H13-249
BOTTOM-UP ROAD TRAFFIC EMISSION CALCULATION FOR THE TUNISIAN ROAD NETWORK BY MEANS OF A TRAFFIC ASSIGNMENT MODEL

Alessandro Nanni[1], Fanny Velay-Lasry[2], Eva Eriksson[2], Amina Soudani[3], Sami Abid[4]

[1]ARIANET, Milano, Italy; [2]ARIA Technologies, Boulogne-Billancourt, France; [3]ANPE, Tunis, Tunisia; [4]I2E, Tunis, Tunisia

Abstract: The calculation of road traffic emissions to air has been performed in Tunisia as part of the national emission inventory and for air pollution dispersion modeling purposes. The emissions have been estimated on the basis of a traffic assignment model, including daily traffic volumes and average speeds on the road network and the origin/destination (O/D) values at the sources and sinks of traffic. The road network studied includes virtually all the motorways and main rural roads in Tunisia as well as the major urban roads of Tunis and other main cities. The traffic model simulation has been based on traffic counts taken at a large number of road sections. The availability of such rich experimental data is a guarantee for the accuracy of the traffic model simulation in order to assure coherence among the different measurements, to attribute values to links without traffic counts, and to estimate the O/D matrix (i.e. the boundary conditions capable to extrapolate at best the measured traffic flows over the entire network). An emission model, based on COPERT methodology, has further been used to estimate atmospheric emissions from “line sources” (the links corresponding to the main roads of the network) and “area sources” (zones of aggregation of O/D nodes giving the contribution of diffuse traffic on the secondary roads). Emissions from area sources, have been estimated from the average trip length inside the area and the extension of the secondary road network. Since the COPERT methodology includes fuel consumption factors, the modeling results have been compared to real data. The methodology shows a good correspondence with the national Tunisian statistics on fuel consumption declared for road traffic, with modeling results only 14% higher than the national fuel consumptions declared for the year 2006. The small differences could be explained by the uncertainties in the distribution of traffic densities and vehicle fleet as well as on the hypothesis made on the vehicle speeds.
Key words: *Atmospheric pollutant emissions, road traffic, COPERT methodology, traffic modelling, origin/destination matrix****.***

INTRODUCTION

National emission inventories are usually developed through a “top-down” approach, starting from aggregated data like fuel consumption or energy production and estimating emissions by means of emission factors. This approach has the advantage to start from consolidated data and the disadvantage to require space and time disaggregation when using the inventory to feed atmospheric simulations. The alternative approach to build an emission inventory is the “bottom-up” method, multiplying disaggregated “activities” (like traffic flows and speeds on different links of a road network) with proper emission factors (such as the emissions factors given by the EU COPERT methodology for on-road traffic). In this second case, as far as road traffic emissions are concerned, traffic flow data are available only a on limited number of sections of the road network and the remaining sections need to be assigned, preferably by using a traffic model. Traffic models can in principle treat all the links of a network, but performing such a simulation on a national scale is not feasible; nevertheless, a particular class of traffic models can overcome such complexity problems by estimating the number of origins/destinations for trips between different zones, using traffic counts.

Among the various activities carried out to build a national emission inventory for Tunisia, traffic sector emissions were estimated by traffic assignment and emission models. Thanks to the capacity of the assignment model for estimating the O/D values, the contribution of emission from secondary roads was further estimated and aggregated into area sources.

THE TUNISIA CASE

Tunisia is the northernmost country on the African continent, bordered by Algeria to the west and Libya to the southeast. It is the smallest of the nations situated along the Atlas mountain range. Around forty percent of the country is composed of the Sahara desert, with much of the remainder consisting of particularly fertile soil and a 1300 km coastline.

Tunisia ranks high among Arab and African nations in reports released by The World Economic Forum; The country is subdivided into 24 governorates and maintains 19232 km of roads, where the A1 Tunis-Sfax, P1 Tunis-Libya and P7 Tunis-Algeria are major highways. The urban population (64% of total) is located mainly in Tunis and, secondarily, in Sfax, L’Arianah, Ettadhamen, Sousse. The particular location, surrounded by the Mediterranean sea to the north and east and by the Sahara desert to the south, restricts road traffic exchange with the adjoining countries, so that Tunisia can be regarded as an almost closed traffic system.

DESCRIPTION OF THE TRAFFIC MODEL

The traffic simulation was performed by means of an assignment model (CarUSO) based on one of the major algorithms (Willumsen’s) able to estimate the O/D matrix and the traffic flows on a transport network.

The Willumsen’s model is a method to estimate the O/D matrix from traffic flows in a non congested network. It is based on the entropy principle and it postulates that, among all the O/D matrixes satisfying the counts of traffic flows (or minimizing the errors, if no solution exists), the best solution maximizes the path entropy, where the entropy is calculated as the product of the O/D matrix elements containing the numbers of travels between each pair of zones. A complete description of the model can be found in: Willumsen L.G. (1978) and Van Zuylen H.J., Willumsen L.G. (1980).

Description of the Tunisia road network

A transport network is composed by links (the roads), nodes (crossroads) and O/D zones (traffic sources/sinks). The network selected for the simulation was a subset of the Tunisian road system provided in GIS format. The original file had a very high degree of detail and was composed of more than 344000 roads (shown in light grey in figure 3). According to a hierarchical classification, a subset of 3314 streets was selected for the CarUSO simulation (black polylines in figure 3); among the criteria applied for the selection were: high hierarchy level and availability of traffic measurements.

The “network connection” is mandatory (any couple of nodes must have at least one connection path) so two ferry lines were added to connect the islands (Jorf – Ajim and Sfax – Sidi Youssef lines) to the mainland. However, the calculated traffic flows on these links were found to be quite low, and when estimating the emissions, they were cut from the traffic network and treated differently elsewhere in the inventory.

Measurement availability

The availability of traffic measurements was very high (48% of the selected links); they are the result of extended campaigns, led over the country in a few years. The collected data (daily averages) was quite inhomogeneous in time and needed harmonization. This is one of the reasons why a traffic model was applied despite the high availability of traffic measurements. The traffic model further allowed obtaining:

1. the assignment of traffic flows on the remaining links (around 50% of total model road network). The model simulation uses an objective algorithm (instead of merely using arbitrary assumptions), including iterative calculations in order to minimize the errors on traffic flow;
2. an O/D matrix estimation needed to calculate diffuse emissions on the secondary traffic network.

Speed function

The average speed on each link was estimated by using a function of vehicle speed related to link saturation (figure 1). According to this function, the speed does not change significantly for F/C ratios lower than 50%, then it rapidly drops to 25% of the free flow speed at F=C to thereafter decrease slowly (congestion regime).

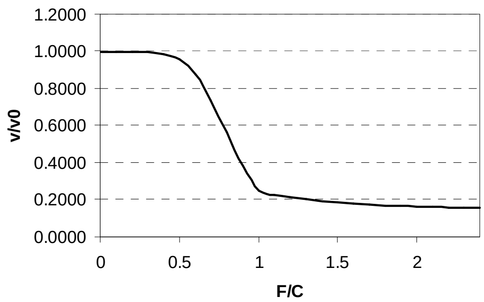

Figure 1. Speed function – v/v0 : real versus free-flow speed ratio; F/C : traffic flow versus road capacity.

Table 1 shows free flow speeds and capacities adopted in this study according to road hierarchy; since no calculated traffic flow was found to be higher than 50% of road capacity, the speeds were all estimated to be close to the free flow values.

Table 1. Free flow speeds and capacities according to road hierarchy for the Tunisia CarUSO simulation.

Road hierarchy level	Free flow speed (km/h)	Capacity (veh/d)
1	110	144000
2	90	115200
3	70	48000
4	50	38400
5	30	28800
Ferry Jorf – Ajim (£)	*1*	*500*
Ferry Sfax – Sidi Youssef (£)	*15*	*15000*

Note: (£) – The speeds are estimated from the ferry travel time and distance and the capacities are based on the maximum number of vehicles per ferry and the number of ferry trips per day

Origin/Destination zones

A number of nodes have been defined as O/D zones, i.e. sources and sinks of traffic inside the network. In principle, the selection of these zones should be done according to the real situation (correspondence with big districts, modal interchange points, parking lots, …) but the attachment points of these real zones to the virtual network (the selected links used in the simulation) is often uncertain, not obvious or objective. Moreover, all the terminal nodes should be treated as O/D zones and some zones are further added or (slightly) moved in the process of model configuration and optimization. Nevertheless, if used after aggregation inside consistent areas, O/D values have proven to give a picture of diffuse traffic on the secondary network realistic enough for the sake of emission calculation (Calori *et al.*, 2009).

Figure 3 shows the position of the selected O/D zones, for the whole network as well as for the northern part of the country (city of Tunis); finally a number of 289 O/D zones were selected for the entire road network.

Setup and results of the traffic simulation

The CarUSO simulation was performed starting from the network described above. It is the result of iterative refinements, from a “zero” simulation, made on the local scale to improve the model performance at the traffic counting sections.

The two most important traffic link attributes, free flow speed and road capacity, were chosen according to the street hierarchy (see table 1). To better account for situations of congestion, a relative high maximum number (5) of alternative paths were allowed between 2 different O/D zones as in such contexts vehicles normally tend to change itinerary to avoid queues.

The results of the simulation in terms of traffic and O/D flow are shown in figures 3. The model confirms that the highest volumes can be found in the northern (Tunis, Banzart, Nabeul, Hammamet) and north-eastern (Sousse, Monastir, Moknine, Sfax) parts of the network; south of Zarzis, which is the entry point to the Djerba island, the estimated traffic flows are much lower. As for the western part of the state, some concentration of traffic is estimated around Le Kef and Gafsa.
Table 2 presents a summary of the numerical simulation. The total length of the simulated network is about 15000 km (1/11 of the length of the original road network); more than 24 * 10^6 kilometres are run by vehicles in a day (1629 veh/d is the average throughput); the model estimates that more than 1.6 * 10^6 vehicles daily either enters to or exits from the main network.

As for the uncertainties of the simulation, evaluated at the traffic counting sections and compared with the mean traffic flow, the root mean square error (RMSE) obtained was 59% and the mean module of relative errors (MMRE) 44%. The errors might seem high, but considering the fact that the model is not deterministic and doesn't include human behaviour, the results are quite reasonable. The stage of preprocessing and harmonization of the traffic counting input data which was quite inhomogeneous as well as the selections made of road links to include in the simulation, further explains part of the error. However, figure 2 shows that the relative errors actually are quite low at the links with high traffic flow.

Table 2. Numerical overview of the Tunisia CarUSO simulation.

Description	Total	Network average
Length	15085 km	
Traffic flows	24569247 veh*km/d	1629 veh/d
O/D flows	1654972 veh/d	5727 veh/d
Errors	RSME: 58.8%	MMRE: 43.8%

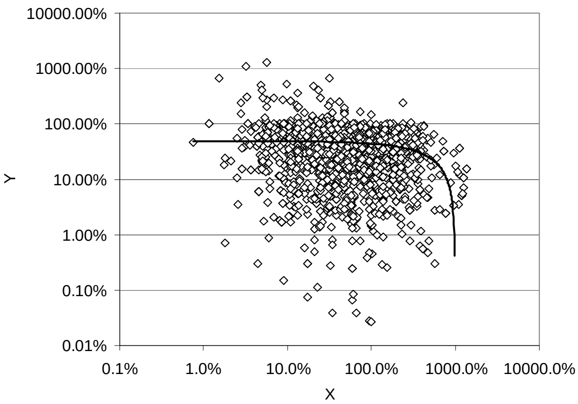

Figure 2. Diagram of modules of relative errors (Y) vs. relative flows (X). Relative flows are expressed with respect to the network average value; the black line shows the linear fitting.

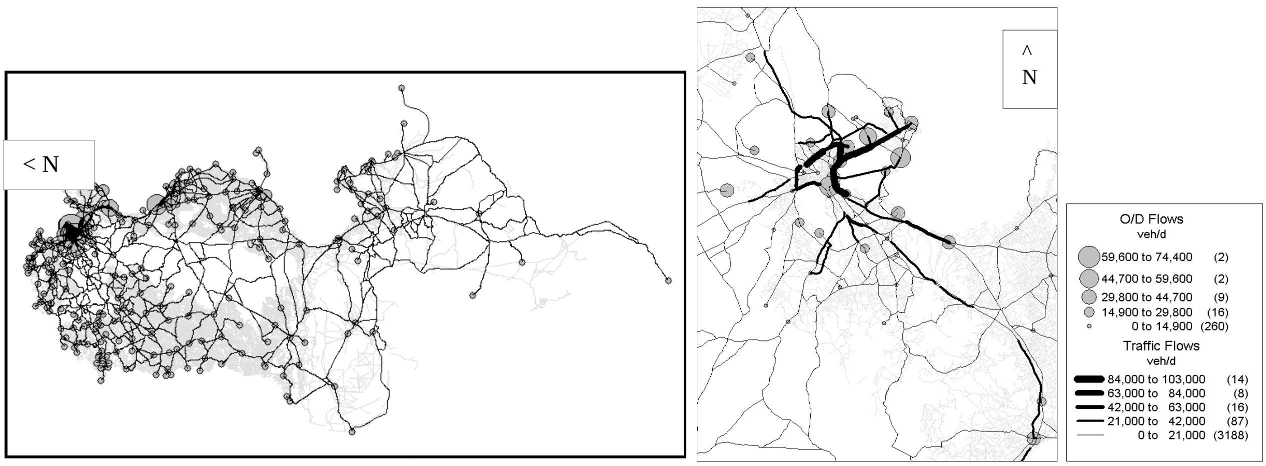

Figure 3. Traffic simulation results at national scale (left) and city scale (Tunis, right).

FROM O/D ZONES TO AREA SOURCES

Once the traffic model simulation was completed, the difficulty remained how to use the model output (road links and O/D flows) as "activities" to be crossed with "emission factors" (EF) to finally obtain "emissions". As the set of EF used in the modeling are based on the official EU-COPERT methodology and are given in grams per kilometer per vehicle, the number of kilometers travelled inside the network had to be estimated. Since the traffic flows on the main network is directly associated to linear sources the total number of kilometers driven can be calculated by simply summing up the product of traffic flow and road length on each road segment. The resulting O/D matrix can however not be used as easily for estimating the emissions from traffic on the secondary roads (not included in the CarUSO network).

Thus, the set of O/D zones was divided into 35 territorial areas and the total O/D flows per area was aggregated; thereafter each area was given an internal average trip length and for each area the driven kilometers were calculated as a product of O/D flows per average trip.

Each area was identified according to:

- the number of estimated O/D flows: the major values were treated separately (or in smaller aggregations), the minor values were further aggregated;
- the accessibility to and from the O/D zones;
- the homogeneity of the secondary network texture and density.

The extensions of the defined areas varied from 2.2 to 18839 km^2 and the O/D flows from 1750 to 148686 veh/d.

As observed in previous projects, for example in Kaliningrad (Calori *et al.*, 2009) and in Doha, a good "conventional" estimation of the average internal trip length is ¼ of the circumference of a circle having the same area (CCSA). Nevertheless, this estimation doesn't account for the road density inside the area, a property which presumably influences the average trip inside. In order to include the road density on the secondary road network in the estimation of the average trip length for the traffic area sources prepared for the Tunisia inventory, a linear function of the square root of total length of secondary roads inside the area was derived (equation 1).

$$L_T = 19.5 * (L_{SR})^{0.5} \tag{1}$$

where: L_{SR} is the total length of secondary roads inside the O/D area and L_T is the average internal trip length.
As a matter of fact, Figure 4 shows the linear correlation between ¼ of CCSA and $(L_{SR})^{0.5}$; thus, in formula (1) L_T includes both extension and road density aspects.

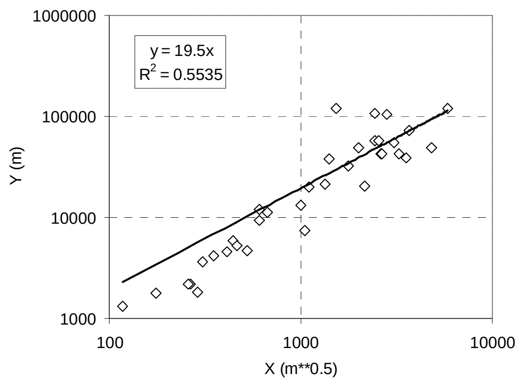

Figure 4. O/D areas. Linear regression model of 1/4 of CCSA (Y) vs square root of total lengths of secondary roads inside (X).

About 2/3 of the areas showed total distance densities lower than 15000 veh*km/km^2/d; seven between 15000 and 65000 veh*km/km^2/d (Sousse, Tunis-Beb El Falla, Rades, Manubah, North Tunis, Soukra-Carthage, Gammarth, (areas are named according to main town or district)); five higher than 65000 veh*km/km^2/d (Tunis-Marine, Tunis-Citè el Kadra, Tunis-Airport, Zahra-Keredine, Marsa-Sidi Bou Said).
The total number of kilometres run by vehicles on the secondary network according to the O/D matrix was found to be 4.7 times higher than those observed on the main network.

TRAFFIC EMISSIONS CALCULATION

Total distances travelled, on the main and secondary road networks, were subsequently used to calculate emissions, according to EU-official COPERT methodology. The COPERT methodology is part of the EMEP/CORINAIR Emission Inventory Guidebook, being fully consistent with the Road Transport chapter of the Guidebook (EMEP/CORINAIR, 2007). COPERT is also a software program aiming at the calculation of air pollutant emissions from road transport (Gkatzoflias D. *et al.*, 2007). As atmospheric dispersion modelling needs to be fed with emission data highly disaggregated in time and space, a software tool, TREFIC, has been developed integrating the COPERT methodology. TREFIC can directly treat data from a traffic model and expand the COPERT program functionalities to satisfy dispersion modelling requests (Nanni A. and Radice P., 2004). As the present study was led during a transition period between the old COPERT 3 and the new COPERT 4 versions of the methodology, COPERT 3 was used: this approximation was acceptable as the target year for the national fleet was 2006 and COPERT 3 covers all the emission standards related to this year (up to the EURO 4 vehicle emission standards). A comparison between the two methodologies is presented below.

COPERT estimates emissions of all major air pollutants (CO, NOx, VOC, PM, NH3, SO2, heavy metals) produced by different vehicle categories (passenger cars, light duty vehicles, heavy duty vehicles, mopeds and motorcycles) as well as greenhouse gas emissions (CO2, N2O, CH4) and fuel consumption. The methodology also provides speciation for NO/NO2, elemental carbon and organic matter of PM and non-methane VOCs, including PAHs and POPs. Emissions estimated are distinguished in three sources: Emissions produced during thermally stabilized engine operation (hot emissions), emissions occurring during engine start from ambient temperature (cold-start and warming-up effects) and NMVOC emissions due to fuel evaporation. Non-exhaust PM emissions from tyre and break wear are also included. The total emissions are calculated as a product of activity data provided by the user and speed-dependent emission factors calculated by the software.

In addition to the COPERT methodology, the TREFIC program includes optional PM emission factors developed by the IIASA institute in the framework of the development of the GAINS model (IIASA, 2010). TREFIC further includes a simplified congestion treatment, it generates time disaggregated emissions and the program yields output compatible with main GIS software

.

Fleet Distribution

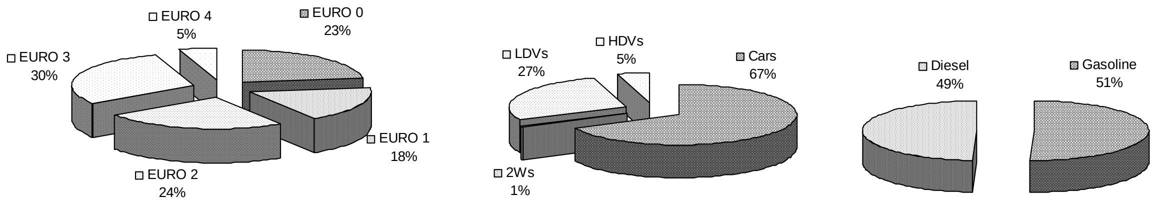

Figure 5. Tunisia 2006 vehicle fleet distribution per emission standards (left), categories (centre) and fuel (right).

Another parameter of importance for the traffic emission calculation is the distribution of the circulating fleet into COPERT vehicle categories. For the present work, statistics provided by the ATTT (“Agence Technique des Tranports Terrestres”, Tunisia) was used. The percentages of vehicles divided into different emission standards, vehicle categories and fuels are given in figure 5.

RESULTS

Table 3 presents the emission and fuel consumption results. The contribution of emissions from area sources is about 2/3 of the total emissions.

Thanks to the availability of national data on fuel consumption for road traffic (1474 ktep/y) it is possible to compare the methodology results with observations. Even if the comparison is made only for this variable and on a national aggregated level, the results are quite satisfactorily. The small difference could be explained by the uncertainties in the distribution of traffic densities and vehicle fleet as well as on the hypothesis made on the vehicle speeds.

Table 3. Road traffic emissions and fuel consumption calculated for Tunisia (kt/y or ktep/y)

	Total	**Line sources**	**Area sources**
NOx (kt/y)	**31**	10	21
NMVOC (kt/y)	**7**	2	5
PM10 (kt/y)	**2.3**	0.7	1.5
PM2.5 (kt/y)	**1.9**	0.6	1.3
CO (kt/y)	**56**	21	35
Fuel consumption (ktep/y)	**1 559**	510	1049

Comparison between COPERT 3 and 4 methodologies

As COPERT 4 methodology recently has been incorporated and tested with TREFIC, a comparison between the emission factors used in the study (COPERT 3) and its latest release (COPERT4) has been possible; the results are shown in table 4. All differences in the results obtained can be explained by the modifications in the emission factors between the two methodologies. Fuel consumption in particular is now lower than the national data; this is probably more realistic considering that, for example, the calculation did not account for intra-zonal trips (trips starting and ending inside the same zone) and, Tunisia being surrounded by low population density regions, the balance of fuel for inter-national trips (starting from or ending outside the national borders) is probably positive. Concerning the different pollutants, the increase of NO_X emissions on major roads (line sources) and the decrease of NMVOC, dusts and CO emission in urban areas (area sources) can be noticed.

Table 4. Road traffic emissions and fuel consumption calculated for Tunisia (COPERT 4)

	Total diff. (C4–C3)	**Line sources**	**Area sources**
NOx (kt/y)	**37 (+19%)**	17	20
NMVOC (kt/y)	**4 (-43%)**	2	2
PM10 (kt/y)	**1.6 (-30%)**	0.7	0.9
PM2.5 (kt/y)	**1.3 (-32%)**	0.6	0.7
CO (kt/y)	**47 (-16%)**	22	25
Fuel consumption (ktoe/y)	**1 265 (-19%)**	475	790

CONCLUSIONS

The Tunisia national emission inventory for road traffic sector was fed via a bottom-up approach involving the results of a traffic assignment model. This method has the advantage to estimate the emissions from the main roads as “line sources” and the secondary ones as “area sources”, using respectively the links and the O/D zones of traffic flows. Thanks to our previous experiences we proposed a formula to estimate the average trip length inside each O/D zone, needed to calculate the total kilometers driven inside each zone (the activity data used for emissions estimation). Through this semi-empirical formula, information on road extension and density are considered. The emissions were then calculated using the COPERT3 methodology. Results for fuel consumptions, when compared against national statistics, proved the reliability of the method in estimating energy consumption from road traffic with very good approximation. The switch to the more recent COPERT4 methodology showed differences that are negative (lower emission factors) for NMVOC, CO and dusts on urban roads and positive for NO_X on major roads. Estimated fuel consumptions were lower than the ones estimated with COPERT3, which is probably realistic as in principle our approach should underestimate the real national figure.

The presented methodology can be easily adapted to other contexts, at national and local scales and with road networks of different levels of detail.

REFERENCES

Calori G., Eriksson E.M., Ilina E., Moussafir J., Nanni A., Samerkhanova A., 2009. Kaliningrad Air Pollution induced by Traffic (KALAIR): modeling system design, installation and validation. 17th Transport and Air Pollution Symposium, Tolouse, France, 2-4 June 2009.

EMEP/CORINAIR, 2007. Emission Inventory Guidebook. Technical report No 16/2007.

Gkatzoflias D., Ntziachristos L., Samaras Z., 2007. COPERT 4 Computer programme to calculate emissions from road transport - Users Manual. ETC-ACC.

IIASA, 2010. GAINS Europe. http://gains.iiasa.ac.at/gains/EUR/index.login?logout=1.

Nanni A., Radice P., 2004. Sensitivity analysis of three EF methodologies for PM10 in use with climatological dispersion modelling in urban Italian study cases. Proc. of 9th Int. Conf. on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, 1–4 June 2004, Garmisch-Partenkirchen (Germany), Vol. 1, 309-314.

Van Zuylen H.J., Willumsen L.G., 1980: The Most Likely Trip Matrix Estimated from Traffic Counts, Transportation Research B, vol.14B, p.281-293.

Willumsen L.G., 1978: Estimation of an O/D Matrix from Traffic Counts. A Review, Institute of Transport Studies, University of Leeds, England, Working Paper #99.