TEE2003: Transport Energy & Environment: an advanced software tool for the estimation of direct impacts from transport

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Abstract

TEE (Transport Energy and Environment) is flexible software for the estimation of direct impacts (pollutant & noise emissions, accident occurrence) from transport, developed by ENEA and ASTRAN srl.

The new version of the TEE model (TEE2003) has been developed with many features allowing the user to better analyse transport related impacts, taking into account: vehicle kinematics, cold emission distribution, parking process, emissions of new categories of pollutants, noise emissions and accident occurrence.

As regards the kinematics, TEE code can calculate link emissions starting from standard correlations based on average speed or from instantaneous emissions data. This flexibility allows detailed emissions calculations, according to the traffic input data available, either from measurements or from traffic models.

As it concerns the estimation of the effects of cold emissions, spatial and temporal distributions, TEE offers alternative solutions for the user, according to the more or less disaggregated information, allowing one in any case to distinguish different situations (e.g. morning traffic in residential areas or evening traffic in city centres where cold vehicles represent a majority).

The parking process algorithm provides an approximated but meaningful treatment of traffic flows from and to parking areas allowing the location of cold vehicle emissions in space and time and a greater accuracy in the estimation of evaporative emissions distribution.

The pollutants added within the TEE2003 version are N2O, Benzene, PM10, Aromatics, Benzo-(A)-pyrene, PAH, Dioxins and Furans.

Two new models have been inserted: the noise emission model, and the accident occurrence model. The first model is sensitive to vehicle speed and heavy-duty vehicle presence. The accident model calculates the total number of accidents involving only vehicles or vehicles and pedestrians.

Furthermore, a new routine for calculating the effect of the electric load (air conditioning, lights and other devices) has been inserted.
1 Introduction

TEE 2003 model contains distinctive features that enable the user to analyse many transport related environmental issues affecting the environmental quality of a city. These capabilities are related to the detailed kinematics representation of the traffic movements, the possibility of a description of the parking process and the possibility to calculate the emissions related to the most important pollutants affecting the air quality.

The kinematics representation of the traffic flows was the goal of the main developments of the computer code during the recent years. It allows the representation of the effect of vehicles kinematics on pollutants hot emissions in different ways, respect to the amount and detail of the data available from a general traffic model either micro or macro, in order to satisfy two different aspects of the problem: the first one is the possibility of the emissions detailed calculation, the second being the flexibility of the input data available from measurements or from traffic models.

The TEE offers alternatives to the ‘average speed approach’ and to the detailed ‘speed cycle’ Model for the calculation of passenger cars hot emission, in order to avoid the low accuracy of the average speed emissions, especially for urban traffic, and the instabilities of instantaneous ones. Such alternatives include the simplified ‘reconstructed cycle’ Model and the approach named ‘Kinematics Correction Factor’, developed for CO and HC emissions, and fuel consumption and successfully applied and assessed with tests in Rome.

As it regards the spatial and temporal distribution of cold emissions, TEE offers alternative solutions for the user having more or less disaggregated link information, on the fraction of cold vehicles or on the average distance travelled by vehicles along the link. Anyway, if the user doesn’t have link-based information, TEE can estimate the cold fraction on the basis of the area including the link and the time hour of the day. This multiple-defaults option allows in any case to distinguish between very different situations, for example between morning traffic in residential areas where cold vehicles represent a majority, and afternoon traffic in CBD areas when cold vehicles are a minority.

The modelling of parking process is another characteristic of TEE model searching for a much greater accuracy in the estimation of cold vehicles fraction, in order to locate cold vehicles in space and time.

Thanks to the existence of parking monitoring systems within cities, the knowledge of the time profiles of flows entering and leaving off road parking lots is developing, so that it can be possible to quantify the parking flows and to characterise the kinematics of vehicles moving in and out of the two different kinds of parking areas, concentrated and distributed, with their own distinctive parameters.

Furthermore, the parking and inserting flows are essential for the estimation of the evaporative emissions, in terms of ‘running', 'hot soak' losses, and of 'diurnal losses' with the other 'already-parked' vehicles in the road-stretch area.

Two new models were implemented in TEE 2003 version, developed in the framework of the ISHTAR Project [1].
The first is the noise model: it can perform the noise levels calculation starting from a small set of data provided in input, giving in output the sound emission levels produced by the traffic flow.

The second is the accidents occurrence model which calculates the number of accidents involving only vehicles and the number of accidents involving pedestrian, taking in input the same data needed by the traffic module.

![Diagram of TEE2003](image)

Figure 1:  Main Subroutines of ‘TEE2003’.

## 2 Hot emissions

The hot emission calculation is performed in different ways according to the user Kinematic choices. For all the options the code performs the emission calculation link-by-link and hour-by-hour, but it produces the aggregated results for the complete network considered and for the complete temporal window set, so that the user can evaluate the emission and consumption results for each link or for the complete network considered.

The default calculation starts from the use of the basic emission correlations provided by COPERT III [2] and use only the average speed provided for each link of the study. For each vehicular category present into the fleet composition related to a specific link the ‘normal’ emission values are calculated using the COPERT III and MEET [3] correlations. It is also possible to calculate the hot emission, starting, as the previous calculation, from the average speed, but splitting it in different average speeds for the diverse vehicle categories by an internal TEE algorithm, in order to take in account their specific kinematic
behaviour, related to different speed limit values and engine powers, and consequent different contributions to the total emissions.

The ‘speed cycle’ model calculation is performed starting from two instantaneous emission databases present in the file system: the MODEM [4] database, provided by INRETS, and the DVB [5] database, provided by TUG. These databases supply the instantaneous emissions related only to a little set of passenger cars (ECE 15-03, ECE 15-04, Catalyst and diesel) with different displacements (< 1.4 lt, between 1.4 and 2 lt, > 2 lt). For the use of databases with emission data related to other vehicular categories the results of various European Projects like ARTEMIS [6] or The COST action 346 [7] must be expected. With this option the emissions are calculated second by second in grams and summed up for the complete speed cycle.

The alternative options offered by the TEE are the simplified ‘reconstructed cycle’ Model and the ‘Kinematics Correction Factor’ approach [8], and they are available only for the same vehicular categories of the speed cycle option, as they use the instantaneous emission databases.

Figure 2: Qualitative time fractions spent in kinematics phases in free flow conditions, including the effect of lanes number.

The first one aims at obtaining a reasonably adequate kinematics description on the basis of an essential speed cycle ‘reconstructed’ by the model itself as a function of the average speed along the link, a congestion indicator such as the ‘lane flow density’ (flow to speed ratio in the link lanes), and the fraction of green time at the intersection at the end of the link. The information required in this case is more easily obtainable instead of the ones needed for the ‘speed cycle’ model, and is provided by most of the traffic models currently available. Moreover, in contrast to the ‘average speed’ model, the reconstructed cycle can
be sophisticated enough for taking into account the congestion level represented by traffic density (measured in vehicles/km per lane), used for calculating the fractions of time spent during the four kinematic phases: cruising, acceleration, deceleration and idling (Fig. 2).

The other option, the ‘Kinematics Correction Factor’ (KCF) approach, assumes that the effect of speed variability can be expressed by means of a ‘kinematics correction function’, i.e. a multiplying variable coefficient of the classic hot emission term based on the average speed, representing the variability of emissions with the kinematics content of a given cycle. According to this approach, the ‘corrected’ emission is obtained as the product of the ‘average’ emission, calculated from the average speed, and the ‘kinematics correction factor’ KCF, function of four parameters: average link speed, green time percentage at link end, link length and traffic linear density.

The KCF is derived from a set of emission calculations, in which both the ‘reconstructed cycle’ model and the average speed correlation are used. Through the emissions ratios, the influence of the modelled speed variability on the emissions was quantified and the calculation of the KCF as a function of speed, density, green time fraction and link length was performed.

3 Parking modelling

The modelling of parking process is another feature of TEE flexible kinematics, searching for a much greater accuracy in the emission calculation, with respect to the estimation of cold start and evaporative contributions.

The capability of TEE to provide an approximated but meaningful treatment of traffic flows from and to parking areas allows to locate cold vehicles emissions in space and time, simulating the parking and the inserting kinematics, in and from two types of parking areas, concentrated and distributed parking. It additionally allows the locating of the parking and parked vehicle for the estimation of evaporative emissions.

The parking and inserting flows can be provided by the user, otherwise they can be calculated by the code starting from the following input data: transit flow, occupancy rate, hour of the day, type of area and type of link considered.

Specific 'mini-cycles' have been modelled to describe the kinematics of the parking and inserting processes (Fig. 3).

![Figure 3: 'Mini-cycles' for inserting and parking processes.](image-url)
The parking cycle represents vehicles parking both along street sides and inside 'parking lots' (either 'open-air' or underground) accessed from the considered stretch ('concentrated parking'), and it is based on the consideration of four subsequent fundamental phases: drive, slow-down, search and final parking. The parameters describing these four phases (characteristic duration, accelerations and speeds) are partly provided by the user, and partly calculated by the subroutine. An automatic correction of user provided data concerning the parking cycle is performed (with provision of warning messages on the screen) if such data are not compatible with the length of the stretch (the user can generally 'image' parking cycles which are 'too slow' to be completed inside the stretch length).

The insertion cycle represents vehicles entering the road main flow from concentrated or distributed parking areas, and it is modelled, as the parking one, through a series of specific phases (engine heat-up, exit from the parking area, acceleration to main flow ('transit') speed, final drive with the 'transit' vehicles) described in terms of time duration and speed profile. The user provided data on the 'insertion cycle' are automatically corrected if the model identifies an inconsistency with the geometric length of the road stretch (in practice the mini-cycle is 'accelerated' in order to be completed by the end of the stretch).

The use of the parking model is linked to the availability of instantaneous emission functions: these functions exist at present only for Passenger Cars, but new data for heavy duty vehicles are expected from FP5 Projects (COST 346 [7] and ARTEMIS [6]).

4 Cold start emissions

Cold start emissions are crucial for a good emission estimation, due to the great impact of the engine temperature on emissions (especially of CO and VOC), and their calculation is particularly critical due to the difficulties in correctly evaluating the influencing parameters.

Cold start emissions are calculated according to the INRETS [9] and COPERT III [2] methods. The correlations used are principally provided by COPERT III and they are functions of:
- the vehicle category (for the different sensitivity to engine temperature);
- the vehicular flow (because of the different velocities);
- the traffic mode, 'transit' or 'insertion' ones.

The TEE-2003 ‘default’ cold start estimation is performed through the following three steps:
1. The evaluation of the percentage of cold vehicles in the given street, as a function of street type and time hour (MOBILE [10] approach): this information is crucial for the correct calculation because a cold catalyst vehicle produces 10 or more times emissions respect of a hot vehicle. The user can provide link by link the fraction of cold vehicles, hindering the code internal estimation. Some traffic models can provide information link by link about the driven distance of vehicles in the given link, allowing such
an estimate. Besides, if the user doesn’t have link based information, TEE estimates the cold fraction, using its default table of reference values of the cold % based on the hour of the day, the type of the day, the type of link and the type of area involved into the calculation. This is the main difference, concerning this calculation, between TEE and COPERT: in TEE the cold % is a parameter for each link at each hour.

2. The calculation of cold/hot ratios for emissions of pollutants depending on ambient temperature: this correction is calculated taking in account the average hourly temperatures for each month (24 x 12 data), stored in a specific file accessible to the user for modification.

3. The combination of such results through the calculation of the corrective factors, stored inside three 3-D arrays (one for each traffic mode) having vehicle categories, vehicular flows and pollutant type as dimensions.

5 Evaporative emissions

Evaporative emissions are calculated according to the CORINAIR [11] methodology. The code considers three type of evaporative emissions: running losses, diurnal losses and hot soak. For these three contributions we must consider the three fundamental types of flows; transit, parking and inserting flow. The consideration of three different types of flow is important because the evaporative emissions calculation needs also the information related to the number of vehicles parked. As mentioned in the parking model paragraph, the user can provide the transit flow and the parking and inserting flows, otherwise they are calculated by the code.

The Running Losses calculation regards transit, parking and inserting flows, for which the code needs the cold percentages and the distance driven to park or to insert in transit flow.

The Diurnal Losses calculation considers running or stopped vehicles: the minimum temperature and its variation during the day are needed.

For Hot Soak Emissions emission the model considers only stopping vehicles (i.e. the vehicles arriving to the parking place), so that the cold percentages and the fraction of vehicles with fuel injection are needed.

6 Other correction factors

The code considers many corrective factors affecting the emissions, apart from cold correction, as just mentioned above and all the corrections are made by multiplicative coefficients applied to the normal emissions. They are:

1. Correction due to the vehicles age. Since the reference emissions are based on 'average ages' of vehicles, the corrective factors have to take into account age distributions different from the 'reference' one. The correction factors, for each pollutant, depend on the vehicle category, therefore such factors are stored in a matrix having pollutant type and vehicle categories as dimensions.
2. Correction in relation to the effect of maintenance level on pollutants emissions. TEE-2003 model assumes vehicle-dependent corrections as function of one single maintenance parameter (the maintenance period (months) of the vehicle). Given the dependencies from vehicle category and pollutant type, the corrective factors are stored in a matrix. The corrective factor is given by the ratio between emissions of a vehicle (belonging to a given category) with reference maintenance and the emissions of the same with input-providing maintenance.

3. Correction due to the slope of the road stretch. Since this correction will generally depend on both the pollutant type, the vehicle category and the vehicular flow, the correction factors are stored in a 3-D array. The fundamental input to the routine is the value of the road gradient (either positive or negative) for the given vehicular flow.

4. Correction due to the altitude above sea level. Such correction will generally depend on the altitude itself, the type of vehicle, the vehicle speed and the type of pollutant. Therefore the corrective factors are stored in a 3-D array having the vehicle categories, the vehicular flows (defining an average flow speed) and the type of pollutant as independent variables. The factors are calculated as functions of altitude and average speed (having influence on the emissions sensitivity to the altitude).

5. Correction according with the loading of heavy vehicles. The initial hypothesis for this approach is that the load parameter will be the same for the whole network and not related to the single stretch.

6. Correction on the calculation of the consumption related to the electric load of a vehicle. It takes into account the air conditioning, the lights and other parameters affecting the electric load of a single vehicle. It provides a corrective factor to the ‘normal’ consumption.

The gradient, altitude and load corrections are performed according to the MEET [3] and CORINAIR [11] methodologies. The age, maintenance and electric load corrections are performed on the basis of a set of experimental data available in literature.

7 New impacts models: accidents and noise

Two new models are present within TEE 2003 version.

The first is the noise model, developed on the basis of the NMPB model [12]. The code can perform the noise levels calculation starting from a little set of data provided in input. The output of this model is the sound emission levels produced by the traffic flow. The data related to the noise source are provided by the abacus of the ‘Guide De Bruit’ [13] that contains the values of the noise emissions of different macro categories in different traffic conditions (congestion, traffic fluid and so on).

The model doesn’t take into account any propagation or diffraction of the noise along the space near the link considered.
The second is the accidents model developed on the basis of the documents provided by INRETS [14].

This model calculates three different types of accidents; the total number of accidents, the total number of accidents involving only vehicles and the total number of accidents involving pedestrian. It takes in input the same data needed by the traffic module; link length (in Km), traffic hourly flow and pedestrian hourly crossing flow (ped. /Km).

8 Conclusions

TEE2003 Model offers a variety of solutions for representing in an accurate way the most crucial processes related to vehicle emissions: cold start, vehicle kinematics, parking processes and in general the other affecting parameters. The development process has also taken into account the need of a spatial representation of the emissions for the exposure estimation, so TEE2003 is particularly GIS oriented.

Furthermore the new submodules regarding noise emission and accident occurrence make the TEE2003 a complete tool for assessing the various direct impacts of vehicular traffic.

References

