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Provision of Accessible Transportation Alternatives for the Transportation Handicapped in Taiwan

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Four transportation handicapped groups are identified in Taiwan (impaired ambulation, visually impaired, aged, and others) and nine accessible transportation alternatives are proposed. The costs and potential ridership for these nine alternatives in the Taipei area are estimated. Using analytic hierarchy process (AHP) and multicriteria evaluation with qualitative and quantitative data (MEQQD) methods, the most appropriate accessible transportation alternatives for each of the four handicap groups are selected. It is found that the best accessible transportation alternative for the impaired ambulation, the aged, and others would be a demand-responsive lift-equipped specialized van, while half-fare subsidized taxi would be the second-best option. By contrast, the best alternative for the visually impaired would be half-fare subsidized taxi, while conventional bus with broadcast equipment would be the second-best choice.

Introduction

In 1988 the disabled population in Taiwan was 143,473, which constituted 0.72% of the population of about twenty million. Approximately 16 percent of them (22,872) lived in the Taipei area. Meanwhile, the population of age over 65 (the aged) in Taiwan was 1,089,406, which constituted 5.40 percent of the population. About one-fourth of them (269,992) resided in the Taipei area [Lan, 1990a]. Over the past ten years, the disabled population has been slightly increased (from 0.71% to 0.72%); however, the aged population has been significantly increased (from 4.28% in 1980 to 6.22% in 1990). It is anticipated that the aged population in Taiwan by 2000 will constitute 8.5 percent of the population and their travel demands will inevitably increase due to better education, medical care and economic conditions [Lan, 1990c]. Thus, provision of accessible transportation for the mobility of the handicapped will become an important issue in the near

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future.

Since the Welfare Law for the Handicapped and Disabled was promulgated in 1980 in Taiwan, the government has been continuously improving medical care, special education and job training for disabled persons. Yet provision of a barrier free living environment, especially, accessible transportation services for the mobility of the handicapped has long been ignored. For instance, the intercity and intracity public transit, such as trains and buses, were completely designed and operated for able bodied people. They could hardly accommodate the special needs of the mobility handicapped persons. Very little attention was paid to the improvement of accessible transportation services until early 1988 when the Taipei Municipal Government, after numerous debates, decided to spend more than three billion NT dollars (US$1 = NT$25) on a barrier-free station redesign for the Taipei Rapid Transit System.

On August 16, 1988, the Ministry of Transportation and Communications not only revoked a ban on the disabled persons driving on the freeways but also released several restrictions on their driving license tests. In 1989, the Taipei Municipal Government realized a growing demand for transporting people with mobility handicaps and initiated a demonstration of lift-equipped specialized buses and vans exclusively used by the mobility handicapped persons. In order to widen the coverage of services for the disabled, the Ministry of Interior accomplished a thorough revision of the Welfare Law on January 24, 1990 by requiring all new public facilities/buildings and public transit to provide barrier free facilities and/or equipment and also requiring the old public facilities/buildings unable to accommodate the disabled to be improved within five years. Since then an introduction of accessible transportation services for people with mobility handicaps has become one of the national transportation policies.

In some western countries, the utilization of lift-equipped accessible public transit is low, despite the fact that tremendous capital, maintenance and operating costs have been invested [Middendorf, 1983]. The Ministry of Transportation and Communications attempted to evaluate what kinds of accessible transportation alternatives would be most cost effective for Taiwan and thus commissioned a research project "Planning of Barrier Free Transportation Services" [Lan, 1990b]. This paper, basically, is produced as part of that project.

Alternatives of Accessible Transportation

According to their mobility and communication abilities, the transportation handicapped in Taiwan can be divided into four groups: (1) impaired ambulation: with difficulty in walking, needing wheelchairs, crutches, or walkers for movement; (2) visually impaired: blindness or weak vision, with difficulty in reading external messages such as maps, bus stops, and route information; (3) aged: slow movement or any disabilities due to age (e.g., difficulty in movement caused by the reduction of cardiovascular capacity), and (4) others (including hearing, speaking impaired, mentally retarded, and multiple disabilities): with difficulty in communicating, with public announcements at stations or on boards, or in learning or understanding external information.

Four types of accessible transportation which may serve these four groups of transportation handicapped are identified. Nine alternatives are further distinguished based on the designs of the transportation facilities, the means of subscription or reservation, and the amount of government subsidy. Details of the characteristics for these nine alternatives are listed in Table 1.

Bus Transit

The first type of accessible transportation is to use conventional buses operated with fixed-route and fixed-schedule. According to the laws, the transportation handicapped only pay half of the full fare. Such bus services should be shared with the general public. Depending on the equipment, three alternatives are further proposed:

A. All the buses are equipped with bus-stop display and broadcast devices to accommodate the visually and hearing impaired.
B. In addition to alternative A, 10% of the buses are also equipped with lifts to facilitate those with impaired ambulation.
C. In addition to alternative A, 20% of the buses are also equipped with lifts to facilitate those with impaired ambulation.

Specialized Vehicles

The second type of accessible transportation is to use specialized vehicles operated either with fixed-route/schedule or by demand-response. These specialized vehicles are all equipped with lifts

Table 1. Characteristics of nine alternatives of barrier free transportation

Type	Alternative	Route/Schedule	Mode	Special Equipment	Amount of Subsidy	Phone Subscription	Usage
Conventional Buses	A	fixed	bus	displaying/broadcasting	50% fare discount	no	shared
	B	fixed	bus	displaying/broadcasting plus 10% with lifts	50% fare discount	no	shared
	C	fixed	bus	displaying/broadcasting plus 20% with lifts	50% fare discount	no	shared
Specialized Vehicles	D	fixed	bus	displaying/broadcasting plus lifts	free of charge	no	exclusive
	E	demand-responsive	van	lifts	free of charge	yes	exclusive
Paratransit	F	door-to-door	taxi	(ramps)	25% fare discount	yes/no	personal
	G	door-to-door	taxi	(ramps)	50% fare discount	yes/no	personal
Private Vehicles	H	door-to-door	motortricycle	necessary modification	50% modification fee subsidized	no	private
	I	door-to-door	car	necessary modification	50% modification fee subsidized	no	private

or ramps which can accommodate the mobility handicapped. They are free of charge and exclusively used by the mobility handicapped. Depending on the modes selected and on the ways of operation, two alternatives are further proposed:

D. Use specialized buses operated with fixed-route and fixed- schedule similar to conventional buses.
E. Use specialized vans operated on demand-response and by phone reservation.

Paratransit

The third type of accessible transportation is to use paratransit (taxis) providing door-to-door services. The taxis may be equipped with ramps and may be subscribed by phone. A portion of the fare is subsidized by the government. Depending on the amount of fare subsidized, two alternatives are further proposed:

F. The government subsidizes 25% of the taxi fare.
G. The government subsidizes 50% of the taxi fare.

Dehandicapped Private Vehicles

The fourth type of accessible transportation is to use private vehicles with necessary modification to accommodate disabled drivers. They are exclusively used by those with impaired ambulation and half of the modification or conversion costs are subsidized by the government. Depending on the modes selected, two alternatives are further proposed:

H. Use dehandicapped motor tricycles.
I. Use dehandicapped cars.

Goals, Objectives, and MOEs

Four interest groups (users, nonusers, operators, and government agencies) are considered in the evaluation of proposed accessible transportation alternatives. The goals, objectives, and measures of effectiveness (MOEs) for each of the four interest groups are identified as follows (also see Table 2):

Table 2. Goals, objectives and measures of effectiveness for barrier free transportation

Sectors	Goals	Objectives	MOEs
users	promote usage of barrier-free services for the aged and handicapped	(1)maximize the potential ridership	trips per month
		(2)minimize the out-of-pocket costs	dollars per trip
nonusers	enhance support from the normal people	(3)maximize the degree of support from the general public	scores{1,2,...,9}
operators	enhance support from the suppliers and drivers	(4)minimize the capital and operating costs	dollars per trip
		(5)maximize the degree of support from the suppilers	scores{1,2,...,9}
		(6)maximize the degree of support from the drivers	scores{1,2,...,9}
government	increase administrative feasibility	(7)minimize the expenditure of subsidy	dollars per trip
		(8)maximize the degree of administrative ease	scores{1,2,...,9}

Note:For the qualitative MOEs, a nine-point scale is used;1.extremely low; 2.very low; 3.low; 4.slightly low; 5.moderate 6.slightly high;7.high; 8.very high; 9.extremely high.

Users

The main goal for providing the transportation handicapped with accessible services is to facilitate them engaging in various socioeconomic activities. Maximizing the potential ridership and minimizing the out-of-pocket user costs are considered as two objectives for the accomplishment of this goal. The number of potential trips per month and dollars per trip are used as MOEs corresponding to these two objectives.

Nonusers

The basic goal for providing the transportation handicapped with accessible transportation services, from the general public perspective, is to receive support from the normal passengers and road users. Maximizing the degree of their support is selected as the objective under this goal. A nine-point scale is used to evaluate this objective qualitatively (1: extremely low; 2: very low; 3: low; 4: slightly low; 5: moderate; 6: slightly high; 7: high; 8: very high; 9: extremely high).

Operators

The fundamental goal for the operators (including the suppliers of accessible transportation services and the drivers) in providing accessible transportation services is also to receive support from them. Minimizing the extra capital and operating costs, maximizing the service motivation for both suppliers and drivers are chosen as the objectives under this goal. Dollars per trip is used to measure the extra capital and operating costs; while a nine-point scale qualitative measure (1: extremely low; ...; 9: extremely high) is used to evaluate the motivation for both suppliers and drivers.

Government agencies

From the government agency perspective, the major goal for providing accessible transportation services is to increase the feasibility of administration. Minimizing the amount of subsidy and maximizing the ease of administration are chosen as the objectives for the accomplishment of this goal. Dollars per trip is used to measure the amount of subsidy; while a nine-point scale qualitative measure (1:

extremely low; ...; 9: extremely high) is used to evaluate the degree of ease of administration.

Relative Weights of MOEs

The AHP Method

The analytic hierarchy process (AHP) method proposed by Saaty [1980] can decompose a complicated problem through a hierarchy of objectives, criteria and alternatives. Its main purpose is to estimate the relative importance (weight) for each level of hierarchical structure. To obtain the weights, AHP introduces a pairwise comparison matrix which has the following form:

$$A = \begin{bmatrix} w_1/w_1 & \cdot & \cdot & w_1/w_k & \cdot & \cdot & w_1/w_n \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ w_i/w_1 & \cdot & \cdot & w_i/w_k & \cdot & \cdot & w_i/w_n \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ w_n/w_1 & \cdot & \cdot & w_n/w_k & \cdot & \cdot & w_n/w_n \end{bmatrix} \quad (1)$$

where the w_i are weights and the ratio w_i/w_k (denoted by β_{ik}) are assigned by the decision makers. The pairwise comparison matrix has the following properties: (1) $\beta_{ik} = w_i/w_k$, (2) $\beta_{ik} = 1$, for $i = k$, and (3) $\beta_{ik} \times \beta_{ki} = 1$. Therefore, only the proportion of the matrix above the diagonal needs to be known in order to fill in the entire matrix.

Let $\underline{W}$ denote a vector of relative weights, i.e., $\underline{W} = \{w_1,\ldots,w_n\}$. Weights can then be estimated by solving the eigenvector equation:

$$A\underline{W} = n\underline{W} \quad (2)$$

where $\underline{W}$ is an eigenvector of A and n is the associated eigenvalue. Since the observed matrix A may not be consistent, the estimation of $\underline{W}$ could thus be found out by satisfying

$$A\underline{W} = \lambda_{max}\,\underline{W} \quad (3)$$

If λ_{max} is exactly the same as n, the pairwise comparison matrix A is perfectly consistent; however, the chance of this perfect consistency is rather small. A consistency index (CI) is thus used to evaluate the consistency of the observed matrix A:

$$CI = (\lambda_{max} - n) \ / \ (n-1) \quad (4)$$

If the CI value is less than 0.1, the consistency of a decision maker is considered satisfactory in general, and the vector $\underline{W}$ is thus presumed to provide the relative weights. If we take each size of matrix n into consideration, we can generate random matrices and calculate their mean CI value, called the random index (RI). A consistency ratio (CR) is defined as the ratio of the CI to the RI (i.e., CR = CI/RI). Then we can use CR as a measure of how a given matrix compares to a purely random matrix in terms of their CI's. A value of the CR less than 0.1 is typically considered acceptable; larger values for CR require the decision maker to reduce the inconsistencies by revising judgments.

To make pairwise comparisons, a nine-point scale (from 9:1, 8:1,..., 2:1 to 1:1, 1:2,..., to 1:9) was originally suggested by Saaty [1980]. Since it is rather difficult to clearly distinguish the difference of meanings in Chinese between any two adjacent scales, this paper makes a modification by using a five-point scale instead -- 5:1 represents absolute importance, 4:1 demonstrated importance, 3:1 essential importance, 2:1 weak importance, and 1:1 equal importance. The same modification also applies to the reciprocal scale (from 1:2 to 1:5).

The Relative Weights

Following the above-mentioned analytic hierarchy process (AHP) method, a pairwise comparison is first made by a panel of selected twenty specialists. The relative weights of the eight MOEs are then estimated by solving Eq. (2). It is found that the CI values of Eq. (4) are less than 0.1, implying that the consistency of each response is satisfactory and thus the vector $\underline{W}$ provides the relative weights.

The results of this survey show that potential ridership (0.232) is the most important measure of effectiveness, followed by supplier's support (0.145), operator's extra capital and operating costs (0.129), amount of government subsidy (0.128), out-of-pocket user costs (0.103), ease of administration (0.097), driver's support (0.085), and non-user's support (0.081). Notice that the relative weights for the eight MOEs should sum to 1.0.

Estimation of MOEs

The eight measures of effectiveness are divided into two categories: quantitative and qualitative. The quantitative MOEs are mainly estimated based on previous studies [Lan, 1990c, 1991] in which a local survey on the costs and latent demands for the proposed accessible transportation alternatives are carried out. The qualitative MOEs are measured by a group decision in such a way that a score in the nine-point scale is assigned to each of the proposed accessible transportation alternatives. The results of estimation are briefly narrated as follows:

The Quantitative MOEs

(1) Potential Ridership

The potential ridership for each accessible transportation alternative is measured by a latent demand [Miller, 1976], defined as "the difference between the number of trips generated by the transportation handicapped under existing transportation environment and the number of trips they would have taken under the condition that a specific accessible transportation alternative is provided." Based on the 1990 questionnaire survey on the four different transportation handicap groups in the Taipei area, four trip generation models are first constructed by using a stepwise regression method. The latent travel demand for each accessible transportation alternative is then estimated through a "gap analysis," a concept developed by Burkhardt and Eby [1973]. Detailed procedures of the "gap analysis" are given in Lan [1991].

It is found that for the impaired ambulation, the latent travel demands for alternatives A through I would be 0, 5.2, 10.4, 35.5, 71, 34, 68, 19, and 2 thousand trips per month, respectively. For the visually impaired, alternatives A through G would have latent travel demands of 28, 28, 28, 18.5, 37, 37.5, and 75 thousand trips per month, respectively. For the aged, alternatives A through G would have latent travel demands of 100, 100, 100, 350, 700, 330, and 660 thousand trips per month, respectively. Finally for others, alternatives A through G would have latent travel demands of 58, 58, 58, 63.5, 127, 57, and 114 thousand trips per month, respectively.

(2) Out-of-pocket User Costs

The bus fare in the Taipei area has a flat fare structure of eight NT dollars per person trip. Since the government subsidizes half of the bus fare for the aged and the disabled, the out-of-pocket user costs for alternatives A, B, and C for the four transportation handicap groups are all the same, 4.0 NT dollars per trip. For alternatives D and E, the government provides free-of-charge specialized vehicles, thus the out-of-pocket user costs are zero. The average travel distance by taxi in Taipei is about 4.6 kilometers which costs 85 NT dollars, thus the mean out-of-pocket user costs for alternatives F and G are 63.5 and 42.5 NT dollars per trip, respectively.

The average conversion cost for a motor tricycle is about 10 thousand NT dollars which is equivalent to 167 NT dollars per month assuming a five-year service life. A dehandicapped motor tricycle user would on average generate 71.7 trips per month in Taipei with trip length of 5.86 kilometers. Thus, the unit conversion cost for a motor tricycle is 2.33 NT dollars per trip, and the unit trip expense (mainly fuel cost) can also be calculated as 3.4 NT dollars per trip. Since half of the conversion cost is subsidized by the government, the total out-of-pocket user cost for alternative F would be 4.57 NT dollars per trip.

Similarly, the average conversion cost for a car is about 20 thousand NT dollars which is equivalent to 208 NT dollars per month assuming an eight-year service life. A dehandicapped car user would on average generate 36.8 trips per month in Taipei with trip length of 6.55 kilometers. Thus, the unit conversion cost for a car is 5.65 NT dollars per trip, and the unit trip expense (mainly fuel cost) can be calculated as 9.5 NT dollars per trip. Since half of the conversion cost is subsidized by the government, the total out-of-pocket user cost for alternative G would be 12.33 NT dollars per trip.

(3) Extra Operator Costs

For alternatives A, B, and C, the operator's extra capital and operating costs would reach 802, 1,585, and 2,362 thousand NT dollars per month; the potential ridership would be 2,873, 3,025, and 3,025 thousand person trips per month; thus the unit costs for providing these three alternatives are 0.28, 0.52 and 0.78 NT dollars per trip, respectively. For the rest of alternatives, the operators do not require extra capital and maintenance costs.

(4) Amount of Government Subsidy

For alternatives A, B, and C, the government subsidizes the aged and disabled passengers half of the bus fare, that is, 4.0 NT dollars per trip. For alternatives D and E, the amount of government subsidy would reach 93.4 and 66.8 thousand NT dollars per month per vehicle; the potential ridership would be 750 and 300 person trips per month per vehicle; thus the amount of subsidy for these two alternatives would be 125 and 223 NT dollars per trip, respectively. The average travel distance by taxi in Taipei is about 4.6 kilometers which costs 85 NT dollars, thus the amount of government subsidy for alternatives F and G would be 21.5 and 42.5 NT dollars per trip, respectively.

As mentioned above, the unit conversion costs for a dehandicapped motor tricycle and for a dehandicapped car are 2.33 and 5.65 NT dollars per trip respectively. Consequently, the amount of government subsidy for alternatives H and I would be 1.17 and 2.83 NT dollars per trip, respectively.

The Qualitative MOEs

In order to determine the scores of qualitative measures of effectiveness (including the degrees of nonuser's support, supplier's support, driver's support, and ease of administration), a seminar was held on January 22, 1990. During that seminar, seventeen selected delegates representing four interest groups -- the user sector (including impaired ambulation, visually impaired, elderly, and others), the nonuser sector (general public), the operator sector (including suppliers and drivers), and the administration sector (government agencies of social welfare and transportation departments) were invited. The seminar reached a conclusion that group decisions would be used by assigning a score on the nine-point scale to each of the qualitative MOEs. One point represents extremely low, two points very low, three points low, four points slightly low, five points moderate, six points slightly high, seven points high, eight points very high, and nine points extremely high. The results of qualitative scores for nonuser's support, supplier's support, driver's support, and ease of administration are shown in Tables 3 through 6.

Table 3. Evaluation of barrier free transportation alternatives for the impaired ambulation

Sectors	Objectives(MOEs)	Weights	Alternatives								
			A	B	C	D	E	F	G	H	I
users	potential ridership (1,000trips/month)	0.232	0.0	5.2	10.4	35.5	71.0	34.0	68.0	19.0	2.0
	out-of-pocket costs (NT $/trip)	0.103	4.0	4.0	4.0	0.0	0.0	63.5	42.5	4.6	12.3
nonusers	degree of support (score)	0.081	4	2	1	5	5	8	8	3	4
operators	capital/operating costs (NT $/trip)	0.129	0.3	0.5	0.8	0.0	0.0	0.0	0.0	0.0	0.0
	supplier's support (score)	0.145	6	2	1	7	8	6	6	9	9
	driver's support (score)	0.085	8	4	4	9	8	6	6	5	5
government	amount of subsidy (NT $/trip)	0.128	4.0	4.0	4.0	125.0	223.0	21.5	42.5	1.2	2.8
	ease of administration (score)	0.097	9	6	6	8	7	1	1	3	4
total appraisal scores			-0.0015	-0.0138	-0.0177	0.0085	0.0133	-0.0019	0.0094	0.0041	-0.0004
relative rankings			VI	VIII	IX	III	I	VII	II	IV	V

Note: 1.Weights are determined by the AHP method.

2.Total appraisal scores are caculated by the MEQQD method.

3.Definition of alternatives A through I, see Table 1.

4.Alternatives H and I are for the impaired ambulation only.

Table 4. Evaluation of barrier free transportation alternatives for the visually impaired

Sectors	Objectives(MOEs)	Weights	Alternatives A	B	C	D	E	F	G
users	potential ridership (1,000trips/month)	0.232	28.0	28.0	28.0	18.5	37.0	37.5	75.0
	out-of-pocket costs (NT $/trip)	0.103	4.0	4.0	4.0	0.0	0.0	63.5	42.5
nonusers	degree of support (score)	0.081	4	2	1	5	5	8	8
operators	capital/operating costs (NT $/trip)	0.129	0.3	0.5	0.8	0.0	0.0	0.0	0.0
	supplier's support (score)	0.145	6	2	1	7	8	6	6
	driver's support (score)	0.085	8	4	4	9	8	6	6
government	amount of subsidy (NT $/trip)	0.128	4.0	4.0	4.0	125.0	223.0	21.5	42.5
	case of administration (score)	0.097	9	6	6	8	7	1	1
total appraisal scores			0.0082	-0.0140	-0.0241	0.0006	0.0035	-0.0025	0.0284
relative rankings			II	VI	VII	IV	III	V	I

Note: 1.Weights are determined by the AHP method.
2.Total appraisal scores are caculated by the MEQQD method.
3.Definition of alternatives A through G, see Table 1.

Table 5. Evaluation of barrier free transportation alternatives for the aged

Sectors	Objectives(MOEs)	Weights	Alternatives						
			A	B	C	D	E	F	G
users	potential ridership (1,000trips/month)	0.232	100.0	100.0	100.0	350.0	700.0	330.0	660.0
	out-of-pocket costs (NT $/trip)	0.103	4.0	4.0	4.0	0.0	0.0	63.5	42.5
nonusers	degree of support (score)	0.081	4	2	1	5	5	8	8
operators	capital/operating costs (NT $/trip)	0.129	0.3	0.5	0.8	0.0	0.0	0.0	0.0
	supplier's support (score)	0.145	6	2	1	7	8	6	6
	driver's support (score)	0.085	8	4	4	9	8	6	6
government	amount of subsidy (NT $/trip)	0.128	4.0	4.0	4.0	125.0	223.0	21.5	42.5
	ease of administration (score)	0.097	9	6	6	8	7	1	1
total appraisal scores			0.0007	-0.0193	-0.0269	0.0124	0.0212	-0.0029	0.0148
relative rankings			IV	VI	VII	III	I	V	II

Note: 1.Weights are determined by the AHP method.
2.Total appraisal scores are caculated by the MEQQD method.
3.Definition of alternatives A through G, see Table 1.

Table 6. Evaluation of barrier free transportation alternatives for the others

Sectors	Objectives(MOEs)	Weights	Alternatives						
			A	B	C	D	E	F	G
users	potential ridership (1,000trips/month)	0.232	58.0	58.0	58.0	63.5	127.0	57.0	114.0
	out-of-pocket costs (NT $/trip)	0.103	4.0	4.0	4.0	0.0	0.0	63.5	42.5
nonusers	degree of support (score)	0.081	4	2	1	5	5	8	8
operators	capital/operating costs (NT $/trip)	0.129	0.3	0.5	0.8	0.0	0.0	0.0	0.0
	supplier's support (score)	0.145	6	2	1	7	8	6	6
	driver's support (score)	0.085	8	4	4	9	8	6	6
government	amount of subsidy (NT $/trip)	0.128	4.0	4.0	4.0	125.0	223.0	21.5	42.5
	ease of administration (score)	0.097	9	6	6	8	7	1	1
total appraisal scores			0.0040	-0.0163	-0.0243	0.0064	0.0254	-0.0110	0.0157
relative rankings			IV	VI	VII	III	I	V	II

Note: 1.Weights are determined by the AHP method.

2.Total appraisal scores are caculated by the MEQQD method.

3.Definition of alternatives A through G, see Table 1.

4.The rest includes hearing/speaking impaired, mentally retarded, and multiple handicaps.

Evaluation of Alternatives

The MEQQD Method

The multicriteria evaluation with qualitative and quantitative data (MEQQD) method developed by Voogd [1982] is a useful mixed data multicriteria evaluation technique. It can deal with an evaluation problem with qualitative and quantitative data. The set of criteria (MOEs) is divided into two subsets denoted as O and C, where O represents the subset of ordinal (qualitative) criteria and C represents the subset of cardinal (quantitative) criteria. A subtractive summation technique is used and its procedures are briefly described as follows.

At first, a dominance score α_{ik} (representing the degree to which alternative i dominates alternative k) for the ordinal criteria is calculated through a function F which is specified as

$$\alpha_{ik} = F\left(e_{ji}, e_{jk}, w_j\right), \text{for} \quad \text{all} \quad j \in O \tag{5}$$

$$= \left\{ \sum_j \left[w_j \operatorname{sgn}\left(e_{ji} - e_{jk}\right) \right]^r \right\}^{1/r}$$

where

$$\operatorname{sgn}(e_{ji} - e_{jk}) = \begin{cases} +1 & \text{if } e_{ji} > e_{jk} \\ 0 & \text{if } e_{ji} = e_{jk} \\ -1 & \text{if } e_{ji} < e_{jk} \end{cases}$$

where e_{ji} represents the qualitative score of criterion j and alternative i and w_j the weight attached to criterion j; while r denotes an arbitrary scaling parameter, for which any positive uneven value may be chosen. If the criterion weights are very reliable r = 1 may be assumed. If this is not true, a higher value for r is assumed. The major drawback for Eq. (5) is that α_{ik} is affected only by the weight w_j and the sign of qualitative dominance measures, but not affected by the magnitude of the difference of measures. Thus, a pairwise comparison of "very good versus very bad," for instance, will not distinguish from that of "very good versus good." This paper modifies the expression of Eq. (5) by considering the effects of the magnitude of the difference of qualitative measures as follows:

$$\alpha_{ik} = \left\{ \sum_j \left[w_j (e_{ji} - e_{jk}) \right]^r \right\}^{1/r} \tag{6}$$

Secondly, a dominance score a_{ik} for the cardinal criteria is calculated through a function G which is specified as

$$a_{ik} = G(e^*_{ji}, e^*_{jk}, w_j), \text{ for all } j \in C \tag{7}$$

$$= \left\{ \sum_j \left[w_j (e^*_{ji} - e^*_{jk}) \right]^r \right\}^{1/r}$$

where e^*_{ji} is the standardized quantitative score of alternative i and criterion j. The main purpose for the standardization of an initial quantitative score e_{ji} is to convert different measurement units into the same unit so that they are comparable. The following standardization procedure is used:

$$e^*_{ji} = (e_{ji} - e_j^-) / (e_j^+ - e_j^-)$$

where e^*_{ji} = the standardized quantitative score of alternative i and criterion j.

e_{ij} = the initial quantitative evaluation score of alternative i and criterion j.

e_j^- = the lowest e_{ji} score of criterion j.

e_j^+ = the highest e_{ji} score of criterion j.

Thirdly, a standardization of α_{ik} and a_{ik} into the same unit is necessary because they have different measurements, otherwise no comparison can be made between the outcomes of Eqs. (6) and (7). The standardized dominance measures can be written by a standardization function H as

$$\delta_{ik} = H(\alpha_{ik}) = \alpha_{ik} \Big/ \sum_{i} \sum_{k} |\alpha_{ik}| \tag{8}$$

and

$$d_{ik} = H(a_{ik}) = a_{ik} \Big/ \sum_{i} \sum_{k} |a_{ik}| \tag{9}$$

Finally, an overall dominance score m_{ik} for each pair of alternatives (i,k) is written as:

$$m_{ik} = w_o \hat{\delta}_{ik} + w_c d_{ik} \tag{10}$$

where w_o and w_c represent the weights of the qualitative criterion set O and the quantitative criterion set C, respectively ($w_o + w_c = 1$). The overall dominance score can not only give the degree to which alternative i dominates alternative k but also may be considered as function K of the appraisal scores s_i and s_k. The K function is defined as:

$$m_{ik} = K(s_i, s_k) = s_i - s_k. \tag{11}$$

Eq. (11) implies that the standardization functions of Eqs. (8) and (9) should be such that $m_{ik} = - m_{ki}$. The appraisal score can now be found by adding the left and right part of Eq. (11) over k:

$$\sum_k m_{ik} = \sum_k (s_i - s_k) \tag{12}$$

$$= I.\, s_i - \sum_k s_k$$

where I is the number of alternatives. Thus, s_i can be rewritten as:

$$s_i = \sum_k m_{ik} \Big/ I + \sum_k s_k \Big/ I \tag{13}$$

Without loss of generality, the mean of the appraisal scores can be assumed to be zero (i.e., $\sum_k s_k \Big/ I = 0$), the appraisal scores si can hence be expressed as:

$$s_i = \sum_k m_{ik} \Big/ I \tag{14}$$

Evaluation Results

Following the above-mentioned multicriteria evaluation with qualitative and quantitative data (MEQQD) method, the appraisal scores corresponding to various alternatives for each handicap group are calculated. Tables 3 through 6 show the results of total appraisal scores and relative rankings. Notice from Eq. (14) that the mean of the appraisal scores is assumed to be zero, thus, the total appraisal scores in Tables 3 through 6 are characterized with a zero mean, representing an "average" or "fair" alternative. Larger values for positive (negative) appraisal scores correspond to better (worse) alternatives. The magnitude of total appraisal scores can also reflect the extent to which one alternative is superior to another.

It is found that the two most preferred alternatives of accessible transportation for the impaired ambulation are demand-response free-of-charge specialized vans and half-fare taxi. Fixed-route/schedule free-of-charge specialized buses and dehandicapped motor tricycles are two other promising choices. For the visually impaired, the two most preferred alternatives of accessible transportation are half-fare taxi and conventional buses with bus-stop broadcast devices. Demand-response free-of-charge specialized vans and fixed-route/schedule free-of-charge specialized buses are two other promising options. For both the aged and others, the two most preferred alternatives of accessible transportation services are demand-response free-of-charge specialized vans and half-fare taxi; two other promising options are fixed-route/schedule free-of-charge specialized buses and conventional buses with bus-stop display and broadcast devices.

Conclusions and Discussions

Demand-response free-of-charge specialized vans and fare-subsidized taxi are evaluated as the most appropriate means to serve the transportation handicapped in the Taipei metropolitan area and therefore should be strongly recommended. Fixed-route/schedule free-of-charge specialized buses and conventional buses with bus-stop display and/or broadcast devices are evaluated as another two promising alternatives and should also be recommended. For those with impaired ambulation, dehandicapped private motor tricycles/cars, with half of the modification costs subsidized by the government, provide another promising alternatives for them and thus can also be considered. By contrast, the conventional buses equipped with lifts are evaluated as the least attractive alternative and therefore are not recommended in Taipei.

Notice that in the determination of relative weights of MOEs, a sample size of twenty specialists cannot be viewed as statistically large. This may produce statistically "insignificant" results. Different results would be anticipated if another panel of twenty persons is selected. In addition, the mobility handicapped themselves are not included in the panel. This may also "bias" the results if the mobility handicapped have different perceptions and priorities than the specialists.

Firstly, the reason for including only twenty specialists in this study is due mainly to a budget constraint. To diversify the sampling, however, these specialists are selected out of six public agencies (including Department of Social Welfare, Department of Transportation, Society of Senior Citizen, and Associations for related Handicapped and Disabled) and three universities (including scholars involved in social welfare and transportation research). Since they have been working on social welfare for the mobility handicapped for years in Taiwan, these "specialists" are presumed to have objective perceptions and priorities in representing the mobility handicapped in this country. Hence, the results are recognized by the project sponsor agency, the Institute of Transportation, Ministry of Transportation and Communications.

Secondly, in order to determine the scores of qualitative MOEs, seventeen delegates are selected, representing four interest groups -- the user sector (the mobility handicapped themselves, including impaired ambulation, visually impaired, elderly, and others), the nonuser sector (general public), the operator sector (including accessible transport suppliers and drivers), and the administration sector (including Department of Social Welfare and Department of Transportation). A score nine-point scale is assigned to each of the qualitative MOEs by group decisions. Different results would be anticipated if another panel of seventeen delegates are selected out of these four interest groups. However, it is thought that such group decisions would share a nearly "unbiased" view in the determination of qualitative MOE scores, thus the results are also accepted by the project sponsor agency.

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