*JKAU: Eng. Sci.*, **Vol. 17** No. 1, pp: 3 - 21 (2006A.D. /1427 A.H.)

# Development of Intercity Mode Choice Models for Saudi Arabia

Hasan M. Al-Ahmadi

*Civil Engineering Department,*
*King Fahd University of Petroleum and Minerals,*
*Dhahran 31261, Saudi Arabia*

*Abstract***.** Several mode choice models are developed all over the world to predict the trip-maker choice of using a specific mode among a set of transportation modes. This modeling is quite important from planning point of view since the transportation systems usually receive huge investment. In Saudi Arabia, there are some characteristics of intercity tripmakers that differ from those of tripmakers in other countries. These characteristics include cultural, socioeconomic, safety, and religious parameters.

In this study, the main purpose was to develop intercity mode choice models for Saudi Arabia. The required data was collected from all major cities throughout Saudi Arabia. Comprehensive questionnaires (Arabic and English) were designed and distributed at airport terminals, bus terminals, train stations, and at gasoline stations located midway between the cities under study.

Behavioral mode-choice models were successfully built and validated with an independent sample for work, Aumra and social trips. These models indicated that in-vehicle travel time, out-of-pocket cost, number of family members traveling together, monthly household income, travel distance, nationality of the traveler, and number of cars owned by the family played a role in decisions related to intercity mode-choices. These models will be helpful in travel demand analysis for Saudi Airlines and Ministry of Transportation. This conclusion will help government and public transportation agencies and private carriers to make marginal decisions, and to prevent under or over-design of their facilities.

## Introduction

Saudi Arabia is one of the rich developing countries. Its wealth comes primarily from oil revenues. The discovery of oil in Saudi Arabia changed the Kingdom of Saudi Arabia from a pre-industrial country to a modern industrial country. This brisk change placed a burden on all public utilities and facilities, especially the transportation system.

There are two types of Islamic religious trips which generate significant intercity and international travel to and within Saudi Arabia. The first is the Hajj, which is the annual pilgrimage to the holy city of Makkah and performed between the 8th and 14th of the Hijri month of Dhul-Hijjah.

The second type of religious trips, Aumra, is again made for the purpose of visiting the holy city of Makkah, and although there are certain preferred visiting times, in general, Aumra trips can be made throughout the year.

Aumra trips make up 19 percent of total intercity trips during school vacations in Saudi Arabia [1] amounting to approximately 3-4 million trips a year within Saudi Arabia alone. Understanding the behavior of tripmakers in selecting a travel mode is necessary for public transportation agencies or private carriers to make managerial decisions, and to prevent under or over-design. For instance, underestimation of future travel demand may lead to congestion, delay, high accident rates on many major roads, and excessive stand-by passengers at major airport terminals. These problems may waste valuable manpower and time, and may impede the economic development of the Kingdom. At the other extreme, if future travel demand is overestimated, too much capital will be tied up in transportation facilities and not used for other more needed aspects of development.

An intercity model must exist to predict the future modal split. The results of this study will provide the transportation agencies with a tool to maximize their revenue and better allocate their resources.

### *Behavior of the Intercity Tripmaker in Saudi Arabia*

The first step in any engineering work is planning. In transportation, planning is especially important because transportation systems are among the most expensive investments to build or modify. The investment in transportation improvements should be based on the understanding of future demand. To achieve this, an understanding of tripmaker behavior is essential.

Understanding the behavior of the tripmaker will provide the model builder with the most likely variables for inclusion in the model. The definition of a tripmaker in this research is a person traveling between cities alone or with family. The following paragraphs discuss the characteristics of Saudi behavior when a person makes an intercity trip. These characteristics may not be applicable to Western culture.

1. In Saudi Arabia, the percentage of females traveling alone from one city to another is very low. This is because some Islamic laws forbid women to travel alone. In addition, women are not allowed to drive in Saudi Arabia. They may use an airplane to travel alone, but only under special circumstances, and relatives must meet them at the airport.

2. Another factor affecting the tripmaker in choosing an intercity mode is the weather. In Saudi Arabia the weather, especially in summer, does not encourage the tripmaker to use ground transportation.

3. Saudi tripmakers are very concerned with safety, because the risk of becoming involved in an car accident is very high [2]. This perception of risk may cause the tripmaker to hesitate to drive his car or use ground transportation for an intercity trip.

4. Another characteristic of Saudi tripmakers is that they prefer, for non-business trips, to travel as families since the average family size is around six [3]. Finally, in Saudi Arabia a unique intercity trip purpose exists. This trip purpose is religious and is called the "*Aumra* trip". This is not a trip purpose commonly associated with intercity travel in the West.

## *Disaggregate Modeling*

The disaggregate approach was the second generation in model building after the aggregate approach in mode choice modeling [4]. The development of disaggregate models provides a more effective tool for predicting an individual's behavior in selecting one mode from among different modes available. The decrease in explanatory power of the aggregate models due to data aggregation was avoided with the disaggregate models [5]. This advantage greatly improved the predictive power of disaggregate models. For example, Watson [6,7] developed and evaluated aggregate and disaggregate binary (rail versus car) mode choice models in the Edinburgh-Glasgow corridor. His results indicated an error in mode choice prediction for this city pair 12 to 15 times higher for an aggregate model than those for a disaggregate model for the same specification. The disaggregate model was preferred over the best aggregate model for intercity travel prediction.

The development of disaggregate models was extensively documented[8-13] and is widely used in urban travel analysis.

The use of disaggregate models is supported by their representation of the individual tripmaker's decision, data efficiency, and superior estimation results. Most disaggregate models are based on the theory of "utility maximization." They assume that a person makes a particular choice from a set of different alternatives depending on the maximum benefit he receives. For example, a person may wish to minimize travel time and cost of the trip, and maximize comfort and convenience in selecting a mode from the available modes.

The primary model form for intercity mode choice utilizing disaggregate data is in a probabilistic form, as seen in the following example:

$$P_k^i = \frac{e^{V_{ki}}}{\sum_j e^{V_{ki}}}$$

Where:

$P^i_k$ = probability of tripmaker i choosing mode k out of j alternatives

$V_{ki}$ = the utility of alternative mode k to trip maker i

= $(X_k, S_i)$

$X_k$ = a row vector of characteristics of alternative mode k

$S_i$ = a row vector of socioeconomic characteristics of a tripmaker i

From this equation, it is clear that the probability of a tripmaker choosing a particular mode is a function of the characteristics of the tripmaker such as, income, age, and sex and of the characteristics of the mode relative to alternative modes.

## Data Required Categories

Based on the literature, the data needed for specifying, calibrating and testing transferability consist of three categories: socioeconomic variables, level-of-service or supply variables, and data regarding the trip. Some of these variables are qualitative and others are quantitative. In model calibration it cannot be predetermined which variables best explain the tripmaker's behavior unless the impact of the other variables is tested in the preliminary modeling stage. The following variables have been collected and used to determine the best fit model for each corridor under study.

### *Level-of-Service Variables*

For the level-of-service variables, which may influence the tripmaker's choice, the following variables have been collected:

1. *In-vehicle travel time.* This is the time in minutes spent in the mode for a one-way trip.

2. *Access time*. This is the time in minutes that the tripmaker spends after leaving the origin until he gets into the mode of choice.

3. *Egress time*. This is the time in minutes the tripmaker spends after leaving the mode terminal until he reaches the destination.

4. *Waiting time*. This variable is the time in minutes between the time the tripmaker arrives at the terminal and departure of the trip.

5. *Total travel time*. This variable is the summation of access time, egress time, waiting time, and in-vehicle travel time.

6. *Travel cost*. Travel cost is the total cost perceived by the tripmaker, such as airplane fare or fuel for the car user. This is mainly out-of-pocket cost. Perceived cost has been found to be more important than actual cost in mode choice decision-making from the traveler's point of view [8]. Trip cost has been estimated in Saudi Riyals. This total cost for travel consists of two parts. One is in-vehicle cost, which includes fare paid for the major

carriers, e.g., airplane or train, and the perceived operation cost for a private car. The other component is the out-of-vehicle cost, which includes costs such as access, egress, and parking costs.

***Socioeconomic Variables***

Another category of data collected consisted of socioeconomic variables. Socioeconomic characteristics for a given tripmaker do not vary across alternatives as do the level of service variables. Socioeconomic characteristics enter into the choice function as mode-specific, or as a function of the level-of-service variables, such as out-of-pocket cost divided by income. The following are the socioeconomic variables collected for use in explaining mode choice behavior:

1. *Income.* This variable is commonly used as an indicator of a trade-off between expense, convenience, and other qualitative variables. Furthermore, it is also used as a proxy for other quantitative variables, such as the number of autos in the household. Income has been considered in the Saudi monetary unit, the Saudi Riyal (SR).

2. *Car ownership*. This variable is used to determine whether the tripmaker owns a car or is captive to other modes. In other words, does the tripmaker have a complete set of choices? Furthermore, the number of cars available to a household may affect the mode choice behavior.

3. *License.* This variable has been used to determine if the tripmaker actually has a choice between a car and other modes.

4. *Group size.* This variable has been used to determine the impact of the size of a group traveling together in the tripmaker's mode choice.

5. *Family.* This variable has been used to determine if the group traveling together is related. The size of the family and the age of the members of the family traveling between cities often reflect the actual cost of the trip.

6. *Age.* This variable has been used to determine if age has an impact on intercity mode choice for the tripmaker or his family.

7. *Nationality.* To determine if there is a difference in travel behavior for intercity mode choice between Saudi citizens and non-Saudis, this variable has been introduced into the questionnaire.

8. *Permanent residence versus non-permanent residence.* This variable will distinguish between tripmaker from outside the country and tripmaker from Saudi Arabia.

***Trip Variables***

Data regarding the trip were collected and are summarized as follows:

1. *Trip purpose*. The distinction among trip purposes is an important step in mode choice analysis because different tripmaker behaviors are expected in selecting a mode for different trip purposes [8]. In order to distinguish between trip purposes, this information should be available to the model builder. Trip purposes include official business, personal business, Aumra, social, recreational, and work.

2. *Duration of stay*. The length of time a tripmaker is planning to stay at the destination city has been collected. The categories for this variable are one day, 2-7 days, and more than 7 days.

## Data Collection and Analysis

A specially designed questionnaire form was distributed for each mode under consideration. Because many tripmakers in Saudi Arabia are from different countries, and the most prevalent languages among tripmakers are Arabic and English, the questionnaire forms were written in both Arabic and English. These forms were distributed at the airport terminal, bus terminal, and train station for tripmakers traveling in the corridors under study. Questionnaires were distributed on-board while the subjects waited for the departure. The completed questionnaires were collected at the destination of each trip.

Tripmakers traveling by car were interviewed at the gas stations located midway between the cities under study. In addition, one-hundred questionnaire forms were placed at the gas stations. However, none of these questionnaires were returned, even though the recipients were asked to complete the questionnaire and return it by prepaid mail.

This questionnaire included a wide range of variables characterizing the trip (by mode, trip purpose, origin destination, duration, etc.), the service characteristics of both the chosen mode and perceived characteristics of other available but unchosen modes (travel time, cost, frequency, etc.), and the tripmaker's characteristics (age, income, occupation, etc.). Moreover, the questionnaires were coded by the name of the four different modes under study: train, airplane, private car, and bus.

Those respondents who said that they will "never consider using" other modes other than the chosen one are assumed to be "captive" to the chosen mode. Captives are excluded from the calibration data set as they do not make a choice.

The intercity mode choice models were calibrated for three trip purposes:

1. Work trips (include work trips, personal business and educational/ study trips).
2. Social/Recreational trips (also include "other" purpose category).
3. *Aumra* trips.

*Aumra* trip purpose category was specially chosen because of the local interest. The data cleaned of missing data and of captive riders were separated for the three work trip categories. Approximately 1/3 of these data sets were reserved for model validation and 2/3 was used for model calibration. Selection for these was randomized. A total of 2192 questioners were used for model calibration and validation as can bee seen in Table 1.

**Table 1. Sample Sizes for Model Calibration and Validation.**

| Trip Purpose Category | Sample Sizes for | | Total |
|---|---|---|---|
| | Model Calibration | Model Validation | |
| Work | 491 | 272 | 763 |
| Social/Recreational | 696 | 324 | 1020 |
| Aumra | 279 | 130 | 409 |

The codes and explanation of the variables used in the final models are given in Table 2. It should be noted that many other variables have been tried during the calibration process. The variables reported in this table all have significant parameter estimates and all have logical signs.

### *Model Specification*

Different specifications for the models have been evaluated to determine which specification best replicates the data for different trip purposes. These specifications include the variables that have been found in the literature review to influence the tripmaker choice [such as total cost (TOTALC), egress travel time (EGTM), access travel time (ACTM), household income (HHIN), total travel time (TOTAT), out-of-vehicle travel time (OVTT), distance (DIST), in-vehicle travel time (IVTT), and waiting time (WTTM)]. Composite variables such as TOTALC/HHINC and OVTT/DIST are used to modify the impact of the pure level-of-service variables TOTALC and OVTT. It is hypothesized that tripmakers with different levels of income perceive travel cost differently. Similarly, out-of-vehicle time is hypothesized as becoming less important as the length of the trip increases. Table 2 shows the description of the abbreviated variables used throughout this research.

**Table 2. Explanation of Variables Included in the Selected Models.**

| Variable Code | Explanation |
|---|---|
| ASC-AIR | Alternative specific constant for air |
| ASC-BUS | Alternative specific constant for bus |
| TIME | In vehicle travel time in hours (generic) |
| COSTT | Total cost in SR (generic) |
| TKITC | Ticket cost for air and bus, total cost for car |
| INVTTA | = In vehicle travel time, for air |
| | = 0, otherwise |
| DNCARB | = 1, if the traveler has no car, for bus |
| | = 0, otherwise |
| DIST | = highway distance, for air |
| | = 0, otherwise |
| DISTC | = 1, if highway distance ≤ 500 km, for car |
| | = 0, otherwise |
| DDURTA | = duration of trip in hrs for air |
| | = 0, otherwise |
| DFMLYC | = 1, if no. of family members > 1, for car = 0, otherwise |
| DNATIONA | = 1, if nationality is Saudi, Americans or Europeans, for air |
| | = 0, otherwise |
| DNATIONB | = 1, if nationality is Far Easterns and other Arabs |
| | = 0, otherwise |
| HHINA | = household income for air |
| | = 0, otherwise |
| DHHINCB | = 1, if household income < SR 2,500, for bus |
| | = 0, otherwise |
| PRIV | Privacy perception (generic) |
| CONV | Convenience perceptive (generic) |
| COMF | Comfort perception (generic) |
| RELB | Reliability perception (generic) |

Different model specifications were tested. Each model estimate is based on a different model utility function. Model specifications were formulated based on prior experience in intercity mode choice modeling, and the impact of introducing additional explanatory variables.

Some of the models tested exhibited poor statistical goodness-of-fit and/or counter-intuitive signs and were rejected. For example, some models produced a very good fit but it has a counter-intuitive sign in the variable total travel time. In summary, the logic employed to move from one specification to another can be described as follows:

- Variables with insignificant coefficients were dropped;
- Variables that had the "wrong" signs were dropped;
- Variables that were related to level-of-service (***i.e.***, those that might be considered supply variables) were considered in both straightforward ways (e.g., the cost variable was added) and in ratio forms (e.g., cost divided by income);
- Sets of variables with high correlations were considered and selected variables were dropped;
- Different versions of several variables with "wrong" signs were considered (e.g., out-of-vehicle time was examined as a mode-specific variable); and finally,
- Several intuitively important variables which had been dropped were reconsidered (in the original form and/or, for example, in mode-specific form).

Of all the model specifications tested, the most satisfactory models for work, social, Aumra and all trip purposes are presented in Tables 3, 4 , 5 and 6 respectively.

The utilities of different models for the work trips are seen in Table 3 and they are as follows:

$$U_{air} = 0.879 – 0.0826\ (TIMEI) – 0.0015149\ (COSTT) + 0.279496\ (HHINA)$$

$$U_{bus} = 1.6189 - .0826\ (TIMEI) – 0.0015149\ (COSTT) + 0.6126\ (DNATIONB)$$

$$U_{car} = -0.0826\ (TIMEI) – 0.0015149\ (COSTT) + 1.456\ (DFMLYC) + 1.03243\ (DISTC)$$

Utilities for other trip purposes can be derived the same way from Tables 4 - 7.

**Table 3. Work Mode-Choice Model.**

| Indep Variable | Estimate | T-Stat | STD.Error |
|---|---|---|---|
| 1ASC-AIR | 0.879166 | 1.93714 | 0.453847 |
| 2ASC-BUS | 1.61886 | 4.83754 | 0.334645 |
| 3TIMEI | -.826134E-01 | -2.37859 | 0.347321E-01 |
| 4COSTT | -.151494E-02 | -2.42632 | 0.624378E-03 |
| 5DFMLYC | 1.45624 | 4.53257 | 0.321284 |
| 6DNATIONB | 0.612579 | 2.04689 | 0.299272 |
| 7HHINA | 0.279496 | 4.30456 | 0.649301E-01 |
| 8DISTC | 1.03243 | 3.20249 | 0.322385 |

LOG LIKELIHOOD = -278.957 LOG LIKELIHOOD (0) = -406.941
RHO SQUARED = 0.314502 RHO-BAR SQUARED = 0.307989

Where:

ASC-AIR = Mode-specific constant for air
ASC-BUS = Mode-specific constant for bus
TIMEI = In-Vehicle time in hours
COSTT = Out-of-pocket total cost
DFMLYC = Dummy family for car
HHINA = Monthly household income for air
DISTC = Dummy for distance for car
DNATIONB = Dummy for nationality used for bus

The coefficients of the parameters in the models all have the expected signs. The coefficients of in-vehicle travel time, and total out-of-pocket cost are negative, as expected, while all the dummy variables are positive, as expected.

It is clear from the t-stat (t-statistic) values for the variables in Tables 3-7 that the null hypothesis that the true value of each coefficient is zero can be rejected at least at the 0.10 significance levels.

The goodness-of-fit measure rho-square (p2) for the Work model, Aumra model, and Social model are 0.314, 0.36 and 0.41, respectively. The p2 statistics for these models represent a very good fit.

The adjusted likelihood ratio index (rho-squared bar) for the Work model, Aumra model, and Social model are 0.308, 0.34, and 0.406 respectively.

**Table 4. Aumra Mode-Choice Model.**

| Indep Variable | Estimate | T-Stat | STD.Error |
|---|---|---|---|
| 1 ASC-AIR | -.103048 | -.164336 | 0.627057 |
| 2 ASC-BUS | 1.50867 | 3.42586 | 0.440377 |
| 3 TKITC | -.108737E-02 | -2.47524 | 0.439300E-03 |
| 4 INVTTA | -1.08366 | -2.97417 | 0.0364356 |
| 5 DIST | 0.230093E-02 | 3.55254 | 0.647685E-03 |
| 6 DFMLYC | 0.963813 | 2.09752 | 0.459501 |
| 7 DNATIONB | 0.498106 | 1.42269 | 0.350116 |
| 8 FMLY | -.262451 | -2.45224 | 0.107025 |
| 9 HHINA | 0.192262 | 1.91908 | 0.100185 |
| 10 DNCARB | 1.56602 | 3.69911 | 0.423352 |

LOG LIKELIHOOD = -188.975 LOG LIKELIHOOD (0) = -406.941
RHO SQUARED = 0.35562 RHO-BAR SQUARED = 0.343804

Where:
ASC-AIR = Mode-specific constant for air
ASC-BUS = Mode-specific constant for bus
TIMEI = In-Vehicle time in hours
TKITC = Ticket cost
DFMLYC = Dummy family for car
HHINA = Monthly household income for air
DISTC = Distance for car
DNATIONB= Dummy for nationality used for bus

The null hypothesis that all the parameters are zero (B1=B2= B3…Bk=0) is tested by the log-likelihood ratio test (-2(L(0)-L(B), which is X2 (chi-square) test and has a degree of freedom equal to the number of model parameters [14]. The critical X2 value with degrees of freedom equal to the model parameters, and a 0.05 level of significance (e.g. X2 .05,9), is 16.92, while the calculated X2 test statistics for all the models presented are far away from this value. In other words, the null hypothesis that all the parameters are jointly zero is rejected at the 95% level. Moreover, the null hypothesis that all the coefficients, except, the mode-specific constants, are zero is tested by Ref. [13]:

$$-2(L(C) - L(B)$$

with degree of freedom equal to K-J+1, where K is the number of model parameters, J is the number of alternatives in the universal choice set, and L(C) is the log likelihood for a model with only constants.

**Table 5. Social Mode-Choice Model.**

| Indep Variable | Estimate | T-Stat | STD.Error |
|---|---|---|---|
| 1ASC-AIR | 0.703660 | 1.53316 | 0.458962 |
| 2ASC-BUS | 1.60056 | 5.32653 | 0.300488 |
| 3TIMEI | -.295560E-01 | -1.72598 | 0.171242E-01 |
| 4COSTT | -.201135E-02 | -4.94659 | 0.406613E-03 |
| 5DNCARB | 1.77467 | 5.10126 | 0.347888 |
| 6DFMLYC | 1.56651 | 6.03301 | 0.259656 |
| 7DNATIONA | 1.31574 | 3.75032 | 0.350834 |
| 8DHHINCB | 0.595890 | 1.60300 | 0.371734 |
| 9HHINA | 0.187509 | 3.32426 | 0.564064E-01 |
| 10DISTC | 1.97448 | 7.97325 | 0.247638 |

LOG LIKELIHOOD = -377.261 LOG LIKELIHOOD (0) = -640.448
RHO SQUARED = 0.410943 RHO-BAR SQUARED = 0.406177

Where:

| | | |
|---|---|---|
| ASC-AIR | = | Mode-specific constant for air |
| ASC-BUS | = | Mode-specific constant for bus |
| TIMEI | = | In-Vehicle time in hours |
| COSTT | = | Out-of-pocket cost |
| DFMLYC | = | Dummy family for car |
| HHINA | = | Monthly household income for air |
| DISTC | = | Distance for car |
| DNATIONA | = | Dummy for nationality used for air |
| DNCARB | = | Dummy for number of cars used for bus |
| DHHINCB | = | Dummy for household income for bus |

This X2 test statistic has n degrees of freedom for the null hypothesis B3=B4=B5…Bn=0. For example, the critical value for X2 with 8 degrees of freedom and 0.05 level of significance (X2.05, 8) is 15.51, which is lower than the calculated X2 for the entire model presented. Hence, the null hypothesis that all the coefficients, except the mode-specific constants, are zero is rejected.

### *Model Validation*

Model validation was conducted by using the calibrated model to predict model-split for data other than that used for model calibration. Three-hundred twenty-four observations for the social trips, two hundred seventy-two observations for the work trips and one hundred thirty observations for *Aumra* trips not used in model calibration were used to test model validity as in Table 1.

**Table 6. Pooled Mode-Choice Model.**

| Indep Variable | Estimate | T-Stat | STD.Error |
|---|---|---|---|
| 1 ASC-AIR | 1.936 | 5.472 | 0.354 |
| 2 ASC-BUS | 1.179 | 8.409 | 0.259 |
| 3 TIMEI | -.984652E-01 | -4.393 | 0.224137E-01 |
| 4 COSTT | -.214610E-02 | -6.091 | 0.352366E-03 |
| 5 DNCARB | 1.294 | 5.895 | 0.220 |
| 6 DFMLYC | 1.299 | 7.617 | 0.171 |
| 7 DDURTA | 0.194 | 1.391 | 0.140 |
| 8 DNATIONB | 0.687 | 3.343 | 0.206 |
| 9 HHINA | 0.175 | 4.819 | 0.363044E-01 |
| 10 DISTC | 2.105 | 8.866 | 0.237 |

LOG LIKELIHOOD = -857.851 LOG LIKELIHOOD (0) = -1339.78
RHO SQUARED = 0.359710 RHO-BAR SQUARED = 0.357259

Where:

| | | |
|---|---|---|
| ASC-AIR | = | Mode-specific constant for air |
| ASC-BUS | = | Mode-specific constant for bus |
| TIMEI | = | In-Vehicle time in hours |
| COSTT | = | Out-of-pocket cost |
| DNCARB | = | Dummy for number of cars for bus mode |
| DFMLYC | = | Dummy family for car |
| DDURTA | = | Dummy for duration for air |
| DNATIONB | = | Dummy nationality for bus |
| HHINA | = | Monthly household income for air |
| DISTC | = | Distance for car |

A test of reasonableness validation process was used first in model calibration phase. This process depends on the reasonableness of the model in terms of the expected coefficient signs, and the reasonableness of the parameters. For example, travel time and travel cost always have negative impacts on travel demand; no model which has a positive travel time or cost coefficient would be considered a reasonable or valid model.

Validation tests were conducted by the Likelihood Ratio Test statistic (LRTS). This test is asymptotically distributed as X2 (chi-squared) with degrees of freedom equal to the number of model parameters [13].

This test is used in the validation of the disaggregate mode choice model by restricting the parameters estimated from data j to be used to predict mode choice in data i for the same specification. The likelihood ratio test statistic (LRTS) is as follows:

$$LRTSi(Bj) = -2(LLi(Bj) - LLi(Bi))$$

where LRTSi(Bj) is Likelihood ratio test statistic, LLi(Bi) is the log likelihood that the behavior observed in data I was generated by the model estimated in data j (restricted parameters), and LLi(Bi) is the log likelihood for the model estimated in the same data i (unrestricted parameters). The degree of freedom of this test is equal to the number of restricted parameters.

**Table 7. Dhahran-Riyadh Corridor (With Train) Mode-Choice Model.**

| Indep Variable | Estimate | T-Stat | STD.Error |
|---|---|---|---|
| 1 ASC-AIR | -1.52 | -2.33 | 0.65 |
| 2 ASC-TRAI | 1.22 | 4.55 | 0.27 |
| 3 ASC-BUS | 0.13 | 0.34 | 0.39 |
| 4 TIMEI | -.51 | -3.29 | 0.15 |
| 5 COSTT | -.248607E-02 | -2.24 | 0.110779E-02 |
| 6 DFMLYC | 1.63 | 4.27 | 0.381402 |
| 7 HHINA | 0.27 | 3.17 | 0.865523E-01 |

LOG LIKELIHOOD = -201.016 LOG LIKELIHOOD (0) = -276.199
RHO SQUARED = 0.272208 RHO-BAR SQUARED = 0.264442

Where:

ASC-AIR = Mode-specific constant for air
ASC-TRAI = Mode-specific constant for train
ASC-BUS = Mode-specific constant for bus
TIMEI = In-Vehicle time in hours
COSTT = Out-of-pocket cost
DFMLYC = Dummy family for car
HHINA = Monthly household income for air

The results of the validation tests are presented in Table 8. This table shows that there is no significant difference between the observed behavior and the predicted behavior for mode choice for the validation because all of the calculated chi-square values are less than critical chi-square values of 20.09 for work trips and 23.20 for social and Aumra trips at a significance level of 0.01 and the associated degrees of freedom which is equal to the number of parameters in the models.

**Table 8. Validation Test Results.**

| Trip purpose | $X^2$ (chi-squared**)** |
|---|---|
| Work | 6.68 |
| Social | 20.3 |
| Aumra | 5.08 |

## Conclusions and Recommendations

A general approach to calibrate intercity disaggregate mode choice models in Saudi Arabia was presented. Three specific models were developed for Saudi Arabia. The specification of model utility will help in further study to concentrate on which data is needed as necessary. The main conclusions of the research are summarized as follows:

1. Behavioral mode-choice models were successfully built and validated with an independent sample for work, *Aumra* and social trips. Also, another model was built for Dhahran-Riyadh corridor where train alternative is available. These models indicated that in-vehicle travel time, out-of-pocket cost, number of family members traveling together, monthly household income, travel distance, nationality of the traveler, number of cars owned by the family played a role in decisions related to intercity mode-choices. The co-efficient estimates all had the expected signs, were statistically significant (at least at 10% level) and had satisfactory explanatory power (as revealed by the relatively high values of the p2 values). These models will be helpful in travel demand analysis for Saudi Airlines, Ministry of Communication, bus and train operators.

### *Recommendations*

Further areas of research recommended in this area are listed below:

1. Other aspects of intercity passenger demand, such as traffic generation, distribution and assignment should be studied. Some of these can be analyzed simultaneously using abstract mode models [5].

2. The phenomenon of mode-captivity, although investigated to some extent here, deserves a more extensive study. Problems related to captivity includes, first definition of captivity, its effects on model building and predictions. This phenomenon is similar to "brand loyalty" in marketing analysis and can perhaps be better analyzed through "time-series" rather than "cross-sectional" data. People are most likely to be affected by their past experiences in intercity travel. In future studies, at least an effort should be made to ask questions related to past trips and try to analyze the effect of past choices on the present ones.

3. Another possible area of research involves "stated preferences" as opposed to using "revealed preferences" used in this research [8]. These methods allow the analyst to extract much more information from each respondent including data from a non-existing mode (such as train for various corridors in Saudi Arabia).

4. Finally, it is very important for the transport industry to cooperate with university researchers in developing and applying the current planning technology. With their support, research will become more productive and useful.

***Acknowledgment***

The data used in this research project was collected during a research study supported by King Abdulaziz City for Science and Technology, whose support is gratefully acknowledged. The author also wishes to thank King Fahd University of Petroleum and Minerals for the support provided for this work.

**References**

[1] **Al-Ahmadi, H.M., Ergün, G., Al-Senan, S.H.** and **Ratrout, N.T.,** *Development of a National Intercity Modal Split Model for Saudi Arabia,* Final Report, King Abdulaziz City for Science and Technology, Riyadh, Saudi Arabia (September 1993).

[2] **Riyadh Traffic Directorate Site** "*http://www.rt.gov.sa/english/accidents1.php*" Riyadh, Saudi Arabia, (2005).

[3] **Ministry of Economy and Planning**, **Central Department of Statistics Site** (CDS), *http://www.planning.gov.sa/docs/DS2K23.htm* , Riyadh, Saudi Arabia, (2000).

[4] **Koppelman, F. S., Kuah, G.** and **Hirsh**, **M.,** *Review of Intercity Passenger Travel Demand Modeling: Mid-60's to the Mid-80's*, Department of Civil Engineering, Northwestern University, Draft copy (1984).

[5] **Kanafani, A.,** *Transportation Demand Analysis*, McGraw-Hill Book Company, New York (1983).

[6] **Watson, P. L.,** Predictions of Intercity Model Choice from Disaggregate Behavioral and Stochastic Models, *Highway Research Record,* **446**, pp: 28-35 (1972).

[7] **Watson, P. L.,** Comparison of The Model Structure an Predictive power of Aggregate and Disaggregate Models of Intercity Mode Choice, *Transportation Research Record,* **527**, pp: 59-65 (1974).

[8] **Ben-Akiva, M.T., Morikawa** and **Shiroishi**, **F.,** Analysis of the Reliability of Stated Preference Data in Estimating Mode Choice Models, *Selected Proc., 5th WCTR,* Vol. 4, Yokohoma, Japan, pp: 263-277 (1989).

[9] **Algarad, S. N.,** Disaggregate Mode Choice Modeling for Intercity Non-Business Travellers in the Saudi Arabia-Bahrain Corridor, *Unpublished Ph.D. Dissertation*, Indiana University, Bloomington, IN (1993).

[10] **McFadden, D.,** The theory and Practice of Disaggregate Demand Forecasting for Various Modes of Urban Transportation, *Emerging Transportation Planning Methods* (1978).

[11] **Ben-Akiva, M.,** Structure of Passenger Travel Demand Models, *Ph.D. Dissertation*, Department of Civil Engineering, MIT, Cambridge, Mass. (1973).

[12] **Ortuzar, J.** and **Willmusen, L.,** *Modelling Transport*, John Wiley & Sons Press, third edition (2001).

[13] **Ben-Akiva, M.** and **Lerman**, **S.R.,** *Discrete Choice Analysis*, MIT, Cambridge, Mass. (1985).

# بناء نماذج النقل بين المدن للمملكة العربية السعودية

**حسن مساعد الأحمدي**

*قسم الهندسة المدنية - جامعة الملك فهد للبترول والمعادن*

*الظهران 31261, المملكة العربية السعودية*

*المستخلص.* تم بناء عدة نماذج للنقل على مستوى العالم للتنبؤ باختيار المسافر لوسيلة نقل من بين عدة وسائل متاحة له. ونظراً لحجم الاستثمارات في قطاع النقل، يعتبر بناء هذه النماذج مهمًا جداً لمخططي هذا القطاع . وفي المملكة العربية السعودية تختلف الخصائص الاجتماعية والدينية والاقتصادية والثقافية للمسافرين بين المدن عن مثيلاتها في الدول الأخرى، ولهذا تهدف هذه الدراسة إلى تطوير نموذج لتخمين حصص وسائل النقل المستقبلية بين المدن في المملكة العربية السعودية. وتم جمع البيانات خلال استبانات باللغتين العربية والإنجليزية وزعت على عينات عشوائية من المسافرين في المطارات ومحطات النقل بالحافلات ومحطات البنزين الواقعة في منتصف الطرق بين مدن المملكة.

وتم استخدام طريقة معايرة النماذج الانفرادية لتطوير نماذج النقل بين المدن لرحلات العمل والعمرة والرحلات الاجتماعية. وأشارت نتائج المعايرة إلى إن مدة السفر داخل المركبة وتكلفة السفر والدخل، وعدد السيارات المملوكة والعمر والجنسية وحجم العائلة المسافرة و مسافة الرحلة تلعب دوراً في اختيار المسافر لوسيلة السفر. وتُمكن هذه النماذج صُناع القرار وشركات النقل من تقدير حجم الطلب المستقبلي على النقل بين المدن لكل وسيلة من وسائل السفر، وذلك لتطوير المرافق الخاصة بها حسب حجم الطلب والاستخدام الأمثل للإمكانات المتاحة.