Application of a Simultaneous Transportation Equilibrium Model to Intercity Passenger Travel in Egypt

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Safwat and Magnanti have developed a combined trip-generation, trip-distribution, modal-split, and trip-assignment model that can predict demand and performance levels on large-scale transportation networks simultaneously, that is, a Simultaneous Transportation Equilibrium Model (STEM). The major objective in this paper is to assess the behavioral applicability of the STEM methodology by using it to analyze intercity passenger travel in Egypt. Though results were greatly influenced by the misspecification of the trip-distribution model (particularly its attractiveness measure) and the existence of severe fleet capacity constraints (particularly along the Cairo-Banha-Tanta corridor in the middle Delta region), there were strong indications that the approach was able to predict rational behavioral responses of users to policy changes in the system. Appropriate modifications to current specifications, which can easily be incorporated within the STEM framework, were suggested. Computational issues of the application are addressed in detail in a companion paper by Safwat in this Record.

Modeling of transportation systems must invariably balance behavioral richness and computational tractability. Safwat and Magnanti *(1)* developed a combined trip-generation, trip-distribution, modal-split, and trip-assignment model that can predict demand and performance levels on large-scale transportation networks simultaneously, that is, a Simultaneous Transportation Equilibrium Model (STEM). Moavenzadeh et al. *(2)* developed a methodology for intercity transportation planning in Egypt with the STEM as one of its central components.

In this paper, the major objective is to assess the behavioral applicability of the STEM methodology. The main concern is assessing the ability to represent observed behavior and to predict behavioral changes. Computational issues of the application are addressed in detail in a companion paper by Safwat in this Record.

To achieve this objective, the STEM approach was applied to a real-world transportation network, the Egyptian intercity transportation system. In the next section, a STEM is briefly introduced. Next, the major issues related to intercity passenger travel in Egypt are presented. Then the focus is on the behavioral modeling of passenger transport on the system and the design of a case study. The results of the application are discussed last, followed by a summary and conclusions.

A STEM

In this section the behavioral assumptions and formulations of the components of a STEM are briefly introduced. For a detailed description, the reader is referred to the paper by Safwat and Magnanti *(1)*. It should be emphasized at this point that although the assumptions of individual components of the STEM are not necessarily new, it is their internally consistent combination and simultaneous prediction that distinguishes a STEM formulation from other approaches.

Trip distribution is given by a logit model whose measured utility functions include the average minimum origin-destination (O-D) travel costs as variables with linear parameters. That is,

$$T_{ij} = G_i \frac{\exp(-\theta U_{ij} + A_j)}{\sum\limits_{k \varepsilon D_i} \exp(-U_{ik} + A_k)} \quad \text{for all } ij \varepsilon R$$

where

T_{ij} = number of trips distributed from origin i to destination j,
G_i = number of trips generated from origin i,
U_{ij} = average minimum travel cost from i to j,
A_j = attractiveness measure of destination j,
θ = parameter that measures the sensitivity of travelers to O-D travel costs,
D_i = set of destinations accessible from origin i, and
R = set of all O-D pairs ij.

Trip generation is given by any general function as long as it is linearly dependent on the system's performance through an accessibility measure based on the random utility theory of travel behavior (i.e., the expected maximum utility of travel). That is,

$$G_i = \alpha S_i + E_i \quad \text{for all } i \varepsilon I$$

$$S_i = \max\,[0, \ln \sum_{j \varepsilon D_i} \exp(-\theta U_{ij} + A_j)] \quad \text{for all } i \varepsilon I$$

where

S_i = accessibility variable that measures the expected maximum utility of travel for travelers at origin i,

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E_i = given minimum trip generation from i due to socioeconomic and land use forces,
α = parameter that measures the sensitivity of travelers to accessibility of the system, and
I = set of origins in the network.

Modal split and traffic assignment are simultaneously user optimized [the STEM framework allows for modal split to be given by a logit model or to be system optimized together with traffic assignment *(3)*].

In the following sections, the issues involved in the application of this STEM to intercity passenger travel in Egypt are addressed.

INTERCITY PASSENGER TRAVEL IN EGYPT

For more details the reader is referred to *Egypt National Transport Study,* Phase 1 *(4)* and Phase 2 *(5)*; papers by Safwat *(3, 6)*; and *Egypt Intercity Transport Project (7)*.

Existing modes for intercity passenger travel in Egypt include private car, taxi, and bus on a highway network with a total length of about 28,500 km, of which 15,000 km is paved. There are also different types of service on the railway network, which is owned by the Egyptian Railway Authority and has a total route length of about 3,260 km, excluding the Sinai lines.

Historically, rail was the dominant mode. During the last decade, however, rail has been quickly losing its position in favor of an increasingly competitive mode, the taxi. Table 1 shows the passenger kilometers produced in 1974 and 1979 by each mode in the system. In 1974 the system produced 23.5 billion passenger-km, of which 55 percent was produced by rail, 22.5 percent by taxi, 14.5 percent by bus, and 8 percent by private car. In 1979 the system produced 34.5 billion passenger-km (i.e., an increase of 12 billion passenger-km compared with 1974); only 0.9 billion passenger-km of this increase was absorbed by rail, whereas 6 billion passenger-km (i.e., one-half of the increase) was attracted to the taxi. As a result, the rail share dropped from 55 to only 40 percent and the biggest increase was for the taxi, from 22.5 to 33 percent. In terms of the number of passenger trips in 1979 (Table 2), the taxi had the highest share, 37 percent, followed by rail at 30 percent only. Netherlands Engineering Consultants (NEDECO) predicted that this trend was expected to continue for at least five more years *(5)*.

TABLE 1 PASSENGER TRANSPORT, 1974 AND 1979

	Passenger Kilometers (billions)			
	1974		1979	
Mode	No.	Percent	No.	Percent
Private car	1.9	8.0	3.0	9.0
Taxi	5.3	22.5	11.3	33.0
Public bus	3.4	14.5	6.4	18.0
Railway	12.9	55.0	13.8	40.0
Total	23.5		34.5	

This trend is strikingly counterintuitive because rail has extremely low tariffs compared with other modes. Table 3 shows revenues generated and financial costs incurred in milliemes (MM) per passenger-km by mode. In 1979, the rail revenues were 2.37 MM per passenger-km compared with 12.40 MM for taxi. The severity of the problem facing rail is evident given that the financial costs incurred were more than twice the generated revenues, which indicates a large deficit (see Table 3). The problem is becoming even more serious over time because of the rapid increase of demand, estimated at about 9 percent annually during 1974–1979.

The major constraint on the Egyptian Railway is a severe limitation on fleet capacity. NEDECO *(5)* found that between 20 and 30 percent of all rolling stock registered as book stock in 1979 was beyond repair. Officials added that by 1982, about 82 percent was estimated to be beyond repair. The lack of sufficient tractive power was believed to be the main source of limitation. In July 1976 only 889 trains ran and 2,699 were cancelled, 2,614 of them for lack of locomotives *(4)*.

Therefore, in the modeling and analysis of intercity passenger travel in Egypt, fleet capacity constraints must be accounted for in a satisfactory fashion. This is addressed in the next section.

BEHAVIORAL MODELING OF THE EGYPTIAN INTERCITY PASSENGER TRANSPORT SYSTEM

Modeling the Egyptian system to address the major issues indicated in the preceding section involves four major tasks: (a) the definition of passenger type–choice set mapping, (b) the specification of modal split and traffic assignment behavior and network representation, (c) the development of performance functions, and (d) the calibration of demand functions.

Passenger Type–Choice Set Mapping

Passengers may be classified into three types according to their income level: high, middle, and low. Transportation services may also be classified according to their level-of-service attributes such as travel time, tariff, comfort, safety, and so on. In

TABLE 2 PASSENGER TRANSPORT, 1979 *(5)*

	Passenger Trips (millions)		Passengers Kilometers (billions)		Avg Distance
Mode	No.	Percent	No.	Percent	(km)
Private car	47.3	8.0	3.0	9.0	63
Taxi	215.8	37.0	11.3	33.0	52
Public bus	146.3	25.0	6.4	18.0	44
Railway	174.2	30.0	13.8	40.0	79
Total	583.6		34.5		59

TABLE 3 REVENUES AND COSTS OF INTERCITY PASSENGER TRANSPORT IN EGYPT, 1979

Mode	Revenues (milliemes/ passenger kilometer)	Financial Costs (milliemes/ passenger kilometer)
Railway	2.37	6.41
Air-conditioned	4.94	19.9
Non-air-conditioned	2.14	5.22
Bus (52 seats)	6.65	6.65
Taxi	12.40	12.40

fact, service types on the Egyptian system are designed so that each is most suitable for a particular income level. Available services in the system may be categorized as taxi, lux bus (an aggregation of several types of bus service that are considered "excellent," "good," or "sufficient"), normal bus (an aggregation of two types of bus service—"moderate" and "poor"), diesel train [includes first- and second-class air-conditioned (AC) service], express train (includes all types of service on rail ranging between first- and second-class AC to second- and third-class non-AC), and local train (exclusively third-class non-AC service).

In the analysis, it is assumed that a "mapping" exists between passenger income types and transportation service types (choice sets). The required mapping, based on a quality index associated with each service type [from NEDECO *(5)* and discussions with Egyptian transport experts], is defined in Figure 1.

In Figure 1, solid lines indicate main modes and dashed lines indicate modes that may be selected by the particular passenger type whenever capacity is limited on the main modes. The mapping shown is further refined within the train types. The complete mapping may be summarized as follows:

1. Low-income passengers may select among local train, express train (third class only), normal bus, and taxi;
2. Middle-income passengers may select among express train (second class AC and non-AC), taxi, lux bus, and diesel train (second class AC only); and
3. High-income passengers may select among automobile, diesel, lux bus, express train (first class AC only), and taxi.

In this paper, analysis is focused on low-income passengers only, because they represent the majority of users in the system (about 80 percent of train users, 75 percent of bus users, and more than 65 percent of systemwide users have low incomes). Excluding other passenger types is expected to influence the results. Proper definition of low-income mapping, however, should overcome some of these inaccuracies.

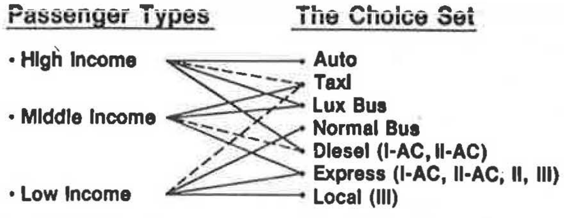

FIGURE 1 Passenger type–choice set mapping.

Multimodal Composed Networks

Because of the existence of transfer between transport modes in the middle of any given trip and because passengers travel as individuals or in small groups, modal split and traffic assignment on the Egyptian system are assumed to occur simultaneously in accordance with the user optimization principle of user behavior. With these behavioral characteristics (i.e., transfer between modes and user optimization behavior) the network may be best represented as a multimodal composed network. An example of such a composed network is shown in Figure 2.

The network in Figure 2 consists of two modal networks, express train and normal bus, connected through three zonal centroids with loading and unloading links that reflect the allowable types of transfers between these two modes at each of the three zones. For example, the leftmost zone is a destination only, whereas the rightmost one can be origin or destination for both modes.

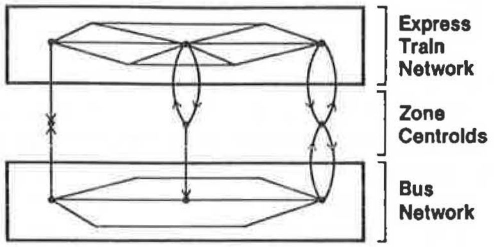

FIGURE 2 Example of multimodal composed network.

In the analysis, four major modal networks were created for express train, local train, taxi, and normal bus. Figure 3 shows one of these modal networks (that for the taxi). There were 24 zones, each represented by its centroid identified with a four-character name that corresponds to the name of its governorate whenever possible, as shown in Table 4. Points of transfer were assumed to be any zone centroid that is accessible to a given mode. For the purpose of analysis, three composed networks were specified. A brief description of each is as follows:

Network	*Modes*	*No. of Links*	*No. of Nodes*
NET1	Express, local trains	244	90
NET2	Express, local trains; normal bus	394	125
NET3	Express, local trains; normal bus and taxi	534	152

Link Performance Functions

System performance may be perceived by users through a set of generalized cost functions. For any given trip, average perceived cost may include travel-time cost, tariff cost, cost of

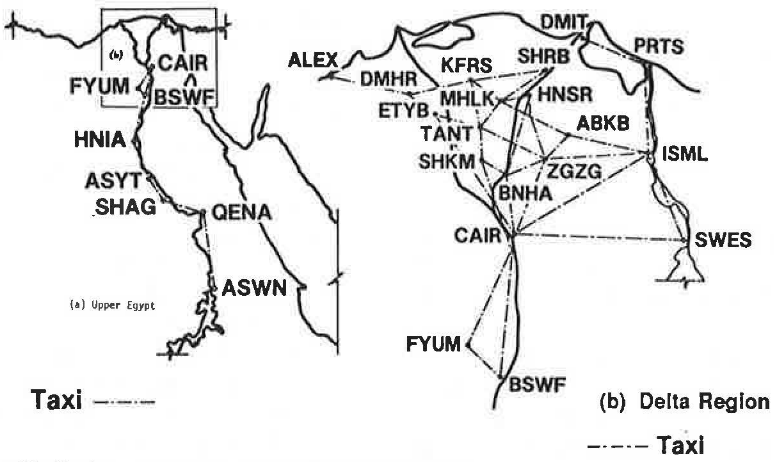

FIGURE 3 Egyptian intercity taxi network.

delay at intermediate nodes, and loading-unloading cost. The average perceived cost depends on several factors, such as system use, design, and operating policies, which may vary among different links and modes on the network. Therefore, performance functions are defined at the level of modal links on the composed networks.

A typical modal link User Perceived Cost (UPC) function, travel-time cost, is the value of time multiplied by the average travel time. The value of time is dependent on the average annual income and was estimated at 0.15078 L.E./hr for the low-income group [based on figures from NEDECO (*5*, Annex II, pp. 3.27 and 3.29)]. Average travel time depends on link free-flow speed (which in turn is a function of link design and classification) and mode type (as reflected through a modal speed factor). The highway classes, railway classes, and modal speed factors were obtained from the Intercity Project *(7)*. The speed factors for taxi and bus were assumed to include delay at intermediate nodes. For express and local trains, delays at intermediate nodes were assumed to depend on the importance of the node as determined by the Intercity Project *(7)*.

TABLE 4 ZONING SYSTEMS

NEDECO Zoning System			Safwat Zoning System[a]
No.	Zone (Governorate) Name	Zone Centroid	
1	Cairo central business district	Cairo-CBD	CAIR
2	Giza	Giza	–
3	Galyubia	Banha	BNHA
4	Sharkia (South)	Zagazig	ZGZG
5	Sharkia (North)	Abu-Kebir	ABKB
6	Dakahlia (East)	Mansoura	MNSR
7	Dakahlia (West)	Sherbin	SHRB
8	Domiat	Domiat	DMIT
9	Port Said	Port Said	PRTS
10	Ismailia	Ismailia	ISML
11	Swes	Swes	SWES
12	Minufia	Shebin El-Kom	SHKM
13	Gharbiya (South)	Tanta	TANT
14	Gharbiya (North)	Mahalla Kubra	MHLK
15	Kafr El-Shaikh	Kafr El-Shaikh	KFRS
16	Beheita (South)	Etay Baroud	ETYB
17	Beheira (North)	Damanhour	DMHR
18	Alexandria	Alexandria	ALEX
19	Western Desert	Marsa Matrah	–
20	Sinai	E-Swes Tunnel	–
21	El-Fayum	Fayum	FYUM
22	Bani-Swaif	Bani-Swaif	BSWF
23	El-Minia	Minia	MNIA
24	Asyut	Ayut	ASYT
25	New Valley	New Valley	–
26	Sohag	Sohag	SHAG
27	Qena	Qena	QENA
28	Aswan	Aswan	ASWN
29	Red Sea Coast	Port Safaga	–

[a] Abbreviations of zone centroid names.

As far as traffic congestion is concerned, it is assumed that on the railway it is captured through the definition of "practical speed" on different track classes. On the highway, NEDECO *(5)* calculated the volume/capacity (V/C) ratio for 80 intercity roadway sections; 80 percent of these were found to have V/C ratios less than 0.5. Hence, it is assumed that traffic congestion on the Egyptian intercity highway network may be ignored.

Tariff cost is estimated by multiplying the tariff per unit distance by the link length. Tariff per unit distance was approximated by the Intercity Project *(7)* because the actual tariff structure is distance-dependent.

Loading and unloading costs are the delays multiplied by the value of time. The average loading and unloading delays associated with different modes at different zones in the system were estimated by the Intercity Project *(7)*. These delays were difficult to estimate and the available information may be considered "crude" estimates.

The fleet capacity constraint on the Egyptian system may have been dealt with accurately by introducing a set of mathematical constraints to the optimization formulation. Such constraints, however, are generally nonconcave or nonconvex functions of the vector of flows of all user types on a given mode, and hence the addition of such constraints to the optimization problem will create computational difficulties. In this application, an approximate solution to the problem is suggested by introducing a term in the link UPC function that drives the user cost to a very high value whenever that capacity is exceeded. Similar approximations to deal with the problem of hard link capacity constraints have been suggested by several researchers [Daganzo *(8)* and Hearn *(9)*]. In this application, however, "capacity" refers to the available fleet capacity for a given user type on a given modal link, which may be calculated given the passenger type–choice set mapping, train composition, load factors, and daily schedule *(3)*.

Demand Functions

As indicated earlier, trip generation is given by a general linear model and trip distribution is given by a logit model. The calibration of these demand functions was based on data from NEDECO *(5)*.

The main types of data required for calibration are O-D matrices of trips and costs and socioeconomic data of passengers and zones. Available data include O-D matrices for automobile, taxi, bus, and rail trips in 1979; O-D distance matrix; and zonal population divided into urban and rural *(5)*. The O-D matrices of trips include synthesized items for highway modes and estimated values for about 50 percent of railway passenger movements based on a sample survey. This weakens their reliability. In addition, it is clear that socioeconomic data are very limited. Furthermore, O-D cost matrices are not available.

In the Intercity Project *(7)* a trip-distribution model was specified as follows:

$$T_{ij} = G_i \; \frac{\exp(-\theta_0 \, d_{ij} + \theta_1 \, \ln D_j)}{\sum\limits_k \exp(-\theta_0 \, d_{ik} + \theta_1 \, \ln D_k)}$$

where

d_{ij} = distance between zones i and j (km),
D_j = number of trips attracted to j (per day), and
θ_0, θ_1 = parameters to be estimated.

This trip-distribution model was calibrated within the Intercity Project *(7)* by Abdel-Nasser for each of the four major modes: automobile, taxi, bus, and rail, using the Gaussian least-squares method.

The corresponding calibration results for the trip-distribution model for low-income passengers are obtained by computing a weighted average of θ_0 and θ_1 where the weights correspond to the modal split of low-income groups between bus and rail as obtained from the modal-split survey conducted in 1979 by NEDECO *(5)*. That is,

$$(\theta_i)_{\text{low}} \;=\; \frac{0.75}{0.75 + 0.80}\,(\theta_i)_{\text{bus}} + \frac{0.80}{0.75 + 0.80}\,(\theta_i)_{\text{rail}}$$

where $i = 0$ and 1.

The results of this calculation imply the following values of θ_0 and θ_1 for low-income passengers: $\theta_0 = 0.01402$ and $\theta_1 = 1.1044$. To estimate the parameter θ so that $\theta_0 d_{ij} = \theta \, U_{ij}$ (recall that U_{ij} is minimum travel cost from i to j), reasonable estimates of U_{ij} for selected O-D pairs were obtained by assuming free-flow conditions (i.e., from the initial solution of the algorithm); a weighted average of those values was then computed, yielding $\theta = 1.50714$.

As far as the trip-generation model is concerned, the observed trip generation for the low-income group, G_i^o, was estimated as the weighted average of bus and rail trip generation based on the modal-split survey results by NEDECO *(5)*. The corresponding accessibility, S_i^o, was computed as the natural logarithm of the denominator of the trip-distribution model (by definition). The minimum trip generation, E_i, was assumed to represent about 90 percent of trips of the low-income group (i.e., there is a large portion of low-income passengers who must travel for socioeconomic reasons). That is, $E_i = 0.90 \, G_i^o$ for all i. A parameter α_i was then estimated for each origin. Table 5 shows the values of G_i^o, S_i^o, E_i, and α_i for the 24 zones of this study. In the table, α_i is observed to be large for the major generators of traffic in the system (i.e., Cairo, Banha, Shebin Kom, and Alexandria). For the remaining zones, α_i is almost consistently less than 200. In this study, an $\alpha = 200$ was assumed; this would lead to underestimating total demands from the major generators.

BEHAVIORAL ASSESSMENT

In this section the applicability of the STEM methodology is assessed from the behavioral point of view. This includes assessment of the ability to represent observed behavior and to predict behavioral changes.

It should be mentioned at the outset that the behavioral capabilities of the STEM depend upon the state of the art of modeling travel behavior, the behavioral assumptions of the STEM itself, the ability of modeling behavior on the particular system, the availability and reliability of appropriate data, and the existence of special peculiar features on that system. The major limitation in relation to the state of the art is the lack of a well-defined theory of trip-generation and trip-distribution behavior. The STEM itself stands somewhere in the middle of the range of behaviorally acceptable transportation planning models. The behavioral modeling of the Egyptian intercity system

TABLE 5 TRIP GENERATION DATA

Zone	G_i^o	S_i^o	E_i	α_i
CAIR	125,540.	9.363	112,986.	1,340
BNHA	81,240.	9.9286	73,116.	818
ZGZG	20,178.	9.9134	18,160.	204
ABKB	6,803.	9.9134	6,123.	69
MNSR	21,004.	9.6107	18,904.	212
SHRB	9,700.	9.6107	8,730.	101
DMIT	6,494.	8.894	5,845.	73
PRTS	2,323.	8.3537	2,091.	28
ISML	7,846.	9.1587	7,061.	86
SWES	2,580.	8.5713	2,322.	30
SHKM	33,200.	10.0362	29,880.	331
TANT	38,677.	9.3537	34,809.	414
MHLK	9,781	9.3537	8,803.	105
KFRS	11,706.	9.538	10,535.	123
ETYB	6,000.	9.334	5,400.	64
DMHR	13.682.	9.334	12,314	147
ALEX	26,615.	8.5737	23,954	310
FYUM	11,226.	8.9846	10,103.	125
BSWF	13,751.	8.7727	12,376.	157
MNIA	6,237.	7.3347	5,613.	85
ASYT	9,867.	6.31	8,880.	156
SHAG	6,934.	5.948	6,241	117
QENA	6,062.	4.9553	5,456.	122
ASWN	2,834.	2.4167	2,550.	118

(see previous section) appears to be reasonable in some, but not all, of its components. The main areas of limitation appear to be the calibration of demand models (because of the lack of theory and supportive data), the estimation of loading and unloading delays (because of the considerable amount of research and data collection efforts required to obtain better estimates), and the modeling of fleet capacity constraints (because of the limitations of the state of the art). The major special features of the Egyptian intercity system are the nonexistence of the usual traffic congestion, the existence of fleet capacity constraints, and the topology of the network (i.e., a very dense network in Lower Egypt and one corridor in Upper Egypt).

The existence of these special features and limitations are expected to limit the generality of analysis. Nevertheless, results of analysis should be fruitful in terms of identifying areas of potential improvements in the particular application at hand as well as in the STEM approach itself.

Table 6 compares the "observed" trip-generation and trip-attraction data with those predicted on the network representing the existing situation (i.e., NET3). On the aggregate level, total demand predicted on NET3 is within 1.5 percent of the corresponding observed value (i.e., 473,045 versus 480,280 trips; see last row of Table 6); this is quite satisfactory. Percent difference between predicted and observed trip generation is less than 10 percent for all origins with number of trips exceeding 10,000 and is less than 20 percent for almost all origins with trips less than 10,000; again this is very reasonable. The greatest differences, percentagewise, are observed for PRTS and SWES (+63.8 and +57.8 percent, respectively). In absolute terms, however, these differences should not be overemphasized. The main reason for these discrepancies is related to the choice of an aggregate average value of the parameter α. This suggests that trip-generation predictions, in general, may be improved by defining a specific parameter α_i for each origin; note that the STEM methodology allows this modification.

Looking at trip-attraction results in Table 6, one finds that the differences are higher both percentagewise and in absolute terms. Recall that the STEM predicts trip attraction indirectly through trip distribution. Therefore, the reasons for these discrepancies may be revealed by analyzing trip-distribution results.

Table 7 shows the results of analysis of trip distribution between the single most important O-D pair in the system—Cairo and Banha. Table 7 shows the observed data and predicted trips distributed between Cairo and Banha. It is obvious that differences between predicted and observed values are very large percentagewise and in absolute terms. Predicted trips from Cairo to Banha represent an underestimation of 32 percent (i.e., 38,549 trips predicted on NET3 compared with 56,886 trips observed) and from Banha to Cairo represent an even greater underestimation of 54 percent (i.e., 32,080 trips predicted compared with 70,729 trips observed).

The main reason for these large biases appears to be the misspecification of the trip-distribution model; namely, the attractiveness measure $A_j = \theta_1 \ln D_j$. It appears that the total number of trips attracted, D_j, is "too aggregate" to capture the

TABLE 6 COMPARISON BETWEEN PREDICTED AND OBSERVED TRIP GENERATION AND ATTRACTION

	Trip Generation			Trip Attraction		
Zone	NET3	Observed	Percent Difference	NET3	Observed	Percent Difference
ALEX	25,688	26,615	−3.5	14,125	26,150	−46
DMHR	14,093	13,682	+3	13,898	13,824	+0.5
ETYB	7,187	6,000	+19.8	7,953	6,224	+27.8
KFRS	12,331	11,706	+5.3	9,820	11,196	−12.3
MHLK	10,644	9,781	+8.8	12,776	9,924	+28.7
TANT	36,644	38,677	−5.2	48,555	38,452	+26.3
SHKM	31,719	33,200	−4.5	44,208	33,628	+31.5
BNHA	74,949	81,240	−7.7	88,104	66,383	+32.7
CAIR	114,739	125,540	−8.6	110,823	139,565	−20.6
ZGZG	19,992	20,178	−0.9	29,205	21,768	+34.2
ABKB	7,939	6,803	+16.7	8,385	5,716	+46.7
MNSR	20,708	21,004	−1.4	18,178	19,692	−7.7
SHRB	10,519	9,700	+8.4	9,765	11,447	−14.7
DMIT	7,605	6,494	+17.1	4,024	6,209	−35.2
PRTS	3,805	2,323	+63.8	2,018	2,975	−32.2
ISML	8,827	7,846	+12.5	6,476	7,524	−13.9
SWES	4,070	2,580	+57.8	2,550	2,903	−12.1
FYUM	11,826	11,226	+5.3	8,156	12,156	−32.9
BSWF	14,102	13,751	+2.6	11,571	12,206	−5.2
MNIA	7,211	6,237	+15.6	4,607	6,777	−32
ASYT	10,368	9,867	+5.1	6,871	9,432	−2.7
SHAG	7,662	6,934	+10.5	5,702	7,294	−21.8
QENA	6,754	6,062	+11.4	4,115	6,025	−55.7
ASWN	3,664	2,834	+29.3	1,162	2,624	−55.7
Total	473,045	480,280	−1.5	473,045	480,280	−1.5

TABLE 7 ANALYSIS OF DEMAND BETWEEN CAIRO AND BANHA

From	To CAIR	BNHA	G_i
Observed Trips			
CAIR	–	56,886	125,540
BNHA	70,729	–	81,240
D_j	139,565	66,383	480,280
Predicted Trips (A2)			
CAIR	–	15,834	114,739
BNHA	21,735	–	74,949
D_j	–	–	473,045
Predicted Trips (A1)			
CAIR	–	51,977	114,739
BNHA	65,206	–	74,949
D_j	–	–	473,045
Predicted Trips (NET3)			
CAIR	–	38,549	114,739
BNHA	32,080	–	74,949
D_j	110,823	88,104	473,045

variability in destination choice behavior of users at different origins. To see this, compare the following two specifications in which the influence of perceived cost is neglected:

A1:

$$A_{ij} = \ln T_{ij} \qquad T_{ij} = G_i \frac{T_{ij}}{\sum_k T_{ik}} \qquad \text{for all } ij \varepsilon R$$

A2:

$$A_j = \ln D_j \qquad T_{ij} = G_i \frac{D_j}{\sum_k D_k} \qquad \text{for all } ij \varepsilon R$$

Table 7 also shows predictions based on A1 and A2 specifications. It is quite obvious that A1 represents a considerable improvement in the model specification, essentially by assuming that attractiveness of alternative destinations can be origin-specific. This modification can be incorporated easily into the STEM.

Another factor that would have introduced biases in trip-distribution behavior is the parameter θ. Again, this parameter is currently specified as a systemwide average. It can, however, be an origin-specific parameter θ_i for each origin. The STEM methodology also allows this modification. A third source of bias, particularly in the application at hand, is the existence of fleet capacity constraints.

The comparison between modal-split predictions on NET3 and observed values is shown in Table 8, which reveals that NET3 predictions imply more, longer trips than what was observed; that is, the average distance traveled is 56 percent greater on NET3 than it is for observed trips. This is one of the implications of the misspecification of attractiveness in the trip-distribution model. That is, the relative importance of destinations in Upper Egypt (Lower Egypt) to users originating from Lower Egypt (Upper Egypt) was overestimated, and the relative importance of destinations in the same region, particularly those in Upper Egypt, was underestimated *(3)*.

On the basis of that observation, the railway results in Table 8 are quite consistent and reasonable. As for the results of normal bus travel, predicted values are far below observed values. It seems that the assumption of the observed number of low-income passengers using the bus (i.e., 75 percent) may be relatively above the national average and hence the actual percentage may be far less than 75 percent. Unfortunately, available data could not provide a better estimate. In addition, it seems that the assumption that low-income passengers will not select lux bus under any circumstances is too restrictive, because lux bus is essentially an aggregation of five types of bus service—first class, Arrow, Flight Pullman, Lux Pullman, and Super Lux Pullman—and two of these types have a "sufficient" quality similar to the taxi *(5)*. Therefore, including these two types in the choice set of low-income passengers should improve modal-split predictions.

At the aggregate level, predictions appear to be reasonable except that they imply longer trips than those observed, as explained earlier.

As far as traffic assignment is concerned, no observed data were available for comparison. Nevertheless, results should essentially reflect the foregoing biases.

In order to assess the ability of the approach to predict behavioral changes, it is necessary to assume that NET3 predictions represent actual behavior. In view of the previous comparison between NET3 predicted and observed trips, this assumption is not valid. However, an attempt to address this issue was made by assuming that express train fleet capacity is doubled everywhere in the system (i.e., NET4). The implications of this change on user behavior were assessed by comparing predictions before (NET3) and after (NET4) the change. The results of this comparison, though influenced by the biases introduced through the misspecification of the trip-distribution model and the existence of fleet capacity constraints, reflected the potential capability of the approach to predict rational behavioral responses of users to policy changes in the system [details on the application have been given by Safwat *(3)*].

TABLE 8 COMPARISON OF MODAL-SPLIT PREDICTIONS ON NET3 AND OBSERVED VALUES

	No. of Passengers			Passenger Kilometers (thousands)			Average Distance (km)		
Mode	Observed	Predicted	Percent Difference	Observed	Predicted	Percent Difference	Observed	Predicted	Percent Difference
Rail	381,808	348,861	–8.6	30,247	43,268	+43	79	124	+57
Bus	300,616	75,707	–75	13,151	5,035	–62	44	66.5	+51
Taxi	–	59,097	–	–	3,903	–	52	66	+27
Total	682,424	519,615	–24	43,398	52,206	+20.3	64	100	+56

SUMMARY AND CONCLUSIONS

In this paper, the major objective was to assess the applicability from the behavioral point of view of the STEM methodology developed by Safwat and Magnanti *(1)*. The main concern was assessing the ability to represent observed behavior and to predict behavioral changes.

To achieve this objective, the STEM approach was applied to a real-world transportation network, namely, the Egyptian intercity transportation system.

The major conclusions may be summarized as follows:

- As to the ability to represent actual behavior, it was found that most of the biases between predicted and observed data were attributed to the misspecification of the trip-distribution model (particularly its attractiveness measure) and the existence of severe fleet capacity constraints (particularly along the Cairo-Banha-Tanta corridor in the Middle Delta region). Appropriate modifications to the current specification, which can easily be incorporated within the STEM framework, were suggested.
- As to the ability to predict behavioral changes, results were greatly influenced by the preceding conclusion. However, there were strong indications that the STEM would be capable of predicting rational behavioral responses of users to policy changes in the system.

As indicated at the introduction, the computational issues of the application are addressed in a companion paper by Safwat in this Record. In addition, a recent application to a large-scale urban transportation network (in Austin, Texas) has further demonstrated the computational tractability of the STEM methodology *(10)*. The value of the approach as compared with other existing methodologies was highlighted by Safwat and Magnanti *(1)*. Several case studies involving passengers and freight on the Egyptian intercity system have recently been completed *(11)*. An extended version of the STEM model was a central component of the methodology used in these case studies.

Further research in relation to the STEM methodology should include more applications, particularly in the urban context, as well as more refinement of the model assumptions and computational procedures.

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REFERENCES

1. K. N. A. Safwat and T. L. Magnanti. *A Combined Trip Generation, Trip Distribution, Modal Split and Trip Assignment Model.* Working Paper OR-112-82. Center for Operations Research, Massachusetts Institute of Technology, Cambridge, 1982.
2. F. Moavenzadeh, M. Markow, B. Brademeyer, and K. N. A. Safwat. A Methodology for Intercity Transportation Planning in Egypt. *Transportation Research A*, Vol. 17A, No. 6, 1983.
3. K. N. A. Safwat. *The Simultaneous Prediction of Equilibrium on Large-Scale Networks: A Unified Consistent Methodology for Transportation Planning*. Ph.D. dissertation. Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, 1982.
4. Louis Berger, Inc. *Egypt National Transport Study, Phase I, Final Report.* Ministry of Transport, Cairo, Egypt, 1977.
5. Netherlands Engineering Consultants. *Egypt National Transport Study, Phase II, Final Report.* Ministry of Transport, Cairo, Egypt, 1981.
6. K. N. A. Safwat. *Egypt Intercity Transport Project—A Comprehensive Report.* Technology Adaptation Program, Massachusetts Institute of Technology, Cambridge, 1981.
7. *Egypt Intercity Transport Project.* Technology Adaptation Program, Massachusetts Institute of Technology, Cambridge, 1982.
8. C. F. Daganzo. On the Traffic Assignment Problem with Flow Dependent Costs, I and II. *Transportation Research,* Vol. 11, 1977, pp. 433–441.
9. D. W. Hearn. *Study of Introducing Flow Bounds to Traffic Assignment Models.* Final Report. Mathtech, Inc., Princeton, N.J., 1979.
10. K. N. A. Safwat and C. M. Walton. Application of a Simultaneous Transportation Equilibrium Model to Urban Travel in Austin, Texas. Presented at the Joint National Meeting of The Institute of Management Science and Operations Research Society of America, Los Angeles, Calif., April 1986.
11. *Update and Application of the Intercity Transport Model: Final Report.* CU/MIT Technology Adaptation Program, Development Research and Technological Planning Center, Cairo University, Egypt, 1986.