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Sensitivity of Transport Mode Choice in Alexandria, Egypt

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***Abstract*—Transport mode choice in Alexandria has radically changed during the last decades, since many trips were shifted from public transport to private transport and informal public transport. This research aims at analyzing the sensitivity of transport mode choice in Alexandria under different transport policies and assess the impact on modal shift to public transport. For that aim, a Multinomial Logit Model for Alexandria has been developed, calibrated using Biogeme Software. Having validated the calibrated model, the behavior of modal split under different policies is analyzed. The proposed transport policies includes improving public transport attributes and/or increasing trip cost for other transport modes. The analyses results reveal that improving current public transport trip time and trip cost have moderate and minor effect on modal shift to public transport share respectively. Improving public transport utility constant has a significant effect, which can be achieved by introducing reliable, attractive, efficient and frequent public transport system. The impact of increasing private car, taxi and collective taxi trip cost on modal shift to current public transport is minor. The combination between the proposed push and pull policies may achieve a modal shift to public transport mode effectively.**

***Keywords*— Sustainability, Mobility, Multinomial Logit Model (MNL), Modal Split, Biogeme Software,**

I. Introduction

In many cities, particularly those in developing countries, urban transport conditions are getting worse. The travel demands have been continuously increasing as a result of rapid urbanization, rapid economic growth, high densities and overconcentration in the capital areas [1]-[2]. In addition, developing cities did not supply adequate road infrastructure and efficient public transport services to respond to travel demand growing trends [2].

Current public transport services are characterized by poor planning, unreliable time-table, inadequate line capacity, etc. Public transport attractiveness has been decreasing, in spite of it was the main mode of transport during the eighties [3]-[4].

Due to the absence of adequate public transport services, the transport system in many areas has been feeded by informal public transport services. For example, in Egypt the 14-seats collective taxi (called locally microbus) has become the main transport facility in Egypt [3]-[4].

All the above factors have changed the transport modal split significantly over the last decades, where private vehicle share and informal public transport share have increased considerably during the decline of public transport ridership [4]-[5]-[6]-[7].

A little has been done to test the effect of policy measures on shifting modal share in Alexandria. Hence, the objective of this research is to analyze the behavior of mode choice in Alexandria under different push and pull policies.

The structure of the article is as follows. After the introduction, existing situation in Alexandria is illustrated in the second section. The third section presents the structure of Alexandria Multinomial Logit Model (MNL). Fourth section illustrates data collection and analysis. Alexandria MNL model calibration and validation using Biogeme Software is shown in section five. Section six analyzes the behavior and sensitivity of the calibrated model to different push and/or pull policies. Finally conclusions of this research are stated.

II. Existing Situation

Alexandria is the second metropolitan area in Egypt, and one of the country's largest economic cities, it is bordered from the north by the Mediterranean Sea and from the south by Lake "Maryout" and rich farmland. Accordingly, the city has a coastal strip shape and the development is restricted to the east and to the west [8].

A. Urban Growth

Alexandria built-up area has grown by an average yearly growth factor equals 6.2% between 1987 and 1999 and 2.8% between 1999 and 2013 [9]. The recorded total number of buildings, total number of units and number of residential units have increased from 301,000 to 419,000, 1,183,000 to 2,073,000 and 845,000 to 1,702,000 respectively between 1996 and 2006 [10].

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B. Population Growth

Alexandria population has increased by 41% from 3.691 million to 5.217 million in the period between 2002 and 2018 [10]. Population growth in Alexandria is not only caused by normal population growth, but also internal immigration from rural to urban areas. Since the limited resources of the country maximize the major attention and investments towards big and urban areas. So that around 37% of population growth in Alexandria is caused by internal immigration [11].

C. Population Density

Population density has increased from 2,203 inhabitants per square km. of inhabited area in 2003 to 2,896 inhabitants per square km. of inhabited area in 2015 [10].

D. Urban Roadway

The total length of road network in Alexandria did not increase by a considerable growth rate during the last two decades. It has changed from 8,660 km to 9,337 km between 2005 and 2016 with an average annual growth rate 0.69% [10].

The urban road network in Alexandria was exposed to many unsustainable decisions that were taken to increase the roads' capacity, due to the rapid, random and unplanned urban growth of Alexandria during the last three decades. For example, footbaths and medians were minimized to increase the number of lanes for traffic and parking places. Currently, the road network has become inadequate for all; traffic, parking and pedestrians [11].

E. Modal Split

In 2016, Alexandria City, as shown Table I, had only 18% of motorized daily trips were completed using public transport [11], compared to 54% in 1985 [8]. This occurred due to the deterioration of public transport service quality. Since the priority of government funding is mainly directed to the construction and maintenance of roads, while public transport does not receive the same care. Public transport was exposed to many unreasonable decisions. For example, few public transport lines have been canceled on the assumption that public transport increases delays for private cars.

Passenger car ownership has changed from 78 cars/1000 inhabitants in 2010 to 86 cars/1000 inhabitants in 2017 with an average yearly growth factor equals 1.31% [10].

As public transport did not meet the rapid increase in transport demand. Since the eighties, the law in Egypt authorized private vehicles with maximum 14 seats to operate in urban areas as collective taxi. The routes (from terminal to terminal) and fares are defined by the local authorities.

The collective taxi network in Alexandria covers the whole city. It has expanded more on areas where bus supply is inadequate. The shared taxis are generally ill-maintained, randomly operated and play a major share in traffic congestion. Their stops between terminals are not previously defined, and the vehicles can stop anywhere, sometimes on major streets [11] [8].

TABLE I. MODAL SPLIT OF MOTORIZED TRIPS IN ALEXANDRIA IN YEARS 1985 AND 2016 [11] [8]

Year	Private Cars	Taxi	Collective Taxi	Public Transport	Other
1985	16%	11%	9%	54%	11%
2016	24%	3%	52%	18%	3%

III. Alexandria Mode Choice Model

The third step in the traditional transportation planning process is Mode Choice Modelling [12]. Discrete choice models are represented by a theory that is based on the utility maximization of a choice between transport modes. The higher the mode choice utility, the greater the possibility that this choice will be selected by the traveler.

In this research, a Multinomial Logit (MNL) Model for the City of Alexandria has been calibrated. MNL Models are mainly the most widely used model of discrete choice analysis. It was proposed for many researches and studies because of its ease of calibration and application. In addition, it showed satisfactory results in many applications. For the development of MNL model, maximum likelihood is regularly used for parameters estimation from a random sample of observations [12] [13] [14] [15] [16] [17] [18] [19].

In this study, four main choices will be modelled, which are Private Car (PC), Public Transport (PT), Taxi (T) and Collective Taxi (CT). Public transport modes were combined in one category to overcome Independence of Irrelevant Alternatives (IIA) property of MNL models [13] [16] [18].

The structure of Alexandria MNL model is as follows:

$$P_{PC} = \frac{e^{U_{PC}}}{e^{U_{PC}} + e^{U_T} + e^{U_{CT}} + e^{U_{PT}}}$$

$$P_T = \frac{e^{U_T}}{e^{U_{PC}} + e^{U_T} + e^{U_{CT}} + e^{U_{PT}}}$$

$$P_{CT} = \frac{e^{U_{CT}}}{e^{U_{PC}} + e^{U_T} + e^{U_{CT}} + e^{U_{PT}}}$$

$$P_{PT} = \frac{e^{U_{PT}}}{e^{U_{PC}} + e^{U_T} + e^{U_{CT}} + e^{U_{PT}}} \quad (1)$$

The attributes of utility function include trip time (βt) in minutes, trip cost (βc) in EGP, Taxi Constant (CT), Collective Taxi Constant (CCT) and Public Transport Constant (CPT).

Utility equation can be explained as [13]:

$$U_{PC} = \beta t \times TT_{PC} + \beta c \times TC_{PC}$$

$$U_T = C_T + \beta t \times TT_T + \beta c \times TC_T$$

$$U_{CT} = C_{CT} + \beta t \times TT_{CT} + \beta c \times TC_{CT}$$

$$U_{PT} = C_{PT} + \beta t \times TT_{PT} + \beta c \times TC_{PT} \quad (2)$$

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IV. Data Collection

In this research, the analysis was based on data samples taken from the Household Survey carried out during data collection stage of Alexandria Urban Transport Study [11].

The main purposes of the conducted household survey carried out during data collection stage of Alexandria Urban Transport Study include:

- Trip activity characteristics of the travelers; such as: number of trip purpose, car ownership, chosen mode, etc.
- Modal trip characteristics; such as: travel time and cost by mode, trip length by mode, etc.

Some of the survey characteristics are outlined below.

A. Sample size

The sample included 2,997 successfully collected responses and distribution reasonably among different transport modes.

B. Zoning system

As shown in Fig. 1, the adopted traffic zoning system in Alexandria Urban Transport Study included 17 main zones. These zones were disaggregated in 149 traffic zones.

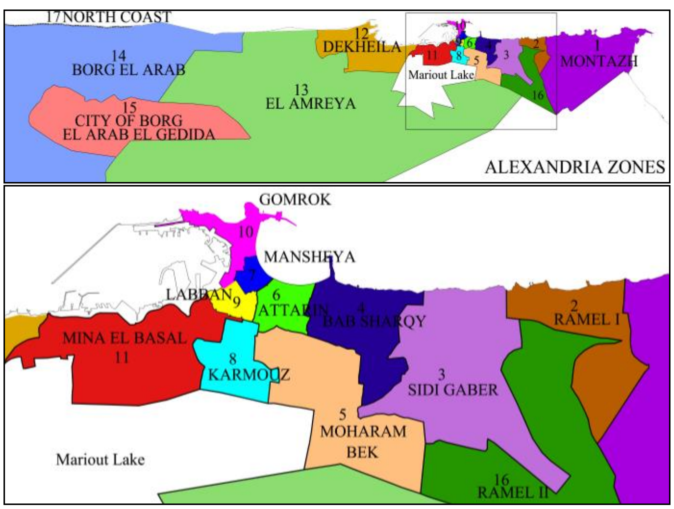

Figure 1. 17 Main zones of Alexandria [11]

C. Temporal Distribution

Temporal distribution shows the fluctuation of trips over the day. It increases the reliability of the collected sample as it reflects the current traffic condition. The distribution of trips over the day is shown in Fig. 2. The results show that two significant peaks are occurred at the morning and afternoon. The variation of purpose during the day is typical with work and education related trips being the vast majority in the morning and diminishing throughout the day as other purposes like shopping or leisure increase.

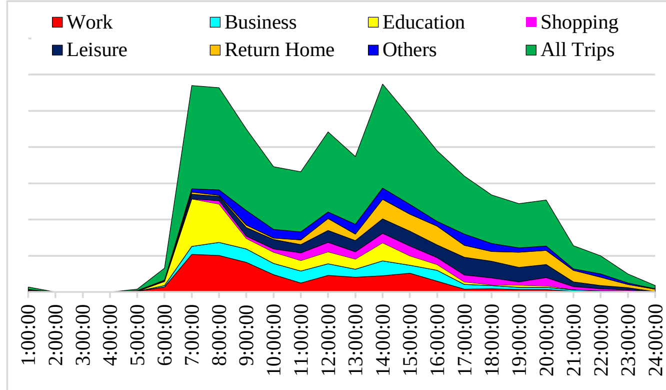

Figure 2. Distribution of collected sample over the day

D. Service Availability

The availability of service is one of the main parameters that affect the accuracy of calibrated mode choice models [13]. The availability of service for public transport modes is investigated at both the origin and destination of individuals' trips. Fig. 3 presents the results. It indicates that bus mode has the highest availability between different public transport modes in Alexandria, while the availability of City Tram and Abo Keer Railway is very limited.

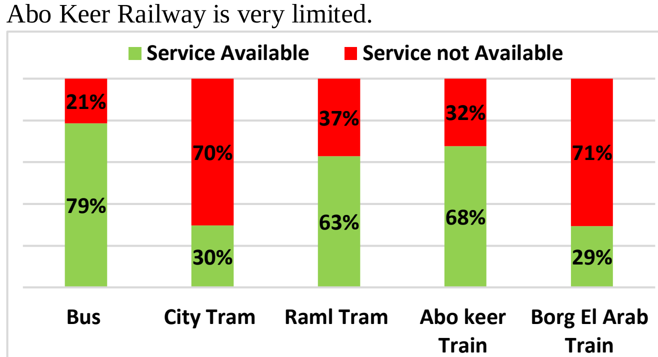

Figure 3. Service availability of public transport modes

E. Service Quality

The surveyed passengers have been asked for their appraisal of the quality of their trip (either good, fair or bad). The results stands out that, except for taxis, around 50% of the passengers appraise the quality of their trip as fair. The rail systems (Abo Keer + Borg El Arab) have the worst rank.

F. Speed Profile

The fluctuation of average speed for each transport mode is captured along the day, as shown in Fig.4, where the average speed during peak periods is lower than off peak periods. It is observed that the lowest average speed is recorded for public transport.

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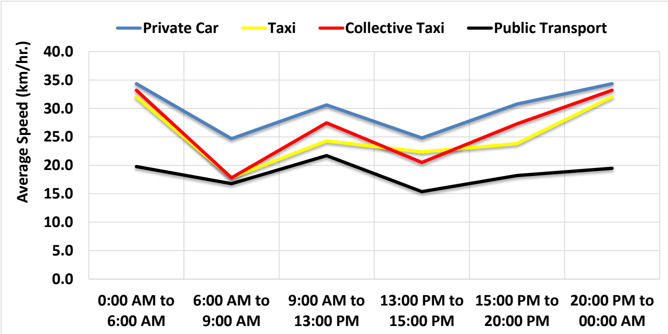

Figure 4. Average speed profile of main considered modes

V. Alexandria MNL Model Calibration and Validation

A. Model Calibration

Generally, the calibration process was performed using Biogeme software [20]. The software consists of two main files: model specification file and data file. Data are prepared for the input file, including the chosen alternative and non-chosen alternatives. Data include service availability, trip time and trip cost for each alternative, in addition to the chosen alternative

Service availability affects the calibration of mode choice model [13]. Private car mode availability was based on household car-ownership. Taxi and collective taxi modes were considered available for all sample since they are available everywhere in Alexandria. Public transport availability was investigated and taken into consideration.

Non-chosen alternative data were estimated based on the average survey results for each transport mode [13]. The average travel speed was used in calculating the trip time after estimating trip distance. Trip distance was calculated based on the airline distance between origin and destination and applying an adjustment factor equals 1.3 to reflect the difference between airline distance and actual distance, where it was estimated using Google Maps after getting the airline and actual distances of the same trip for a random sample of travelers. Trip cost for the non-chosen alternative was calculated using the survey average cost per distance for each transport mode and the estimated trip distance.

Having prepared Biogeme model specification and data files, model runs were conducted and the values of the coefficients as an output are presented in Table II below.

TABLE II. COEFFICIENTS VALUES OF THE CALIBRATED MODEL

Utility parameters	Value	t-test	p-value
Collective Taxi Constant (C_{CT})	-0.294	-2.73	0
Public Transport Constant (C_{PT})	-0.983	-8.43	0
Taxi Constant (C_{CT})	-1.54	-13.53	0
Trip Cost (β_C)	-0.0314	-8.42	0
Trip Time (β_T)	-0.00755	-9.75	0

Thus, the utility functions will take the following forms:

$$U_{PC} = -0.00755 \times TT_{PC} - 0.0314 \times TC_{PC}$$

$$U_{T} = -1.54 - 0.00755 \times TT_{T} - 0.0314 \times TC_{T}$$

$$U_{CT} = -0.294 - 0.00755 \times TT_{CT} - 0.0314 \times TC_{CT}$$

$$U_{PT} = -0.983 - 0.00755 \times TT_{PT} - 0.0314 \times TC_{PT}$$

The calibration results are as follows:

1) Checking coefficients signs

Coefficients of all variables have the expected logical signs. This appears in the negative signs of travel time and travel cost. This emphasizes the fact of the negative impact of these variables on the utilities of individuals. These signs imply that the greater the values of these variables, the less mode utility perceived by an individual will be.

2) t-statistic

As for the t-statistic, all coefficients are found to be statistically significant at the 5% level of significance as the t-statistic values for all parameters are greater than ± 1.96.

3) P-value

As for the P-value, all coefficients are found to be statistically significant at the 5% level of significance as the P-value values for all parameters are less than 0.05.

4) Goodness of fit measures

Goodness of fit measures are used to compare different specifications of the utility function. If everything else being equal, a specification with a higher maximum value of the likelihood function is considered to be superior. The value of the likelihood ratio index (ρ^2) is 0.251 while the adjusted likelihood ratio index ($\bar{\rho}^2$) is 0.249 and these values are considered satisfactory.

B. Model Validation

Value of time (VOT) is used to validate the calibrated model [13]. VOT is an important factor that reflect the local economic condition and validate the calibrated mode choice models [13]. The estimation of the value of time depends on the parameters of trip time and trip cost. For the calibrated model, the VOT equals 14.4 EGP/hr. The estimated VOT is compared with previous studies to validate the calibrated model. Ref. [21], 2013 estimated the VOT of Cairo calibrated model to be 9.4 EGP/hr. Ref. [13], 2017 estimated the VOT of Alexandria calibrated model to be 14.50 EGP/hr. In conclusion, the calibrated model allows to estimate the VOT for the city of Alexandria successfully.

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VI. Sensitivity Analysis

Having calibrated and validated Alexandria MNL model, it is used in carrying out sensitivity analysis to estimate the effect of different policies in the share of the transport modes for the aim of calculating percentage of passengers intended to switch to the public transport from current modes under different polices. To conduct the targeted application, two approaches are tested firstly on the do-nothing scenario to understand the effect of public transport service availability on the modal split in Alexandria. These are:

1- Application on the aggregate model and
2- Application on Alexandria origin-destination daily matrix

The first approach is used during the absence of detailed data. All transport modes are assumed available. The average trip time and trip cost of each mode are applied in the utility function of the MNL model.

The second approach is applied on the origin-destination matrix (O.D matrix). The application was performed on Alexandria daily O.D matrix between each origin and destination (149x149). As the developed MNL model was based on the survey conducted along the whole day, it was urgent to apply this application on the daily matrix. The daily matrix was not available, so the peak hour matrix was first transposed to reflect the off-peak hour behavior. Then the average matrix of both peak hour matrix and the transposed peak hour matrix were uplifted using the peak hour factor that extracted from the survey which equals 0.15 between each pair of zones.

The transport modes trip time and trip cost were calculated based on the survey average speed and trip cost rate of each one and using the airline distance between each O.D pair and applying an adjustment factor equals 1.3 like the calibration process. Private car, taxi and collective taxi were considered available at all O.D pairs, while service availability of public transport was investigated.

The application results of the two approaches show that the share of public transport is affected by assuming the service is available. The results show that public transport share in the aggregate model application equals 20% while it equals 17% in the O.D matrix application. As a result, the second approach is used in the sensitivity analysis application.

Sensitivity test is performed for Alexandria MNL model by varying model inputs and checking results for reasonableness.

Decreasing the preference of commuters towards the use of private vehicles, taxi and collective taxi along with encouraging the use of public transport are the most sustainable way to reduce traffic congestion on roadways than investing heavily in constructing new infrastructure.

In this context, few policies were synthesized and sensitivity analysis was conducted based on the calibrated Alexandria MNL model to investigate the implications of such policies on modal shift.

The tested policies include three scenarios as follows:

Scenario 1: Pull Policies
Scenario 2: Push Policies
Scenario 3: Scenario 1 and 2 combined.

A. *Scenario 1: Pull Policies*

In this research, pull policies included improving public transport trip time, trip cost and constant for the aim of increasing public transport share.

As shown in Fig. 5, the effect of improving public transport constant is the highest, while the effect of trip cost is the lowest. The reduction of 50% of public transport trip cost, trip time and constant developed an increase in public transport share from 16.94% to 17.34%, 19.59% and 24.43% respectively. The effect of constant improvement on public transport share can be considered significant, while the effect of trip time and trip cost reduction can be considered moderate and minor respectively.

Improving public transport constant may be achieved by upgrading public transport system to new attractive, modern, efficient and comfortable public transport system, having reliable timetable, strong accessibility and connectivity and supported pedestrian facilities.

The maximum effect on other transport modes is noticed for collective taxi. As shown in Table III, 50% reduction of public transport constant may decrease collective taxi usage by 3.57%, while the decrease is 3.38% for private car and 0.53% for taxi.

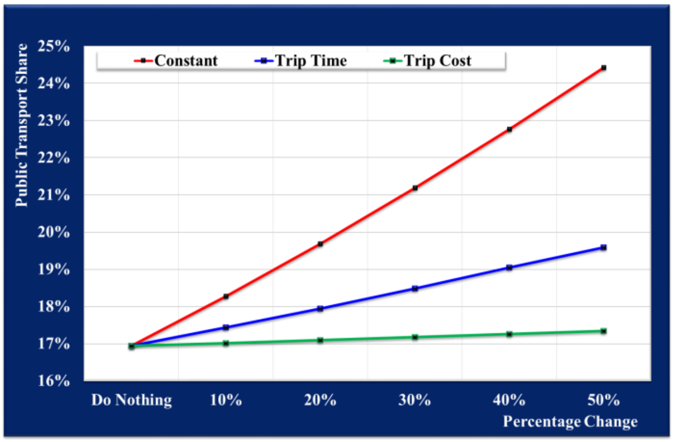

Figure 5. Effect of decreasing public transport trip time, trip cost and constant on public transport share

TABLE III. EFFECT OF DECREASING PUBLIC TRANSPORT TRIP TIME, TRIP COST AND CONSTANT ON MODAL SPLIT

Case	Modal Split			
	Private Car	Taxi	Collective Taxi	Public Transport
Do-nothing	37.42%	5.95%	39.69%	16.94%
50% Trip Time Reduction	36.48%	5.84%	38.09%	19.59%
-50% Trip Cost Reduction	37.27%	5.93%	39.46%	17.34%
-50% Constant Reduction	34.04%	5.41%	36.12%	24.43%

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B. Scenario 2: Push Policies

Push policy included increasing private car, taxi and collective taxi trip cost.

As shown in Table IV, the impact of increasing private car, taxi and collective taxi trip cost is minor on current public transport. This can be explained as the value of collective taxi constant is significantly higher than public transport constant, thereafter private car and taxi users prefer shift to collective taxi rather than public transport. The 50% increase of private car, taxi and collective taxi trip cost may increase public transport share by 2.05%, while collective taxi share may be increased by 2.67%. Hence it can be concluded that this policy has failed to make a considerable shift to public transport because of the strong value of collective taxi mode constant compared to public transport mode constant.

TABLE IV. EFFECT OF INCREASING PRIVATE CAR, TAXI AND COLLECTIVE TAXI TRIP COST ON MODAL SPLIT

Policy	Modal Split			
	Private Car	Taxi	Collective Taxi	Public Transport
0%	37.42%	5.95%	39.69%	16.94%
10%	36.61%	5.73%	40.30%	17.36%
20%	35.83%	5.53%	40.87%	17.77%
30%	35.08%	5.33%	41.40%	18.18%
40%	34.36%	5.16%	41.90%	18.59%
50%	33.66%	4.99%	42.36%	18.99%

C. Scenario 3: Push and Pull Policies

This scenario included all the above pull and push policies in scenario 1 and scenario 2 (improving public transport trip time, trip cost and constant along with increasing private car, taxi and collective taxi trip cost).

As shown in Table V, the effect of 50% has a major effect on public transport share as its share may be increased from 16.94% to 30.68%, while private car, taxi and collective taxi share may be decreased by 8.16%, 1.56 and 4.02% respectively.

TABLE V. EFFECT OF ALL POLICIES OF SCENARIO 1 AND SCENARIO 2 COMBINED ON MODAL SPLIT

Policy	Modal Split			
	Private Cars	Taxi	Collective Taxi	Public Transport
0%	37.42%	5.95%	39.69%	16.94%
10%	35.80%	5.61%	39.25%	19.34%
20%	34.16%	5.29%	38.58%	21.97%
30%	32.52%	4.98%	37.76%	24.75%
40%	30.88%	4.68%	36.78%	27.67%
50%	29.26%	4.39%	35.67%	30.68%

VII. Conclusions

This research aimed at analyzing the sensitivity of transport mode choice in Alexandria. Firstly, a MNL mode choice model for Alexandria have been developed and calibrated using Biogeme software. Having validated the calibrated model, two approaches are tested firstly on the do-nothing scenario to explore the effect of public transport service availability on the modal split in Alexandria.

In approach 1 the share of each transport mode was estimated from an aggregate model using the utility function of each mode and assuming the service is available. In approach 2, they were estimated from a zoning-based application applied on Alexandria origin- destination daily matrix between each origin and destination that equals **149x149 O.D pairs**, including the investigation of service availability. The application results for the do-nothing scenario shows that the share of public transport in approach 1 is greater than the share in the second approach. As a result, the second approach is used in the sensitivity analysis application to avoid any overestimation of public transport share after adding the pull and/or push policies.

Then three different pull and/or push policies were suggested and tested. Scenario 1 included improving public transport attributes for the aim of increasing public transport share. Scenario 2 included increasing private car, taxi and collective taxi trip cost for the aim of restricting their usage. Scenario 3 included all the pull and push policies considered in scenario 1 and scenario 2.

The analysis results of scenario 1 revealed that the improvement in public transport constant has significant effect on public transport share, while it is moderate and minor for trip time or trip cost. Improving public transport constant may be achieved by upgrading public transport system to new attractive, modern, efficient and comfortable public transport system, having reliable timetable, strong accessibility and connectivity and supported pedestrian facilities.

For scenario 2, it can be concluded that the impact of increasing private car, taxi and collective taxi trip cost is minor on current public transport. This can be explained as the value of collective taxi constant is significantly higher than public transport constant, thereafter private car and taxi users prefer shift to collective taxi rather than public transport.

Scenario 3 may be considered the most effective approach.

In conclusion, travelers currently in Alexandria prefer choosing private car and collective taxi rather than public transport. For collective taxi users, the availability of service along the day, service headway, vehicle capacity and number of stops are the main reasons.

On the other hand public transport has very low level of service, in terms of delays, timetable reliability, passing priority at intersections, comfort and seat availability. The only reason of the current public transport usage may be the very low trip cost rate compared to transport modes. So, it can be concluded that most of public transport riders in Alexandria are from the lowest income levels. For private car users, they are from the highest income level and the current public transport system does not match their needs largely.

Finally, it is recommended to apply strong pull and push policies to develop a major sustainable shift towards public transport in Alexandria. Pull policies should be proposed basically on upgrading public transport service by attracting

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travelers to new modern, efficient and comfortable public transport systems, which should have reliable timetable, strong accessibility and connectivity and supported by intelligent transportation systems and pedestrian facilities.

Push policies may include an effective approach to restrict the use of private car and collective taxi modes. The current cross section of road network should be redesigned to dedicate exclusive lanes for rapid public transport while the rest of lanes are kept for other modes of transport. Parking should be limited in the city center or prevented in high congested areas. Collective taxi service should be limited along the main public transport routes. Pedestrian areas and free-emission zones should be applied in Alexandria city center.

Finally, it is greatly important to carry out a Stated Preference Survey to capture the traveler's behavior to the above major policies. Also the new model should be developed based on market segmentation approach based on income level and/or car ownership. It is significantly required in Alexandria to carry out a deep analysis on the issue of mode choice and mode captivity of each people level.

In addition, the calibrated MNL model in this research has combined all public transport modes in one category to overcome the IIA property, accordingly it is recommended to develop a Nested Logit (NL) model for Alexandria to represent all different public transport modes in the model structure.

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