \end{bmatrix}$$

$$C.R. = 0.033 \qquad \lambda_{max} = 3.0385$$

$$V37 = (.2583 \quad .1047 \quad .6370)$$

the absolute priority vector of Level 3 is given by:

$$W3 = (.0478 \quad .0179 \quad .0948 \quad .1800 \quad .1084 \quad .2058 \quad .1316 \quad .0903 \quad .0379 \quad .0528 \quad .0046 \quad .0281)$$

$$S.C.R. = 0.0206$$

From the result we know that the most crucial problem is over crowded buses. The results also help to identify additional problems such as: (B1) inconvenient transfers; (B2) the major causes of the poor situation are the non-existence of reasonable buses routes; (C6) and shortages of buses; (C4).

In 1988, the transportation department of Tianjin city government made the decision to invest in public transit, i.e. to buy buses. With the new allocation of resources, the public transit company took measures to improve the aforementioned problems. The company found our results to be most useful.

3. Problem b

This problem has given rise to much controversy-- how the quantitative evaluation of urban transportation planning is made. We have attempted to use AHP to solve this problem. The hierarchical structure of the evaluated system indicators is shown in Figure 2.

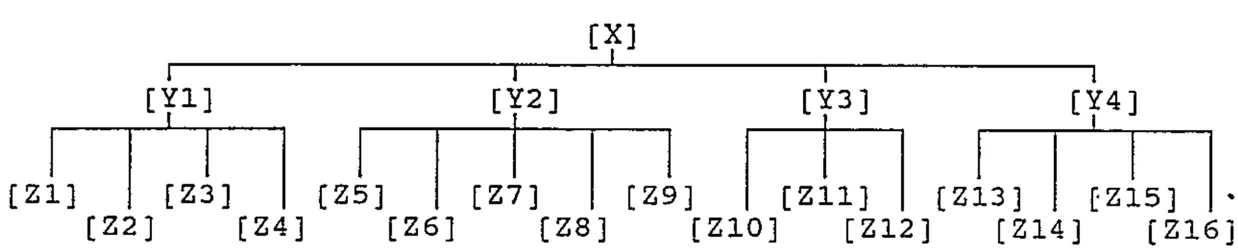

Figure 2. Hierarchical Structure of Problem b

where

X : Objective level, the overall evaluation result.

Y : Criteria level.

Y1 : Overall reasonableness of the planning.

Y2 : Coordinability of the planning.

Y3 : Adaptability of the planning.

Y4 : Effective of the planning.

Z : Indicators level.

Z1 : Range of the planning.

Z2 : Suitable number of the years of the planning.

Z3 : Organ of the planning.

Z4 : Strategy objective of the planning.

Z5 : Adaptability of the planning to the land use planning.

Z6 : Coordinability of the planning to the overall planning of the city.

Z7 : Coordinability to the planning of the socioeconomic development in the city.

Z8 : Coordinability to the long-range transportation planning.

Z9 : Coordinability between the goods transportation planning and the passenger transportation planning.

Z10: Adaptability to the transportation land-use planning.

Z11: Adaptability of the roadway network.

Z12: Adaptability between the transportation in total area and the transportation in sub-areas.

Z13: Quality of service.

Z14: Safety.

Z15. Environment impact.

Z16. Combined efficiency.

The judgement matrices are provided by the expert-group: Mx, My1, My2, My3, My4 and the priority vectors are W2, V31, V32, V33, V34 and W3 respectively.

Level 2

$$Mx \quad \begin{bmatrix} 1 & 3 & 3 & 1 \\ .3333 & 1 & 1 & .3333 \\ .3333 & 1 & 1 & 1 \\ 1 & 3 & 3 & 1 \end{bmatrix}$$

$$C.R. = 0.000 \qquad \lambda_{max} = 4.0000$$

$$W2 = (.3750 \quad .1250 \quad .1250 \quad .3750)$$

Level 3

My1 $$\begin{bmatrix} 1 & 1 & 2 & 1 \\ 1 & 1 & 2 & 1 \\ .5 & .5 & 1 & .5 \\ 1 & 1 & 2 & 1 \end{bmatrix}$$

C.R. = 0.000 λ_{max} = 4.0000

V31 = (.2857 .2857 .1429 .2857)

My2 $$\begin{bmatrix} 1 & 5 & 5 & 3 & 1 \\ .2 & 1 & 1 & .3333 & .2 \\ .2 & 1 & 1 & .3333 & .2 \\ .3333 & 3 & 3 & 1 & .3333 \\ 1 & 5 & 5 & 3 & 1 \end{bmatrix}$$

C.R. = 0.012 λ_{max} = 5.0555

V32 = (.3601 .0640 .0640 .1518 .3601)

My3 $$\begin{bmatrix} 1 & 1 & 2 \\ 1 & 1 & 2 \\ .5 & .5 & 1 \end{bmatrix}$$

C.R. = 0.000 λ_{max} = 3.0000

V33 = (.4000 .4000 .2000)

My4 $$\begin{bmatrix} 1 & .3333 & 1 & .2 \\ 3 & 1 & 3 & .3333 \\ 1 & .3333 & 1 & .2 \\ 5 & 3 & 5 & 1 \end{bmatrix}$$

C.R. = 0.016 λ_{max} = 4.0434

V34 = (.0963 .2495 .0963 .5579

the absolute priority vector of the Level 3

W3 = (.1071 .1071 .0536 .1071 .0450 .0080 .0080 .0190
.0450 .0500 .0500 .0250 .0361 .0936 .0361 .2092)

From above, the indicators weighting of the evaluation model of the urban transportation planning are obtained, by which the practical indicators can be weighted. For the practical transportation planning, the indicator Z can be identified first, then indicator y can be computed, followed by the total score x, which can be used to evaluate the transportation planning.

4. **Problem c**

Model split analysis is the important step in the transportation planning process. The purpose of model split analysis is to forecast the proportion of the total number of predicted trips to be allocated to the various transportation modes. We used AHP in model split analysis and in Figure 2. The model split to Figure 2 is denied. The differences between the desired (our model) and the model in Figure 2 are the following:

* More trip characteristics, such as age - group and occupation case of bicycles and motorcycles, by us are considered.
* More trip characteristics, such as trip purpose and trip times of day by us are considered.
* Transportation modes by us are public transit, cars, bicycles, underground modes in the various performance measures.

Applying AHP to this problem the following results occur

* The proportion of the various transportation modes.
* The priorities of the various trip makers with different characteristics in the various transportation modes.

These results are very useful for transportation demand forecasts and planning.

5. Problem d

In order to evaluate the urban traffic system, it is necessary to determine the unified performance measures and the weights of every performance measure.

* Practical Model Structure

Figure 3 represents a hierarchy of the performance measures systems to evaluate urban traffic system.

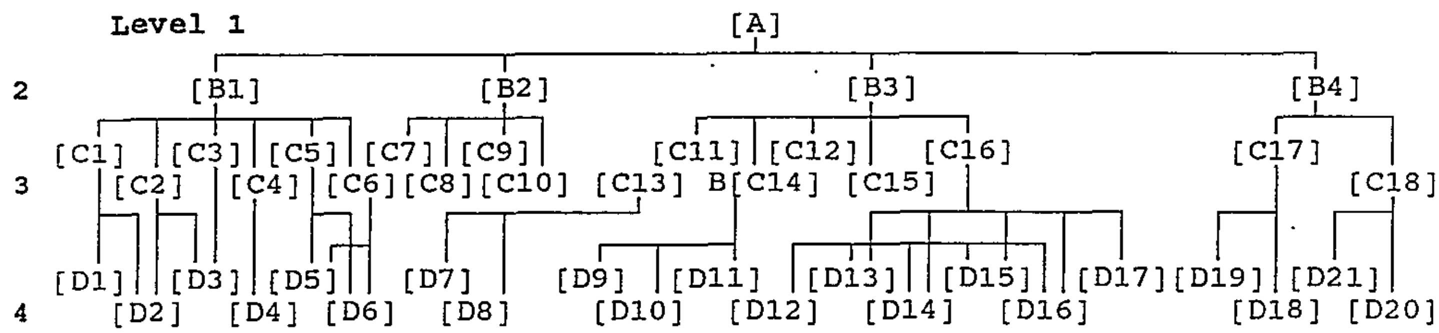

Figure 3. Hierarchy of the performance measures system to evaluate the urban traffic system

where

- A : Combined evaluation score.
- B1 : Distribution of the traffic investment.
- B2 : Traffic structure.
- B3 : Traffic efficiency.
- B4 : Environmental impact.
- C1 : Ratio of the investment for the traffic facilities to the traffic investment.
- C2 : Ratio of the investment for the traffic system operations to the traffic investment.
- C3 : Ratio of the investment for the traffic research to the traffic investment.
- C4 : Ratio of the investment for the public transit to the traffic investment.
- C5 : Ratio of the investment for the goods transportation to the traffic investment.
- C6 : Ratio of the investment for the motor vehicles development to the traffic investment.
- C7 : The structure of the trips modes.

C8 : The structure of the goods transportation modes.

C9 : The structure of the passengers transportation modes.

C10: The structure of vehicle utilization of the public transit company.

C11: Average trip time.

C12: Average speed of buses.

C13: Speed of motor vehicles on the major roadways.

C14: Index of accessibility.

C15: Economic of the public transit company.

C16: Economic of the public goods transportation company.

C17: Average risk of being killed or injured.

C18: Environmental impact combined indicator.

D1 : Density of the roadway network.

D2 : Proportion of the single intersections to the total intersections.

D3 : Proportion of the congested intersections to the total intersections.

D4 : Density of the public goods transportation vehicles.

D5 : Constitute of the buses.

D6 : Constitute of the public goods transportation vehicles.

D7 : Average speed on highway.

D8 : Average speed on street.

D9 : Proportion of the served area of the public transit to the total area.

D10: Average transfer times.

D11: Average walking distance to ride.

D12: Number of passengers.

D13: Energy consumption per revenue vehicle-kilometre.

D14: Cost efficiency.

D15: Labor productivity.

D16: Financial performance.

D17: Quality of service.

D18: Average risk ratio.

D19: Average risk of being killed ratio.

D20: Air quality impacts.

D21: Noise impacts.

* Calculating method

Obviously, there is inner dependence in Level B (Figure 4)

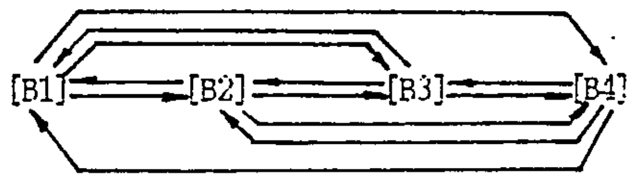

Figure 4. Inner dependence in level B

Let a2, a3 be weights of the level 2 and 3 for the Level 2 respectively and a2 + a3 = 1. w2 is the principal eigenvector of judgment matrix for level 2. Let w22 be the matrix which consists of the principal eigenvector of the impact priority matrix of the level 2. Then vector of priority for Level 2 is V2 and

$$V2 = a2\ w21\ (I - a3\ w22) \qquad (1)$$

$w_{k,k-1}$ is given by:

$$w_{k,k-1} = \begin{bmatrix} u_1 & & & \\ & u_2 & & \\ & & \ddots & \\ & & & u_m \end{bmatrix} \qquad (2)$$

where u_i is the principal eigenector of the judgement matrix for level i, m is the number of elements in level k. The absolute priority vector is given by:

$$V_p = a2\ w21\ (I - a32\ w22)\ w32\ w43\ \ldots\ w_{k,k-1} \qquad (3)$$

Let k = 2, 3, . . ., n, the absolute priority vector V_p for level n can be computed.

* Numerical example

All judgement matrices (Ma, Mb1 ,. . ., Mb4, Mc1, Mc2 ,. . .,Mc10) and all impact priority matrices (Md1, Md2, Md3, Md4) are given by five experts. The absolute priority vectors of the level 1, 2, 3, 4 are W1, W2, W3, and W4 respectively.

Level 2

$$Ma \quad \begin{bmatrix} 1 & 1 & .3333 & .3333 \\ 1 & 1 & .3333 & .3333 \\ 3 & 3 & 1 & 1 \\ 3 & 3 & 1 & 1 \end{bmatrix}$$

C.R. = 0.000 λ_{max} = 4.0000

W1 = (.1250 .1250 .3750 .3750)

$$Md1 \quad \begin{bmatrix} 1 & .2 & .3333 & 1 \\ 5 & 1 & 3 & 5 \\ 3 & .3333 & 1 & 3 \\ 1 & .2 & .3333 & 1 \end{bmatrix} \quad Md2 \quad \begin{bmatrix} 1 & 5 & 3 & 5 \\ 2 & 1 & .3333 & 1 \\ .3333 & 3 & 1 & 3 \\ .2 & 1 & .3333 & 1 \end{bmatrix}$$

$$Md3 \quad \begin{bmatrix} 1 & .3333 & 3 & 3 \\ 3 & 1 & 7 & 7 \\ .3333 & .1429 & 1 & 1 \\ .3333 & .1429 & 1 & 1 \end{bmatrix} \quad Md4 \quad \begin{bmatrix} 1 & .3333 & 3 & 3 \\ 3 & 1 & 7 & 7 \\ .3333 & .1429 & 1 & 1 \\ .3333 & .1429 & 1 & 1 \end{bmatrix}$$

W2 = (.1744 .2243 .2273 .2027) S.C.R = 0.0092

Level 3

$$Mb1 \quad \begin{bmatrix} 1 & 3 & 1 & .3333 & 3 & 3 \\ .3333 & 1 & .3333 & .2 & 1 & 1 \\ 1 & 3 & 1 & .3333 & 3 & 3 \\ 3 & 5 & 3 & 1 & 5 & 5 \\ .3333 & 1 & .3333 & .2 & 1 & 1 \\ .3333 & 1 & .3333 & .2 & 1 & 1 \end{bmatrix}$$

$$Mb2 \quad \begin{bmatrix} 1 & 3 & 3 & 5 \\ .3333 & 1 & 1 & 3 \\ .3333 & 1 & 1 & 3 \\ .2 & .3333 & .3333 & 1 \end{bmatrix}$$

$$Mb3 \quad \begin{bmatrix} 1 & 3 & 3 & 1 & 5 & 5 \\ .3333 & 1 & 1 & .3333 & 3 & 3 \\ .3333 & 1 & 1 & .3333 & 3 & 3 \\ 1 & 3 & 3 & 1 & 5 & 5 \\ .2 & .3333 & .3333 & .2 & 1 & 1 \\ .2 & .3333 & .3333 & .2 & 1 & 1 \end{bmatrix}$$

$$Mb4 \quad \begin{bmatrix} 1 & 3 & 5 \\ .3333 & 1 & 3 \\ .2 & .3333 & 1 \end{bmatrix}$$

W3 (.0327 .0162 .0327 .0731 .0162 .0162 .1167
.0451 .0451 .0174 .0724 .0294 .0294 .0724
.0162 .0162 .1291 .0524)

Level 4

$$Mc1 \begin{bmatrix} 1 & 3 \\ .3333 & 1 \end{bmatrix} \quad Mc2 \begin{bmatrix} 1 & .3333 \\ 3 & 1 \end{bmatrix} \quad Mc3 \begin{bmatrix} 1 & 3 \\ .3333 & 1 \end{bmatrix} \quad Mc4 \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$$

$$Mc5 \begin{bmatrix} 1 & 3 \\ .3333 & 1 \end{bmatrix} \quad Mc9 \begin{bmatrix} 1 & .3333 \\ 3 & 1 \end{bmatrix} \quad Mc10 \begin{bmatrix} 1 & 3 \\ .3333 & 1 \end{bmatrix}$$

$$Mc6 \quad \begin{bmatrix} 1 & .3333 & .3333 \\ 3 & 1 & 1 \\ 3 & 1 & 1 \end{bmatrix}$$

$$Mc7 \quad \begin{bmatrix} 1 & 3 & 1 & 3 & 1 \\ .3333 & 1 & .3333 & 1 & .3333 \\ 1 & 3 & 1 & 3 & 1 \\ .3333 & 1 & .3333 & 1 & .3333 \\ 1 & 3 & 1 & 3 & 1 \end{bmatrix}$$

W4 == (.0245 .0112 .0417 .0731 .0150 .0090 .1167 .0451
.0451 .0174 .0724 .0294 .0220 .0073 .0103 .0310
.0310 .0068 .0078 .0078 .0078 .0078 .0068 .0323
. 968 .0393 .0131)

For a city, the data often collected for the urban traffic system may be used to determine the indicators, then the evaluation of urban traffic system of this city can be given with the indicators weightings obtained from the AHP.

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