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A transport modelling framework for Consensus

Angeliki Kopsacheili [a1], Anastasia Pnevmatikou [a], George Yannis [a], Konstandinos Diamandouros [b]

[a] *Department of Transportation Planning and Engineering, School of Civil Engineering, National Technical University of Athens (NTUA), Iroon Polytechneiou 5, Athens, 15773, Greece*
[b] *European Union Road Federation*

Abstract

Transport models are generally recognised as useful tools for predicting transport demand and analysing the effects of various transport policies of transportation projects. Unfortunately, the complexity of most transport models gets in the way of their widespread use by planning authorities and policy makers. Consensus transport model incorporates most of the transport behaviour parameters desired in a transport model, yet it has a simple structure (sketch-based model) and manageable data requirements.
This paper describes a diversion model that adopts a specific technique for forecasting changes in demand. Demand in this model is assumed to be driven by roadway capacity and generalized cost of travel, as well as by their respective elasticities. The model is planned for use mainly by public authorities, with limited resources or know-how in transport modeling, in estimating traffic and traffic related impacts, when examining road pricing schemes for two generic types of road projects: a new road project and the upgrade of an existing roadway. Among the components taken into consideration within the road pricing schemes tested in Consensus transport model are: project scale, application area, type of authority, road pricing scheme, toll collection technique, and price level.

Keywords: Road pricing, transport modelling, policy making, ex-ante evaluation.

1. Introduction

Modelling has the potential to provide the transport sector with a "quantified understanding of current and future issues" (Furnish and Wignall, 2009); as such it is an important component of the development and assessment –usually ex ante evaluation- of transport policies. Where policies are developed and implemented without recourse to modeling, these are likely to be ineffective, short-lived, have unintended consequences and may even be counter-productive (Furnish and Wignall, 2009).

The key consideration when developing a transport model to support the ex-ante evaluation of alternative policy options is that model's set-up, takes place within the overall evaluation process (Boulter and Wignall, 2008, Department for Transport, 2009a, Furnish and Wignall, 2009, PROSPECTS, 2003). This requires an ordered process, including:

(a) Establishment of a clear policy context; in terms of purpose and alternative policy options. This also includes appreciation of the current circumstances and challenges as well as the available resources (data, time, cost etc.)
(b) Development of a clear assessment context; in terms of the desired outcome and the evaluation objectives.
(c) Review the potential for different modelling techniques to support the selected policy and assessment context requirements.

* Corresponding author. Tel.: +30-210-772-1326;
E-mail address: geyannis@central.ntua.gr

Following such a process, a transport model has been developed in the framework of Consensus project, tailor-made for the evaluation of the Consensus transport policy scenario, which concerned "*the support of public authorities, relevant to the development, planning and management of roads, to comparatively evaluate and identify most optimal road pricing schemes -for further/more detailed assessment- either for a new road infrastructure project or for the upgrade of an existing one, against a range of policy objectives that cover the main pillars of sustainability*" (CONSENSUS, 2014).

To our knowledge, few attempts have been made to formulate simple and comprehensive planning tools. The aim of this study is to address these two linked issues. The framework of developing a sketch-based model for forecasting changes in travel demand is presented.

2. Policy and assessment context of Consensus

There are two main goals behind road pricing as identified by transport economists (Pigou, 1920, VTPI, 2013) and adopted nowadays by the EU: funding of Europe's vital road infrastructure, mainly Trans-European road network (motorways and high-quality roads, whether existing, new or to be adapted) and sustainable use of road transport infrastructures currently affected by congestion and consequent problems (CEDR, 2009, PIARC, 2008).

Despite the fact of the EU encouraging its member states to include road pricing in their political agenda, one of the basic challenges in all governmental levels, is to seek a "balanced way" to do that.

A "balanced way" basically implies the development of a coherent modelling framework to support the assessment of road pricing policy options against -often conflicting- policy objectives. Such an assessment is –by default- not an easy task; especially at the early stages of a project and/or policy development where alternative options are still "just ideas" and should be quickly "scanned" and interpreted as either promising or not suitable for further development.The task is even more difficult in the case of a public authority (of local/regional level) with limited resources or know-how in policy modeling.

Road pricing policy options examined in Consensus are basically (different) combinations of the following components:

i. The project type; entirely new project or upgrade of an existing one.
ii. The project scale: corridor (usually a main axis), facility (a corridor part with specific operational of geographical characteristics) or spot (bridge/tunnel) further differentiated by length (in kms) and typical cross-section (lanes number/ direction)
iii. The application area: urban or interurban. Urban area is further differentiated by population size (small when population < 2.000.000 or large when population > 2.000.000)
iv. The type of authority, responsible for operation: public or private entity
v. The road pricing types: Road tolls (fixed rate), Distance-based charging, Congestion charging
vi. The toll collection technique: Pass, Toll booths, Electronic Toll Collection (ETC) based on transponders or smart cards, combination of toll booths and ETC, Optical Vehicle Recognition System (OVR), combination of ETC and OVR, GPS (or GNSS) based pricing, combination of GPS and ETC.
vii. The price level (how much is the base fee – concerning passenger cars) and structure (differentiations per vehicle –using as base passenger cars' fee-, per day period and discounts for frequent users).

Since the Consensus transport policy scenario aimed to assess policy options for a specific/given project -and not examine also alternative project options-, for any alternative under assessment the upper half of the components list (i) to (iii) are considered fixed (i.e. the project is given and will not change); and the optimal road pricing policy option is produced by searching optimal (combinations of) parameters in the bottom half of the components list (iv) to (vii).

Policy objectives adopted in Consensus transport policy scenario were developed around the four main sustainability dimensions, namely Economy, Mobility, Environment and Society (Schwaab and Thielman, 2011,Valentin and Spangenberg, 2000, UNDPCSD, 1996) and included: economic feasibility, financial viability, impacts on traffic congestion, impacts on safety, impacts on the environment (air quality and noise) and users' convenience.

Policy objectives might reflect general goals and desired outcomes of a road pricing policy but they do not specify performance targets. As a result, it may be difficult to judge whether a proposed policy option is successful or another option should be implemented instead. To this end, based on relevant literature and research review (CEDR, 2009, CURACAO, 2009a, CURACAO, 2009b, Ensor, 2005, Jones, 1995, Jones, 1998, KonSULT, 2014, Litman, 2013, NRTC and NTS, 2003, Omann, 2004, PIARC, 2008, Small and Gomez-Ibañez, 1998, Spear, 2005, Tsamboulas and Kopsacheili, 2003, Verhoef et al. 2008, VTPI, 2013, Walker, 2011), appropriate indicators (and metrics), presented in Table 1, were chosen to measure policy options' overall performance.

Table 1. Objectives and their metrics for road pricing schemes evaluation

Objectives	**Indicator**	**Metrics**
RP economic feasibility	Relative investment cost	Qualitative/Verbal Scale *Indicating how expensive is the installation and/or purchase of Equipment for each toll-collection technology.*
RP financial viability	Relative Operational Cost	Quantitative; % of gross revenues dedicated to cover toll collection costs, including administration, enforcement and consumables *Related to toll-collection technique and operational authority structure*
Reduce traffic congestion	Increase in Level of Service	Quantitative; decrease of ratio Traffic Flow/Capacity *Related to speed, traffic volumes and/or vehicle kilometres travelled*
Improve safety	Reduction of accidents costs	Quantitative; % decrease of accident costs *Related to vehicle kilometres travelled*
Improve air quality	Reduction of air pollution external costs	Quantitative; % decrease of air pollution external costs *Related to vehicle kilometres travelled*
Reduce noise annoyance	Reduction of noise external costs	Quantitative; % decrease of noise external costs *Related to vehicle kilometres travelled*
Ensure user convenience	User convenience level in using the RP system	Qualitative, Verbal Scale *Indicating how convenient is for a user to pay charges using each toll collection technique.*

More than half of the above objectives are traffic-oriented (reduction of traffic congestion) or traffic-related (improvement of safety level, improvement of air quality and reduction of noise annoyance). The rest objectives are not traffic-related; they are heavily depended on toll-collection technique and technology and/or on operational authority's structure and efficiency.

In this framework, there was clearly a need of a simple –yet not simplistic- transport model, with manageable data requirements, for estimating the main effects of road pricing policy options for a typical road project. Main effects include the "immediate" (first-order) impacts of road pricing and more specifically impacts on travel costs and road network's functionality (traffic volume, amount of travel, journey time, speed etc.) (CEDR, 2009, Bowerman, 2007, Eliasson, 2008, Downs, 2007).

Then the estimation of "chain" (second-order) impacts, such as reduction of the external costs of accidents, air pollution and noise, could be estimated relatively straightforward, since they are directly related with the amount of travel and traffic's characteristics (CEDR, 2009, Danna et al., 2012, Elvik & Vaa, 2004, Eenink et al., 2007,CE Delft et al., 2008, IPCC, 2007). Estimation of the rest of the objectives was not based on the transport model but on analysis of readily available domain data and expert judgement.

3. Review of transport modelling techniques

3.1 Modelling Techniques in Transport Sector

Transport models are predominantly used to predict transport demand under specific conditions' changes (i.e. infrastructure provision, management measures implementation, pricing instruments enforcement). Two main model types are commonly used, namely:

- Conventional, four-step transport models; the most well-known and commonly used in practice.

- Simplified models; usually applied to make rapid progress in particular circumstances.

Conventional models tend to be complex, time and data consuming (Furnish and Wignall, 2009, TDM, 2014) and more dedicated in analyzing “operational characteristics” (Hensher and Button, 2007), but when it comes to testing demand management options or price-based measures, conventional transport models are limited and other approaches are needed (ARC, 2009, Furnish and Wignall, 2009).

Simplified models represent the transport system with a high degree of network and zonal aggregation and produce mainly “indicative” or “approximate” forecasts, whereas conventional transport models attempt to provide “precise” or “accurate” results (Ortuzar and Willumsen, 2006). Three main types of simplified models are listed below (Furnish and Wignall, 2009, Khisty and Sriraj, 1996, Matas and Raymond, 2003, Zahavi, 1981):
- Simplified demand models: Mode choice models, Elasticity based models
- Structural models: Generalized relationship models, Regression based models.
- Sketch planning models

Simplified models have a number of comparative strengths (Furnish and Wignall, 2009), including: greater segmentation of demand type, behavior and dynamic aspects compared to the normally possible in conventional models, speed and low cost of use, transparency, ease of understanding and use and testing flexibility and accessibility. A great number of simplified models have been developed internationally (De Corla-Souza, 1998, De Corla-Souza and Cohen, 1999, De Corla-Souza, 2002, Department for Transport, 2009b, Khisty and Sriraj, 1996, Ortuzar, 1992, Ortuzar and Willumsen, 2006, US DoT, 2008, US DoT, 2009).

3.2 Modelling Practices for Estimating the Impacts of Road Pricing

Currently, there is no standard approach for representing tolls in travel demand models (Spear, 2005, Vovsha et al., 2005) and there is no consensus as to the best methods for developing traffic (and revenue) forecasts when examine road pricing implementation (Kriger, 2005). The choice of modelling technique varies, according to the intended application/s, the available resources and availability of calibration and/or validation data (Dehghani and Olsen, 1998, Spear, 2005). A review of current practices for road pricing applications identified five major categories of modelling procedures (Smith et al, 2004, Spear, 2005, Urban Analytics Inc. and URS Corporation, 2004):
- **Activity-based** modelling procedure, which allows pricing to be included explicitly into the decision hierarchy. Often, constraints of time and cost limit the ability to gather the data needed in research.
- **Mode choice**; car trips on a tolled or non-tolled road are considered as distinct modal choices within an existing four-step model, with separate modal split functions for work (or work-related) and non-work trip purposes.
- **Trip assignment** models are used to estimate and forecast route choice decision assuming that trip distribution and modal share remain unchanged in the absence of feedback loops. They are usually applied within an existing four-step model.
- **Diversion models** that calculate the market share of travellers who would use a toll facility at varying levels of toll charges. They are used predominantly by transportation consulting firms who develop toll revenue forecasts for investment decisions.
- **Sketch planning methods**, which are quick-response tools for project evaluation. They are often spreadsheet-based techniques that apply similar to conventional models concepts to aggregated or generalized data. Because of their flexibility, these tools are often developed by Authorities' staff or consultants for a specific project.

3.3 Modelling Assumptions and Data Requirements in Road Pricing Analyses

Regardless of the modelling procedure used, a common underlying assumption exists; travellers make economically rational choices in deciding where to go (destination choice), what means of transportation to use (mode choice), and what route to take (route choice). In other words, all modelling processes assume that travellers choose among a set of alternatives and select those having the lowest generalized cost (a combination of monetary and non-monetary costs of a journey) (Spear, 2005). The generalised cost is equivalent to the price of the good in supply and demand theory, and so demand for journeys can be related to the generalised cost of those journeys using the price elasticity of demand. Supply is equivalent to capacity (and, for roads, road quality) of the network.

In economic theory, it is well established that there is an inverse relationship between demand and cost (Hyman and Wilson, 1968), Lesley, 2009), else the price elasticity of demand (for travel) is negative. As such, changes in generalised cost of travel cause inverse changes in demand for travel and this latter mentioned change is usually calculated using the respective elasticity. Since most benefits/costs from interventions/ changes in transport system result from generalized cost changes (Van Wee, 2011), transport models basing demand forecasts on generalized cost changes can provide relatively straightforward quantitative estimations of dominant benefit/cost categories i.e. safety impacts, environmental impacts etc.

4. Development of Consensus transport model

Review of various modelling techniques and specifically their suitability and/or applicability for road pricing policy impacts' assessment, their comparative advantages and drawbacks, the underlying (modelling) assumptions and their data requirements led to the following main conclusions:

- the inherent structure of conventional models tends to make them complex to use, data and time consuming and often unresponsive to such policy options testing (at least not without substantial modification),
- simplified models and especially diversion (post processor) models or sketch planning methods they are considered more flexible, quick-response, easy to understand and use and as such are often developed and used by Authorities' staff or consultants; they still apply similar to conventional model concepts but to aggregated or generalized data and usually for a specific project.
- regardless of the modelling procedure used, two common underlying assumptions exists; travellers make economically rational choices (based on generalized cost of travel) and there is an inverse relationship between travel demand and generalized cost of travel.

Based on the above and bearing in mind Consensus transport (road pricing) policy scenario specificities:

- the "project basis" implementation level, where road pricing policy concerns imposing tolls on a specific project (either a new project or the upgrade of an existing roadway),
- the necessity of assessment at the early stages of policy development, else at the so-called strategic level, where analysis focuses on quick -yet reliable- investigation of the main -yet broad- impacts on specific toll facilities or roadways,
- the rather limited time-frame during, Consensus project, for modelling procedures and the lack of a readily available (sophisticated) software
- the quantity and quality of publicly available data and literature/research/case studies, especially on transport models basing demand forecasts on generalized cost changes using respective elasticities

Consensus transport model was decided to be a "simplified" sketch model tailor-made for (the generic case of) a new road project or for the upgrade of an existing roadway, adopting diversion models' technique and assuming that main demand drivers are roadway capacity and generalized cost of travel; as such produce/ forecast changes in demand using the selected drivers changes as well as respective elasticities.

To accomplish that, an ordered process of five main stages of development –before its application in the framework of Consensus project - was followed, as depicted in Figure 1.

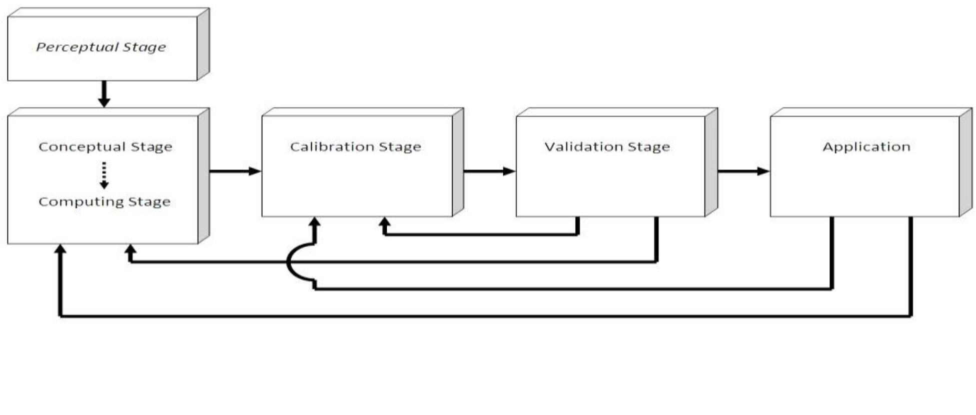

Fig. 1. Model Development Stages

- **Perceptual stage**: It aims at developing the perceptual process that is a general understanding of road pricing policy alternatives' possible impacts on travel costs and road network's functionality (traffic volume, amount of travel, journey time, speed etc.).
- **Conceptual stage**: In this stage, perceptual processes are described and simplified by equations based on transport literature and practice, i.e. default values and/or coefficients of parametric equations.
- **Computing stage**: This third stage involves transferring the conceptual process to computer code. The main product of this stage is a spreadsheet-based model which can be used to efficiently produce estimates of traffic and related factors (speed, time and costs) changes per road pricing policy alternative examined.
- **Calibration stage**: Model calibration is the process of adjusting various model parameters in an effort to better represent real conditions.
- **Validation Stage**: Validation is the process of comparing modelled results against observed data. Ideally, the observed data are data not used for the model development or calibration but, practically, this is not always feasible.

In reality, the process of validating and calibrating a transport model is an iterative process.

Perceptual Stage

Road pricing impacts on travel costs

The direct economic impact of road pricing is a rise in travel and freight costs (Figure 2); this affects in turn the volume of trips and deliveries or the routing of trips and deliveries. If pricing is scaled/differentiated according to the time of day and/or by the characteristics of vehicles, there will also be an impact on the timing of travel and deliveries and maybe on the characteristics of the vehicles used (CEDR, 2009).

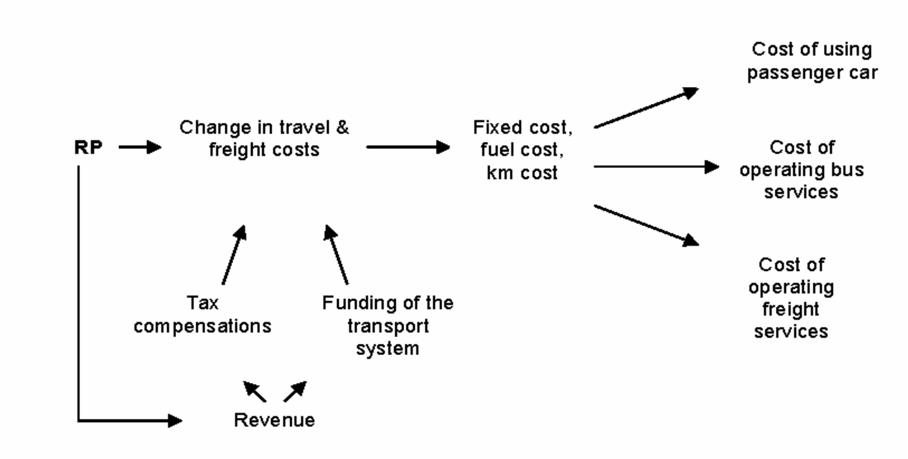

Fig. 2. Impacts of road pricing on travel and transportation costs *(Source: CEDR, 2009)*

Road pricing impacts on road networks functionality

Since road pricing has an impact on travel behavior and freight patterns, it affects the functionality of transport links (Figure 3).

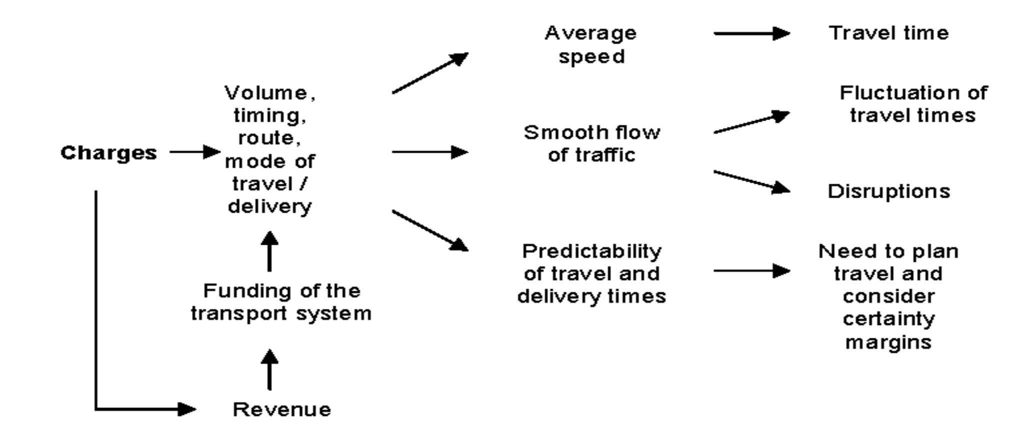

Fig.3. Impacts of road pricing on road network functionality *(Source: CEDR, 2009)*

Pricing can affect the volume, the distance travelled, the timing of travel as well as the modal split or the route choice on local networks (Bowerman, 2007). Functionality improvements take place if congestion or stop-and-go traffic during peak hours is reduced. As the flow of traffic improves, travel times and vehicle operating costs reduce, thereby outweighing the cost impact of charges (CEDR, 2009). Also, travel times become more predictable and travel planning is easier, which in turn causes further time savings as travelers have fewer needs to budget additional time to avoid late arrival (Danna et al., 2012).

Conceptual Stage

The basic equations of this stage include:

- Demand drivers' estimation; mainly generalised cost (incl. travel time cost and vehicle operating costs),
- Demand changes estimation; as a function of specific drivers/factors affecting it (generalised cost and roadway capacity) as well as respective elasticities of demand,

Demand drivers

The development of an analytical model to estimate the likely 'capture' (in percentage terms') of in-scope traffic by toll roads requires the conversion of all costs and benefits in the same units. In particular, time and money needed to be converted to the same currency often termed "generalized cost". As part of this process, a "Value of Time" (VoT) is calculated for all the key behavioural segments in the model.

An improvement in supply conditions due to for example an improvement in the corridor capacity leads to a reduction in equilibrium generalized cost. To define generalized cost; generalized cost is an amount of money representing the overall disutility (or inconvenience) of travelling between a particular origin (i) and destination (j) by a particular mode (m) (Vovsha et al., 2005). In principle, this incorporates all aspects of disutility including the time given up, money expenditure and other aspects of inconvenience/ discomfort, but in practice the last of these is usually disregarded.

For travel between (i) and (j) the user benefit is estimated by:

$$User\ Benefit_{ij} = Consumer\ surplus_{ij}^{I} - Consumer\ surplus_{ij}^{O} \qquad \text{[Eq. 1]}$$

Where 'i' indicates the do-something scenario (in our case the proposed project, either this is an upgrade of an existing roadway or a new corridor) and '0' the do-nothing (the base case). A useful approach in explaining travel choices is to relate demand to a generalized cost which incorporates various important elements.

Generalized cost function should be considered as a linear function of its component variables. More specifically, the **travelers' generalized cost** (Equation 2) is a linear additive function of Level-of-Service (trip length, time) and price components (direct monetary costs such as tolls charged) related to the perceived disutility of travel. The components of the journey are weighted by parameters which are compiled (e.g. km-costs), or perceived by the traveller (e.g. value of time). Generalized costs in are differentiated by vehicle type (passenger cars, trucks) - and trip purposes (commuting, all other) for the variable of 'value of time'-.

$$c_{ij}^{m,tp,ut} = \alpha_1 * \mathrm{T}_{ij} + \alpha_2 * D_{ij} + Toll \qquad \text{[Eq. 2]}$$

where

$c_{ij}^{m,tp,ut}$: generalised cost of travelling from zone (i) to zone (j), by vehicle type (m) for trip purpose (tp) and for user type (ut).

α_1 : value of time, for vehicle type (m) and trip purpose (tp)

T_{ij} : travel time from zone (i) to zone (j).

α_2 : vehicle operating cost for vehicle type (m)

D_{ij} : distance from zone (i) to zone (j).

$Toll$: any toll encountered by a trip from zone (i) to zone (j), for vehicle type (m) and for the specific user type (ut).

m : vehicle type, m= passenger car, truck
tp : trip purpose, tp = commuting, other
ut : user type, ut= frequent (discount), random

Values of time for passenger car users are usually estimated based on Stated Preference (SP) surveys. Well-known research projects and studies (UNITE, 1999, HEATCO, 2006, IMPACT, 2008) summarized and further analyzed scientific and practitioner's knowledge on the issue in order to ultimately recommend a set of values of time. The HEATCO study being one of the most complete, recent and officially suggested by the EC was also chosen in the framework of Consensus. The HEATCO study provides unit values for time in (€/passenger/hour), for each EU country, for different trip purposes (HEATCO, 2006).

Vehicle operating cost is heavily dependent on the road geometry and road operational characteristics, travel speed and pavement condition. Vehicle operating costs include costs for fuel, maintenance, tyre replacement, depreciation, tax and insurance.

To derive vehicle operating costs the methodology proposed by Poriotis and Vakirtzidis, 2001 was used, where vehicle operating cost is calculated as a function of the average travel speed for each vehicle type, using the following equation:

$$VOC^m = a*V^2 + b*V + c \quad \text{[Eq. 3]}$$

where

VOC^m : vehicle operating cost, for vehicle type (m)
V : vehicle's speed (in km/hour)
a,b,c : parameters dependent on vehicle's technical characteristics, and are:

Parameters' values for..	Passenger Cars	Trucks
a	0,00002914	0,000135
b	-0,00502432	-0,017436
c	0,4256765	1,426324

Forecasting demand changes

As already mentioned, Consensus model adopts diversion models' technique, as such the model presented does not account for "induced traffic". It only accounts for generated traffic. Generated traffic is the additional vehicle travel that results from a road improvement, particularly expansion of congested urban roadways (Litman, 2014). The upgrade of an existing corridor or the construction of a new corridor/facility/spot usually leads to generalised cost reductions. Shortly after the road improvement, new traffic is generated coming from other routes, times or modes.

New motorways, especially those in heavily congested urban areas, can have levels of growth higher than those expected; this extra traffic is called "induced traffic". However, usually existing land use (e.g. location of residence or work) constrains such behavioural changes, on most trunk road schemes induced traffic impacts resulting from such changes are likely to appear progressively and be limited to the long term (10 or more years). Furthermore, in most cases, although the new schemes are expected to create significant reduction in travel time, the timesaving benefits will be outweighed by the higher tolls; consequently, induced traffic will be limited.

A number of sensitivity tests were run using the transport model, comparing the Do-nothing and the Do-Something and the increase in the number of trips arising due to elasticity application on the generalised cost by trip purpose was estimated less than 2%. Therefore, it was decided to ignore induced traffic, as the impact on revenues would be negligible.

The key assumption of Consensus transport model, when forecasting demand, is that demand (Y) changes, due to roadway improvements and/or conditions changing, are estimated based on changes of two main demand drivers (factors/variables affecting demand), capacity (CP) and generalized cost (c) (see general Equation 4)

$$Y = f(c, CP) \qquad \text{[Eq. 4]}$$

Key piece of information needed for travel forecasting, in the absence of a 4-stage traffic model, are the elasticities. The elasticities provided in this project are the outcome of a very wide literature review and cover various studies from different geographical locations (BITRE, 2014, Center for Transportation Analysis, 2014, Cervero and Hansen, 2000, De Borger and Wouters, 1998, De Jong et al., 1998, Department for Transport, 2001, Department for Transport, 2004, Greene, 1992, Gunn et al., 1998, Hansen and Huang, 1997, Noland and Lem, 2002, Rothengatter and Doll, 2001, Santos, 2000, Santos and Shaffer, 2004, Schnier, 1999, Small and Winston, 1999, TfL, 2004, TRB, 1980, Troyer, 2002, Winston, 1985, Winter and Hirschhausen, 2005).

Consensus model uses travel demand elasticities (measured in vehicle-kilometers travelled) with respect to capacity and generalized cost, to estimate new travel that may be generated over and above traffic that is simply rerouted from other highways. This includes new trips generated or attracted to new development, and existing trips diverted from other destinations.

An elasticity of demand with respect to capacity of 0.2 and an elasticity of demand with respect to generalized cost of -0.31 were assumed in the transport model. These values were the average of the range of (each) demand elasticity, found in the literature referenced above. The approach taken to determine changes in demand levels due to changes in capacity and generalized cost is based on the PDFH approach (Arup and Oxera, 2010). A very brief outline of this approach is presented in this chapter (for more details refer to Arup's study (Arup and Oxera, 2010). The main idea behind this approach is presented in Figure next.

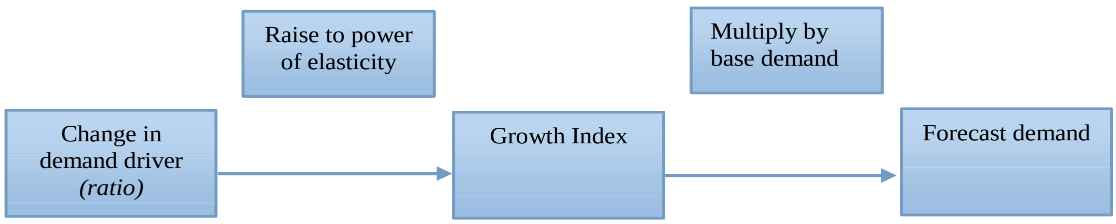

Fig. 4. Schematic of basic PDFH-style forecast *(Source: Arup & Oxera, 2010)*

To estimate/forecast the level of new demand, an index of the ratio of new demand to previous demand is calculated. The index is then applied to an existing demand level to determine the forecasted value of new demand after the roadway improvement and pricing policy implemented. In the Consensus transport model, where demand is changed due to changes in generalized cost and capacity levels, the formula of the index is given below in Equation 5 and then Equation 6 is used to forecast the new demand:

$$I = \left(\frac{CP_P}{CP_{BC}}\right)^{El_{\cdot CP}} \times \left(\frac{c_P^{m,tp,ut}}{c_{BC}^{m,tp,ut}}\right)^{El_{\cdot c}} \qquad \text{(Eq. 5)}$$

$$Y_P^{m,tp,ut} = I \times Y_{BC}^{m,tp,ut} \qquad \text{(Eq. 6)}$$

where:

I : index ratio

CP_P : roadway section capacity, for proposed project

CP_{BC} : roadway section capacity, for base case situation

$c_{P}^{m,tp,ut}$: generalised cost of travelling by vehicle type (m), for trip purpose (tp), for user type (ut), for proposed project

$c_{BC}^{m,tp,ut}$: generalised cost of travelling by vehicle type (m), for trip purpose (tp), for user type (ut), for base case situation

$El._{CP}$: elasticity of demand (in vehicle-kilometres travelled) with respect to roadway capacity

$El._{c}$: elasticity of demand (in vehicle-kilometres travelled) with respect to generalized cost of travel

m : vehicle type, m= passenger car, truck

tp : trip purpose, tp = commuting, other

ut : user type, ut= frequent (discount), random

$Y_{P}^{m,tp,ut}$: demand (in vehicle-kilometres travelled) by vehicle type (m), for trip purpose (tp), for user type (ut), for proposed project

$Y_{BC}^{m,tp,ut}$: demand (in vehicle-kilometres travelled) by vehicle type (m), for trip purpose (tp), for user type (ut), for base case situation

Index and demand (in equations 5 and 6 respectively), are estimated first by user type and trip purpose, then by vehicle type and finally they are aggregated. The basic result of equation 6 is forecasted demand in vehicle-kilometers travelled. Nonetheless, it can be transformed into traffic flow as well (in vehicles).

Computing stage

Third stage involves transferring the conceptual process to computer code. The main product of this stage is a spreadsheet-based model structured in two main interfaces: an Input Data manipulation interface and the Computational interface.

Input Data Interface

The Input Data manipulation interface allows the user: (i) to describe the current situation ("base-case" scenario) that generates the need of a specific road project, (ii) to describe the proposed road project on which the various road pricing policy alternative scenarios will be tested, (iii) to examine the available (pre-defined) set of alternative road pricing policy scenarios under comparison and (iv) enter his/her readily available data concerning the "base-case" and/or proposed/alternative scenario; and –in the case of limited data availability- provide the user with a set of default data in order to assist him/her to make reasonable assumptions without much risk.

More specifically, "Input Data" worksheet contains separate sections for (manageable) data inputs:

General information: Project Country, Project Name, Type of Project (Upgrade of existing roadway or New construction), Scale of Project (Corridor, Facility or Spot), Project Area (Urban/Small, Urban/Large or Interurban),

Base-case Roadway information: Length (in km), Lanes/direction and Roadway Capacity/direction.

Project information: Length (in km), Lanes/direction, Roadway Capacity/direction, Alternative options to the road user (availability of both routes and other modes, availability of other routes but no other modes, availability of other modes but not routes, no available routes or modes),

Base-case Traffic data information: Average annual daily traffic in vehicles, Average annual kilometers travelled – and if not available- Average trip length, Peak hour factor, % of passenger cars in vehicle fleet, % of trucks in vehicle fleet, PCE (passenger car equivalent) of trucks, % of commuting trips, % of all other trip purposes, Speed for passenger cars, Speed for trucks.

Policy options to be examined, which includes basically

- Basic toll (else, the final toll level to be paid by a passenger car, in €/ in bound trip, regardless the pricing structure)

- Data concerning frequent (ETC) users (% of ETC users and % discounts for ETC users)

Other data points in this section are mostly pre-defined options provided to the user (just to view), including:

- Road pricing type,
- Toll collection technique,
- Operation authority,
- Toll unit
- Toll levels per vehicle category (passenger & truck)

Each of these data points/cells is highlighted with a specific colour in order to guide users which data to put, alter or not, choose from a list etc.

Values for the following key parameters for the base case scenario and the roadway improvement (proposed project) scenario should be estimated by users since they cannot be assumed or found –as default values- in any data sources:

- Project's country and name,
- Roadway length (in kilometres), both for base case and proposed project,
- Average Annual Daily Traffic, for base case,
- Estimation of share of commuting trips in total trips,
- Average travel speed for passenger cars,
- Average travel speed for trucks,
- Basic Toll,

All other values are either pre-defined drop-down lists, default values - based on recommended values in transport literature as well as current transport practice depicted from experts in road sector- or calculated values. Default values are further separated into two categories; those that can and those that cannot be altered.

Drop-down lists of values include, the following (lists of values include options in brackets -as formed based on current practice):

- Type of Project (Upgrade of existing roadway or New construction),
- Scale of Project (Corridor, Facility or Spot),
- Project Area (Urban/Small, Urban/Large or Interurban),
- Lanes/direction (1, 2, 3, 4, 5, 6),
- Alternative options offered to the road user (availability of both routes and other modes, availability of other routes but no other modes, availability of other modes but not routes, no available routes or modes),

Default values that can be altered are:

- Peak hour factor; peak hour factor's suggested value is given as 8%,
- % of trucks in vehicle fleet; an average –on EU level- suggested value is 15%,
- Passenger Car Equivalent (PCE) of trucks; a value of 3.5 is used, based on common transport analysis practice)
- ETC market penetration; the values used in this final version of the model vary from 40% to 100%, according to the type of area as well as toll collection technique. *Those values were empirically suggested from road authorities' and operators' representatives that participated in the two Consensus pilot trials.*
- % discount of ETC users; suggested values vary from 0% to 15%, according to toll collection technique. *Those values were empirically suggested from road authorities' and operators' representatives that participated in the two Consensus pilot trials.*

Default values that are not to be changed (users are advised not to alter these values) include:

- Lane capacity (equals 1800 PCE/hour for urban corridors and 2000 PCE/hour for interurban corridors), and
- Average trip length (for urban/small areas the suggested value is 10 km, for urban/large areas 15 km and for interurban areas 35 km),
- Road pricing type (pre-defined types, decided when setting the transport policy context of Consensus: flat-rate, distance-based or congestion charging),
- Toll collection technique (pre-defined techniques, decided when setting the transport policy context of Consensus: pass, toll booths, Electronic Toll Collection (ETC), Optical Vehicle Recognition System (OVR), GPS (or GNSS) based pricing and their combinations),
- Operation authority (public or private entity, based on common practice),
- Toll unit (€/in bound trip or €/km travelled, based on common transport analysis practice)

All other values are calculated, i.e. % of passenger cars in vehicle fleet is calculated subtracting the respective % of trucks or i.e. toll for trucks is calculated multiplying toll for cars with PCE.

After the user provides all necessary input values (either as a direct input, either through confirming/altering model's suggestions or as a choice from the pre-defined lists of options), a range of alternative road pricing policy scenarios, which are applicable/suitable for the proposed project, is provided by the model in order to be tested next in the Computational interface.

These policy scenarios include all possible combinations of: road pricing policy types (flat-rate, distance-based or congestion charging), toll collection techniques (passes, toll booths, Electronic Toll Collection (ETC), Optical Vehicle Recognition System (OVR), GPS (or GNSS) based pricing - *and their combinations*), the authority responsible for road operation (public or private entity), the price level and possible variations (i.e. per vehicle category, per frequency of use/ETC users market penetration and discount of ETC users).

Model produces a unique ID for each policy scenario, in order to ease its identification from the user in one glance i.e. a road pricing policy scenario concerning application of flat-rate Road Toll on a roadway operated by a public authority, where car users pay 3€/in bound trip, either by stopping at toll booths or using ETC smart card, will have an ID of "**Road Tolls_Booths&ETC_3_€/in bound trip_Public**". The "applicability" indication can be found directly below Scenario IDs.

Computational interface

Based on data summarized/provided into the "Input Data" interface and using the algorithms and databases presented in the Conceptual Stage, traffic impacts (else forecasts demand for travel in terms of vehicle-kilometers travelled) of all the applicable road pricing policy scenarios (identified by their IDs) are estimated. No values within this worksheet should be altered by the user.

First, for each alternative road pricing policy scenario the model, based on the average daily traffic of base case, as specified by the user, and the average trip length (the selected default value is based on project's area, as defined by the user) calculates vehicle-kilometers travelled (VKT) in base case. Then, using VKT of base case, the initial daily and hourly VKT (using average days/ year and peak hour factor) per vehicle type and trip purpose (using fleet composition data as well as trip purposes data) are estimated.

Following that the Level-of-Service (LoS) of the base-case roadway is calculated based on the Highway Capacity Manual (HCM) method (TRB, 1994). According to the HCM, the LoS is based on the density of the vehicles, expressed in passenger cars per km per lane and is evaluated with average travel speeds (in our case speed is specified by the user). Average travel speeds for each LoS designation are presented in Table 2.

Table 2. HCM Level of Service Criteria, for basic freeway sections

LoS	**Description**	**Speed (km/h)**		**Flow (veh/h/lane)**	
A	Free flow; motorists have complete mobility.	>=98		0	700
B	Reasonably free flow. Manoeuvrability within the traffic stream is slightly restricted	92	97	701	1100
C	Stable flow. Ability to pass/change lanes constrained. This is target LoS for most urban highways.	88	91	1101	1550
D	Approaching not stable flow. Speeds somewhat reduced, vehicle manoeuvrability limited. Typical urban peak-period highway conditions.	75	87	1551	1850
E	Unstable flow. Flow becomes irregular, speed vary and rarely reach the posted limit. This is considered a system failure.	49	74	1851	2200
F	Forced or break-down flow. Flow is forced; travel time is unpredictable.	0	48	2201	3000

The next step is calculation of the generalised costs of travel for the base case (per vehicle type and trip purpose). This is mainly done using equations 2 and 3 as well as VoT values (based on project's country, vehicle type and trip purpose), speed (based on vehicle type) and average trip length (based on project's area).

Then, investigation of how the additional capacity -in comparison to the base-case - will affect traffic flows and travel speed, takes place. This is estimated using the Index of capacity and the elasticity of demand (in VKM) with respect to capacity. This is done using equation 5. The additional capacity is estimated based on lanes per direction and lane's capacity (based on project's area).

Once vehicle travel speed of the built scenario is estimated (using HCM method) the generalised costs for all vehicle types and trip purposes are calculated, in each alternative road pricing policy scenario, using equations 2 and 3. Then the ratio of old over new generalised cost is calculated (Index), using the elasticity of demand with respect to generalised cost (using equation 5).

The final product is the computation of the final daily VKT per vehicle types for each of the alternative road pricing policy scenario examined, using equation 6.

Calibration/Validation Stages

In practice the meanings of calibration and validation have changed over the years. This is especially true in cases where there exist limited resources-and certain limitations (time and/or funds) preclude the conduct of traffic counts or obtention of real traffic data. In such cases, the processes of calibration and validation may become a single exercise.

In the absence of real traffic data, models can be calibrated by using default values derived from other studies. This is clearly the situation of Consensus transport model, as this model is a simplified sketch elasticity-based one, developed for the generic case of a new or upgrade of an existing project, and as such: (a) there is no specific location and/or network simulated and (b) all parameters and equations are based on extended literature and practice review.

Based on this assumption, the model is by default calibrated, while validation can be performed by reviewing the performance of the model on a number of case studies and by comparing the estimated results with the expected values (traffic and related impacts) based on existing literature.

As this transport model is generally represented by one cordon link, it should be validated against AADT counts (for the base year), and observed average travel speed of a road project either concerning a sole road corridor or at least a very simple network.

The standard theory and method used to compare modeled values against observations on a link involves the calculation of the Geoff Havers (GEH) statistic, which is an empirical form of the Chi-squared statistic, proven extremely useful for a variety of traffic analysis.

The empirical formula for the "GEH Statistic" is:

$$GEH = \sqrt{\frac{2*(M-C)^2}{M+C}} \qquad \text{(Eq. 7)}$$

where M is the average hourly traffic volume from the traffic model and C is the observed average hourly traffic count.

In general a GEH value of less than 5.0 is considered as a good match between the modeled and observed flows. A GEH value in the range of 5.0 to 10.0 may warrant further investigation, and a GEH value >10 means that there is some error either in the modeled volume or the observed volume at that particular location.

A number of tests, based on real/implemented case studies, were run using the transport model and all returned GEH values ranging from 3.5 to 4.7; these results indicated a rather good mach between the modeled and observed flows and to this end the model was successfully validated.

5. Conclusions

The transport model was applied in the framework of Consensus in order to produce a (defensible) simulation of "immediate" (first-order) impacts of road pricing policies (traffic volume, amount of travel, journey time, speed etc.) on a given road project. Model results supported the estimation of the traffic-oriented/-related policy objectives of the Consensus transport policy scenario (i.e. reduction of traffic congestion, improvement of safety level, improvement of air quality and reduction of noise annoyance).

Consensus transport policy scenario final results were evaluated, among others, in terms of "Reliability of results". The specific KPI meant to evaluate, even indirectly, the ability of the transport model in producing (if not accurate at least) approximate, yet comparatively reliable, estimates of road pricing policies' impacts. Pilot evaluation results, for the specific KPI, verified that model's results seem rather realistic and the model was considered as able to supply an objective, scientifically supported 'first glance' of alternative road pricing policy options impacts and as such assist in their pre-screening of those promising/suitable for further development.

Analytical feedback, collected from interviews performed during pilot evaluation process indicated both pros and cons of the developed model.

Consensus model, as all simplified models has certain limitations and its results will always contain uncertainties, no matter how sophisticated this may become; it cannot represent a detailed network or spatial areas and since it relies on the transfer of assumed relationships from one context to another it is not suitable for detailed project appraisal. To this end, Consensus transport model, like all simplified sketch models, need to be used and interpreted appropriately and can only ever provide indicative, comparative and approximate answers.

On the other hand, Consensus transport model does not produce misleading results, order of magnitude type errors or incorrect relationships, any of which would be unhelpful or potentially counter-productive. It might not produce accurate results but it provides "*approximate, yet comparatively reliable, estimates*" (CONSENSUS, 2016). Furthermore, it is -by far- an easier/less complex, less time consuming, less data demanding and as such less expensive to use transport model. Finally, since it is structured for the "generic case" of a new road project or for the upgrade of an existing one it can be adapted to any road project, as long as this project concerns a sole road corridor or at least a very simple network.

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