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URBAN SUSTAINABLE MOBILITY. PART 2: SIMULATION MODELS AND IMPACTS ESTIMATION

Summary. The urban sustainable transport policies are very different in terms of costs and expected benefits, and the effects of these policies and their combinations are difficult to anticipate on a purely intuitive basis and sometimes the end effect could be contrary to intuitive expectations (e.g. policies aimed to reduce pollution, ending up in increasing it). In this context, the concept of eco-rational planning assumes a central role. This means identifying the right mixture of interventions to be implemented on the transport system that is: rational for the transport system and sustainable for people's health and for the environmental and requires minimal economic resources. Starting from the results of the compendium paper (Part 1), the paper investigate on non-rational sustainable transport policies through an ex-post analysis on real casa application in Naples (Italy).

ZRÓWNOWAŻONA MOBILNOŚĆ MIEJSKA. CZĘŚĆ 2: MODELE SYMULACYJNE I OSZACOWANIE ODDZIAŁYWANIA

Streszczenie. Polityki zrównoważonego transportu miejskiego są bardzo różne pod względem kosztów i spodziewanych korzyści. Skutki polityk i ich kombinacje są trudne do przewidzenia na podstawie czysto intuicyjnej i czasem efekt może być sprzeczny z oczekiwaniami (np. polityka zmierzające do zmniejszenia zanieczyszczenia, kończąca się jego zwiększeniem). W tym kontekście pojęcie ekoracjonalnego planowania zaczyna mieć podstawowe znaczenie. Oznacza to identyfikację odpowiedniego zestawu działań (w celu wdrożenia w systemie transportowym), który jest: racjonalny dla systemu transportu i zrównoważony dla zdrowia ludzi i dla środowiska oraz wymaga minimalnych zasobów gospodarczych. Począwszy od wyników pracy przedstawionych w części pierwszej, artykuł przedstawia niezbadane racjonalne polityki zrównoważonego transportu przez analizy prawdziwych przypadków zaistniałych w Neapolu (Włochy).

1. INTRODUCTION

The impact of the transport sector is in the range of 20%-40% in terms of consumption of fossil fuels and emissions of greenhouse gases and particulate matter. In this context, policies aimed at reducing these effects are very important and have dual objectives at the global and local level. To this end, many urban areas are trying to adopt planning strategies aimed to a sustainable use of resources often referred to as sustainable mobility. These policies are very different in terms of costs and expected benefits, both at the global and local level. Because of the well-recognized nonlinear interdependencies of urban transportation systems [4] the effects of these policies and their combinations are difficult to anticipate on a purely intuitive basis and sometimes the end effect could be contrary to intuitive expectations causing a “non-rational effects” (e.g. policies aimed to reduce pollution, ending up in increasing it).

In this context, the concept of rational planning assumes a central role. In the compendium paper Part 1 the concept of “*eco-rationality*” was introduced as acting in the best possible way considering *eco*logical and *eco*nomic aims (pollution reduction; welfare improvement; congestion reduction; economic necessities) and constraints (e.g. budget; resources; levels of pollutants). Eco-rationality means identifying the right mixture of interventions to be implemented on the transport system that is: rational for the transport system, sustainable for people’s health and for the environmental and satisfy the basic economic necessities.

One of the main element for pursuing eco-rationality are the quantitative methods (tools) for ex-ante and ex-post evaluations. The traditional role of quantitative methods in supporting transport-related decision processes is mostly oriented to “forecasting” the impacts of alternative options while little effort is dedicated to ex-post analyses of system performances and to the forecast reliability.

To underline the importance of the ex-ante analysis for sustainable transportation planning, in this paper was applied some transport simulation models for an ex-post evaluation performed to quantify the “*non-rational effects*” of two transport policies applied in Naples, Italy (see the results also in the compendium paper Part1).

2. CASE STUDY AND SIMULATION MODELS

As described in the compendium paper Part 1, the application case study is the city of Naples in southern Italy, a city with a population of about 960 thousand inhabitants and a population density of 8.2 thousand inhabitants/km^2. To estimate mobility characteristics and model’s parameters, a specific traffic counts survey was performed in the period 2007-2011. Starting from these surveys and from the results obtained (see the compendium paper Part 1), a simulation model (Fig. 1) was implemented to simulates the relevant interactions among the various elements of the Naples transportation system and to estimate the performance of the system estimating some indicators (e.g. average speed; km/year travelled by vehicle category; fuel consumption, vehicles emissions) both related to the base scenario (2011) and referring to design scenarios.

Impacts of transport policies were estimated through Nested Logit models to take into account the influence of “lower” choice dimensions on “upper” levels (both for passenger and for freight). In demand model specification, several attributes were considered: socio-economic (e.g. resident population by market segments of the number; employers and firms in economic activity sectors), level of service (e.g. travel time, travel cost, waiting time) and dummy variables (e.g. geographic and accessibility attributes). With respect to the assignment model [2], stochastic user equilibrium assignment was considered for car passenger mode, while stochastic network loading assignment model was used for freight vehicles. In the next sections the main element of the simulation models are reported; for all the details on the data, models and calibration methods and sample see also [1, 3, 5].

2.1. The passenger demand model

For the estimation of the passenger demand the *Activity-based choice model* [4] implemented by Bifulco et al. [1] was applied. The choice dimensions considered in the model were:

1. *activity pattern choice*;
2. *tour choices*, consisting in:
   (a) first tour:
      (i) time-of-day choice;
      (ii) destination choice;
      (iii) mode choice;

(b) second tour:
   - (i) time-of-day choice;
   - (ii) destination choice;
   - (iii) mode choice.

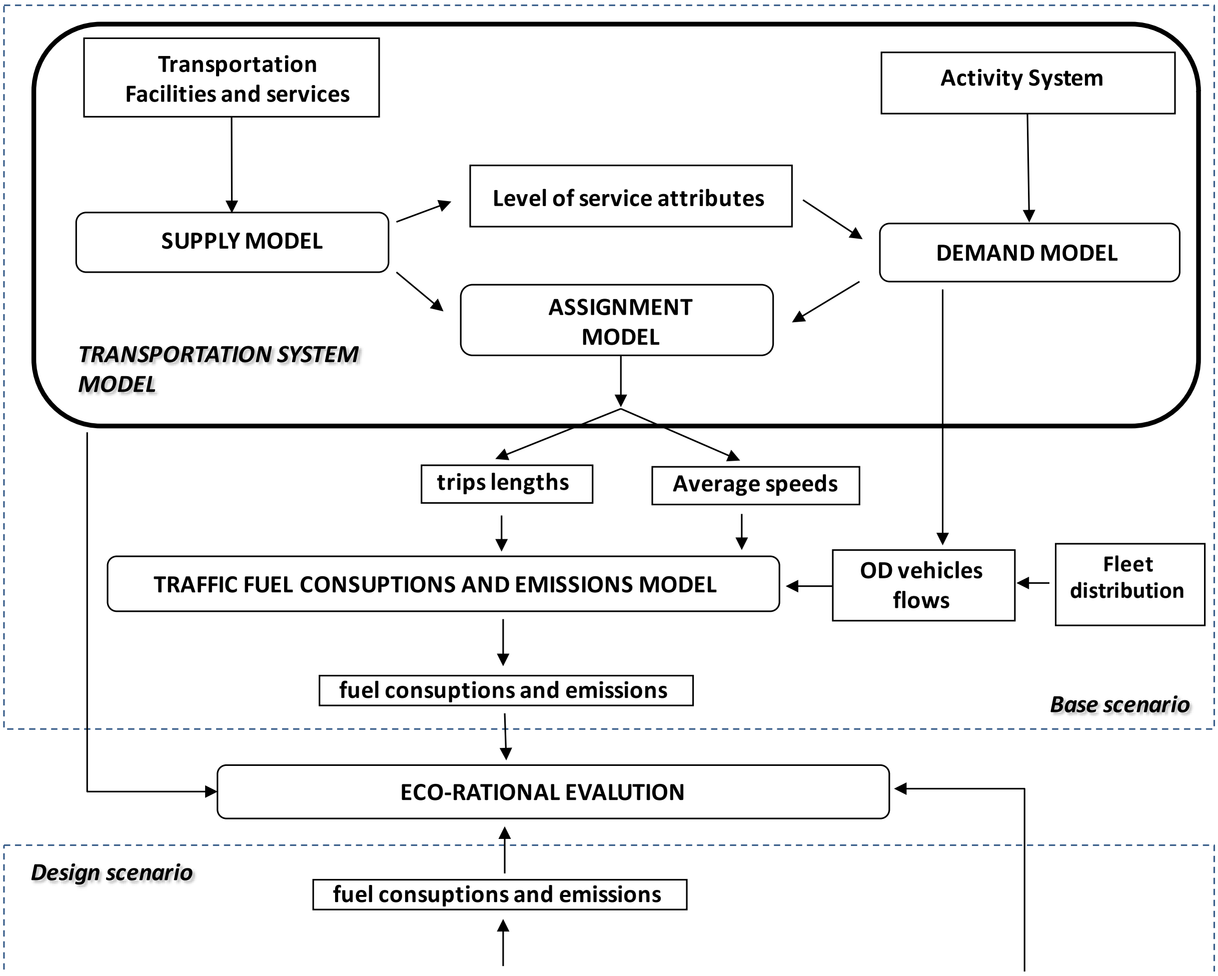

Fig. 1. The eco-rational Decision Support System (DSS)
Rys. 1. Eko-racjonalny System Wspomagania Decyzji (DSS)

From this choice hierarchy the following model structure was considered:

- *Daily Individual Activity Pattern Model (DIAPM*), which combines the individual daily activities leading to actual activity patterns and related trip-chain sequences:
  - *activity pattern choice model*, reproduces the choice of the activity pattern π (with $\pi \in \{1,2,3,4,5\}$ see Tab. 1) for each origin zone *o*;
- *Trip chain Model*, which reproduces the organization of all trips provided within an activity pattern:
  - *first tour time-of-day choice model*, reproduces the choice of the time-of-day I_1 for the first tour (see the alternatives in Tab. 2);
  - *destination choice model for the first tour*, reproduces the choice of the first destination d_1;
  - *mode choice model for the first tour*, reproduces the choice of the mode m_1 for the first tour (with $m_1 \in \{car, public\ transport, motorbike\}$);

- *second tour time-of-day choice model*, reproduces the choice of the time-of-day I_2 for the second tour. The choice set of this choice dimension is considered a function of the time constraints of the first tour (if the first tour has not ended, the second cannot start);
- *destination choice model for the second tour*, reproduces the choice of the second destination d_2;
- *mode choice model for the second tour*, reproduces the choice of mode m_2 (with $m_2 \in$ {car, public transport, motorbike}) for the second tour.

In Tab. 3 the attributes used in the systematic utilities are reported, while in Tab. 4 the values of the model parameters are represented.

Table 1

The activity patter alternatives

Id.	*activity-patterns*	*%*	*activity*	
1	H-W-H	28.5%	H	Home
2	H-W-H-W-H	14.9%	W	Work
3	H-W-H-L-H	4.7%	L	Leisure
4	H-W-H-P/D-H	3.3%	P/D	Pick-up and Delivery
5	H-W-H-O-H	2.7%	O	Other
	Total	*54.2%*		

source: [1]

Table 2

Time-of-day alternatives (first and second tour)

	first tour		*second tour*	
id	*start*	*finish*	*start*	*finish*
1	7:00-9:30	12:30-15:00	15:00-17:30	15:00-17:30
2	7:00-9:30	15:00-17:30	15:00-17:30	17:30-20:00
3	7:00-9:30	17:30-20:00	17:30-20:00	17:30-20:00

source: [1]

Table 3

The attributes used in the systematic utilities

H-W-H is an alternative specific attribute related to the activity pattern 1: Home – Work – Home;
$Y_{o,\pi}$ is the logsum variable corresponding to the first tour time-of-day choice model, related to origin zone *o* and activity pattern π
$male_o$ is a dummy variable of value 1 if the worker is male, 0 otherwise; this attribute reproduces the preference of male workers of choosing activity pattern 2: Home – Work – Home – Work – Home
$female_o$ is a dummy variable of value 1 if the worker is female, 0 otherwise; this attribute reproduces the preference of women of choosing activity patterns with more than one activity and starting their activities early in the morning.
NoWork2 is a dummy variable of value 1 if the activity pattern π consists of two tours without a work activity in the second tour ($\pi \in \{3,4,5\}$), 0 otherwise
$Y_{o,\pi,I1}$ is the logsum variable corresponding to the first tour destination choice model, related to origin zone *o*, activity pattern π and time-of-day I_1
$\pi 1$ is a dummy variable of value 1 if activity pattern $\pi = 1$ (Home – Work – Home), 0 otherwise; this attribute reproduces the preference of choosing time-of-day 3 (start: 7:00-9:30; finish: 17:30-20:00) for *H-W-H* workers
$work\_own_o$ is the work on one's own percentage in origin zone *o*; this attribute reproduces the preference of this class of workers to work till late in the afternoon (and thus finish the tour between 17:30 and 20:00)
Emp_{d1} is the logarithm of the number of employees at destination d_1; this attribute is representative of zone d_1 attractiveness
$Y_{o,d1,\pi,I1}$ is the logsum variable corresponding to the first tour mode choice model, related to origin zone *o*, destination d_1, activity pattern π and time-of-day I_1
car is an alternative specific attribute
$T_{o,d1,I1}$ is the car travel time (in minutes) from origin zone *o* to the first destination d_1 (and return) during time-of-day I_1
Centre is a dummy variable of value 1 if destination d_1 is inside the city centre, 0 otherwise; this attribute reproduces the disutility of choosing the car mode for reaching the city centre (caused for example by parking difficulties)
$Y_{o,d1,m1\pi,I1}$ is the logsum variable corresponding to the second tour time-of-day choice model, related to origin zone *o*, destination d_1, mode m_1, activity pattern π and time-of-day I_1
fare is the public transport fare (in €)
$Tb_{o,d1,I1}$ is the public transport on-vehicle time (in minutes) from origin zone *o* to the first destination d_1 (and return) during time-of-day I_1
$Tw_{o,d1,I1}$ is the stops waiting time (in minutes) from origin zone *o* to the first destination d_1 (and return) during time-of-day I_1
$Tp_{o,d1}$ is the pedestrian walking time (in minutes) from origin zone *o* to the first stop, between intermediate stops and from the last stop to destination d_1 (and return)
$Ntrn_{o,d1,I1}$ is the number of transfers from origin zone *o* to the first destination d_1 (and return) during time-of-day I_1
motorbike is an alternative specific attribute
$Tm_{o,d1}$ is the motorbike travel time (in minutes) from origin zone *o* to the first destination d_1 (and return)
age_o is the employee percentage in origin zone *o* with age $\in [18, 29]$; this attribute allows us to reproduce the preference of young workers to use the motorbike mode.
ExtraUrb is a dummy variable of value 1 if destination d_1 lies outside the Naples metropolitan area, 0 otherwise; this attribute reproduces the disutility of choosing the motorbike mode for extra-urban trips
$Y_{o,I2,\pi,I1,d1,m1}$ is the logsum variable corresponding to the second tour destination choice model, related to the origin zone *o*, the time-of-day I_2, the activity pattern π, the time-of-day I_1, the destination d_1 and the mode m_1
$manager_o$ is the manager percentage in origin zone *o*; this attribute reproduces the preference of this class of workers of doing work activities in the afternoon (starting between 15:30 and 17:30 and finishing between 17:30 and 20:00)
π_NoWork is a dummy variable of value 1 if activity pattern π does not comprise a work activity in the second tour, 0 otherwise; this attribute reproduces the preference of doing no work activities in the second tour between 17:30 and 20:00
Emp_{d2} is the logarithm of the number of employees at destination d_2
Szone is a dummy variable of value 1 if $d_1=d_2$, 0 otherwise; this attribute reproduces the preference of doing the activity of the second tour within the same zone chosen for the first tour
$Y_{o,d2,I2,\pi,I1,d1,m1}$ is the logsum variable corresponding to the second tour mode choice model, related to origin zone *o*, destination d_2, time-of-day I_2, activity pattern π, time-of-day I_1, destination d_1 and mode m_1
Smode is a dummy variable of value 1 if $m_1=m_2=car$, 0 otherwise; this attribute reproduces the preference of doing the second tour by car if this mode was chosen for the first tour

source: [1]

Table 4

Results in terms of model parameter values

Model		*Alternative*	*Attribute*	β_i	*t_student*	ρ^2/ *MAPD*
DIAP	*activity patterns*	1	*H-W-H*	3.241	4.135	0.289 (ρ^2)
			$Y_{o,\pi}$	1.422	1.512	
		2	$male_o$	1.677	4.855	
			$Y_{o,\pi}$	1.422	1.512	
		3, 4, 5	$female_o$	0.675	1.906	
			$Y_{o,\pi}$	1.422	1.512	
Trip-chain Model	*first tour time-of-day*	1	$female_o$	1.374	3.744	0.197 (ρ^2)
			NoWork2	1.337	3.435	
			$Y_{o,\pi,I1}$	1.452	2.713	
		2	$Y_{o,\pi,I1}$	1.452	2.713	
		3	$\pi 1$	1.303	3.852	
			$work\_own_o$	2.818	2.986	
			$Y_{o,\pi,I1}$	1.452	2.713	
	first tour destination	d_1	Emp_{d1}	0.982	-	19% (*MAPD)*
			$Y_{o,d1,\pi,I1}$	0.587		
	first tour mode	*car*	*car*	0.713	-	12% (*MAPD)*
			$T_{o,d1,I1}$ *(minutes)*	-0.032		
			centre	-2.296		
			$Y_{o,d1,m1,\pi,I1}$	0.221		
		public transport	*fare (€)*	-0.002	-	
			$Tb_{o,d1,I1}$ *(minutes)*	-0.037		
			$Tw_{o,d1,I1}$ *(minutes)*	-0.021		
			$Tp_{o,d1}$ *(minutes)*	-0.013		
			$Ntrn_{o,d1,I1}$	-0.307		
			$Y_{o,d1,m1,\pi,I1}$	0.221		
		motorbike	*motorbike*	-1.381	-	
			$Tm_{o,d1}$ *(minutes)*	-0.007		
			age_o	0.631		
			ExtraUrb	-2.314		
			$Y_{o,d1,m1,\pi,I1}$	0.221		
	second tour time-of-day	1	$Y_{o,I2,\pi,I1,d1,m1}$	0.077	0.667	0.342 (ρ^2)
		2	$manager_o$	1.031	2.155	
			$Y_{o,I2,\pi,I1,d1,m1}$	0.077	0.667	
		3	π*_NoWork*	1.776	3.365	
			$Y_{o,I2,\pi,I1,d1,m1}$	0.077	0.667	
	second tour destination	d_2	Emp_{d2}	0.401	-	25% (*MAPD)*
			Szone	0.651		
			$Y_{o,d2,I2,\pi,I1,d1,m1}$	0.604		
	second tour mode	*car*	*car*	0.713	-	22% (*MAPD)*
			$T_{o,d2,I2}$ *(minutes)*	-0.032		
			centre	-2.296		
			Smode	1.651		
		public transport	*fare (€)*	-0.002	-	
			$Tb_{o,d2,I2}$ *(minutes)*	-0.037		
			$Tw_{o,d2,I2}$ *(minutes)*	-0.021		
			$Tp_{o,d2}$ *(minutes)*	-0.013		
			$Ntrn_{o,d2,I2}$	-0.307		
		motorbike	*motorbike*	-1.381	-	
			$Tm_{o,d2}$ *(minutes)*	-0.007		
			age_o	0.631		
			ExtraUrb	-2.314		

source: [1]

2.2. The freight distribution demand model

For the estimation of the freight demand the *Nested LogitModel* implemented by Cartenì and Russo [3] was applied. The choice dimensions considered in the model were:

1. choice of the distribution strategy (number and type of intermediate stops);
2. choice of the possible intermediate destination d_1 (dry port, logistic centre etc.) given the *od* pair;
3. choice of the u_1 loading unit for the first trip $od_{1,}$ heavy goods vehicles (*HGVs)* and light goods vehicles (*LGVs)*;
4. choice of the u_2 loading unit for the second trip d_1d (*HGVs* and *LGVs).*

From this choice hierarchy the following model structure was considered:

- the *market choice model:* allows to simulate the flow between a *o* manufacturer and a *d* retailer ($p^c(d/H,o)$). The choice alternatives are the final destination zones (acquisition zones). For each commodity class, the choice set is characterized by the destinations (origins) which have some firms related to that commodity class *c*;
- the *first trip choice model:* allows to simulate the choice of the d_1 first transit destination, $p^c(d_1/H,o,d)$, depending on the origin *o* and the final destination *d*. The choice set is a function of the commodity class *c*: different classes of firms could use different transit destinations. The choice set consists of the zones which have some "first level" logistic centres (dry port, regional logistic centre…),
- the *loading unit choice model* for the first trip (second trip): allows to simulate the choice of the u_1 loading unit for the first trip (u_2 for the second trip) $p^c(u_1/H,o,d,d_1)$ ($p^c(u_2/H,o,d,d_1,u_1)$), depending on the origin *o* (transit destination d_1) and the transit destination d_1 (final destination *d*). The choice set consists of the available loading unit linking the origin *o* (transit destination d_1) to the transit destination d_1 (final destination *d*).

For freight demand was estimated five *c* commodity classes considering an aggregation of the eleven economic classes proposed by ISTAT and NACE-CLIO: (i) agriculture and foodstuffs; (ii) energy products; (iii) minerals; (iv) chemical and pharmaceutical products; (v) other products.

In Tab. 5 the attributes used in the systematic utilities are reported, while in Tab. 6 the values of the model parameters are represented.

2.2.1. The impacts estimation

The cars and freight vehicles were converted into *equivalent vehicles* through the conversion coefficient: 1 for cars and LGVs and 2.5 for HGVs. Furthermore, the estimated origin-destination demand flows were analysed both from the temporal and from the spatial point of view. From a temporal point of view, different results were obtained for the different simulation time individuated (see Tab. 7). For the average weekday (business day), the peak hour is 7:30-8:00 with more than 127,000 vehicles/hour within Naples (home to work trips). For the rest of the day the demand level is quite constant with about 85,000 vehicles/hour. With respect to the average weekend (holiday) the demand level increases during the first hours of the day reaching its peak between 12:00 and 13:00 with about 71,500 vehicles/hour. After 13:00 the demand level decreases till 20:00 when the evening peak hour occurs.

From a spatial point of view, most of the daily trips occur inside the historical centre and the north basin. On an average weekday a significant number of trips are made towards the east basin (high number of business activities), while on an average weekend a significant number of trips are made towards the city centre where many cultural and free-time activities are concentrated.

Finally the modal share and the main city-specific traffic indicators are reported in Tab. 8 and 9.

Table 5

The attributes used in the systematic utilities

Model	*Attributes*
market choice model $p^c(d/H,o)$	T_{od} is the time (in minutes), calculated on the network, for the *od* trip; Pop_d (Pop_o) is the logarithm of the population of the final destination *d* (acquisition zone *o*); Emp_d^s (Emp_o^s) is the logarithm of the number of employees, in the *s* commodity class, in the final destination *d* (acquisition zone *o*); $Firm_d^s$ ($Firm_o^s$) are the number of firms, in the *s* commodity class, in the final destination *d* (acquisition zone *o*).
first trip choice model $p^c(d_1/H,o,d)$	Emp_{d1}^f is the logarithm of the numbers of employees in freight firms (haulage, warehousing and storage) belonging to the intermediate destination d_1; $Firm_{d1}^f$ are the numbers of freight firms (haulage, warehousing and storage) belonging to the intermediate destination d_1; FLC_{d1} is a dummy variable; it assumes the value of one if there are “first level” logistic centres (ports, dry ports, etc.) in the intermediate destination d_1; $T_{o,d1}$ is the time (in minutes), calculated on the network, for the o d_1 trip (accessibility attribute); $T_{d1,d}$ is the time (in minutes), calculated on the network, for the d_1 d trip (accessibility attribute);
loading unit choice model $p^c(u_1/H,o,d,d_1)$ $p^c(u_2/H,o,d,d_1,u_1)$	D_d (only in *LGV* systematic utility) is the population density (inhabitants/km^2) of the destination zone *d* (intermediate or final); this attribute allows us to simulate the greater probability of choosing *LGVs* in high population density zones; *Intrazone* (only in *HGV* systematic utility) is a dummy variable which assumes a value of one if $o \equiv d_1$ ($d_1 \equiv d$); this attribute allows us to simulate the lower probability of choosing *HGVs* for intrazone trips; $Dist_{od1}$ ($Dist_{d1d}$) is the trip distance (in Km), calculated on the network; this attribute allows simulation of the greater probability of choosing *LGVs* for short-distance trips or the greater probability of choosing *HGVs* for long-distance trips.

source: [3]

Table 6

Results in terms of model parameter values

Attributes	*Class 1*	*Class 2*	*Class 3*	*Class 4*	*Class 5*
T_{od}	-0.0388	-0.0286	-0.062	-0.0884	-0.0206
Pop_d	0.08471	0.03702	0.02344	0.04062	0.09723
$Firm_d^s$	0.00442	0.04081	0.0015	0.0278	0.00029
Emp_d^s	0.06178	0.04381	0.01426	0.05441	0.01981
Emp_{d1}^f	0.0768	0.0981	0.0343	0.0594	0.0581
$Firm_{d1}^f$	0.0027	0.0068	0.0019	0.0023	0.001
FLC_{d1}	1.9263	2.6284	1.7873	1.9123	1.7814
$T_{o,d1}$; $T_{d1,d}$	-0.0238	-0.0436	-0.087	-0.099	-0.0356
D_d	2.36E-05	2.36E-05	2.36E-05	2.36E-05	2.36E-05
Intrazone	-2.2068	-2.2068	-2.2068	-2.2068	-2.2068
$Dist_{od1}^{LGVs}$	-0.1279	-0.1279	-0.1279	-0.1279	-0.1279
$Dist_{od1}^{HGVS}$	-0.0733	-0.0733	-0.0733	-0.0733	-0.0733

source: [3]

Table 7

Naples peak /off-peak hours and OD demand level (in vehicles/hour) for the base scenario (2011)

		Average weekday		*Average weekend*	
		peak hour	*off-peak hour*	*peak hour*	*off-peak hour*
morning	time interval	07:30-08:30	12:00-13:00	12:00-13:00	09:00-10:00
	OD level	*127,411*	*80,160*	*71,483*	*63,625*
afternoon	time interval	15:45-16:45	16:45-17:45	13:45-14:45	16:00-17:00
	OD level	*85,738*	*85,615*	*57,287*	*53,297*
evening	time interval	20:00-21:00	-	20:00-21:00	23:00-24:00
	OD level	*84,037*	-	*17,886*	*57,033*

Table 8

Naples modal share in 2011 (base scenario)

vehicle category	passenger share	vehicle share	vehicle*km share
cars	64.0%	76.6%	69.5%
motorcycles	12.2%	17.4%	12.6%
buses	20.0%	0.4%	5.8%
heavy goods vehicles	1.0%	1.5%	4.5%
light goods vehicles	2.8%	4.1%	7.6%
total	**100%**	**100%**	**100%**

Table 9

Naples transport system: estimated performance indicators (peak hours)

Public transport (bus, metro, rail)	**2011**
Average on-board time (min.)	20,53
Average waiting time	9,09
Average access - egress time	12,84
Average number of transfer	0,77
Passenger * km	2,325,506
Private transport (car, freight vehicles)	**2011**
Passenger * km	1,424,455
vehicles * km	1,107,233

The traffic fuel consumption and vehicle emissions were estimated through an environmental model based on European standards. Through this model the vehicle emissions were estimated for the base scenario (2011). Emissions were divided into greenhouse gases and fine particles:

- **greenhouse gases** are gases in an atmosphere that participate in the greenhouse effect. The main greenhouse gases considered are:
    - carbon dioxide (CO_2);
    - carbon monoxide (CO);
    - nitrogen dioxide (NO_2);
    - methane volatile organic compounds (CH_4);

  - other volatile organic compounds (VOC);

  these greenhouse gases were also converted into equivalent carbon dioxide (eq.CO2) through the Global Warming Potential (GWP) coefficients. The GWP is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is a relative scale which compares the gas in question to that of the same mass of carbon dioxide, CO2, (whose GWP is by convention equal to 1). For this application, the GWP is calculated over a 100 years time interval.
- **fine particles** are tiny subdivisions of solid or liquid matter suspended in a gas or liquid; it is possible to classify:
  - PM10 particles of 10 micrometers or less;
  - PM2.5 particles less than 2.5 micrometers.

In Tab. 10 and Tab. 11 results for yearly emissions of each greenhouse gas and for different fine particle types emitted by vehicle flows moving inside the city are reported. Absolute values and relative percentages are reported for each green-house gas, for two types of fine particles and for each vehicle category.

The entire transport system emits 1,064,877 tons/year of equivalent CO2, 944,583 tons/year of CO2, 23,033 tons/year of CO, 40 tons/year of NO2, 209 tons/year of methane and 3,140 tons/year of VOC. Looking at each vehicle category, it can be easily seen that car transport emits the highest rate of CO2 equivalent (about 54%), followed by goods vehicles (about 25%), bus (about 18%) and motorcycles (about 4%). As regards fine particle emissions (Tab. 10), 385 tons of PM10 fine particles are emitted in a year and it is interesting to note that 343 tons are PM2.5 particles.

Table 10

Naples greenhouse gas emissions in 2011 (base scenario)

vehicle category	**carbon dioxide** CO2 (tons/year)	**carbon monoxide** CO (tons/year)	**nitrogen dioxide** NO2 (tons/year)	**methane** CH4 VOC (tons/year)	**other volatile organic compounds** NM VOC (tons/year)	**equivalent carbon dioxide** **eq.CO2 (tons/year)**
cars	527,604	14,658	32.1	124	1,619	**575,166**
motorcycles	28,954	5,913	0.4	44	956	**41,465**
buses	184,432	724	2.0	17	194	**187,495**
heavy goods vehicles	152,285	682	3.2	17	266	**155,983**
light goods vehicles	101,308	1,056	3.1	7	105	**104,768**
total	**971,517**	**17,930**	**40**	**174**	**2,340**	**1,031,658**

vehicle category	CO2 (tons/year)	CO (tons/year)	NO2 (tons/year)	CH4 VOC (tons/year)	NM VOC (tons/year)	**eq.CO2 (tons/year)**
cars	53.0%	63.6%	79.3%	59.3%	51.6%	**54,0%**
motorcycles	2.9%	25.7%	0.9%	21.2%	30.4%	**3,9%**
buses	18.5%	3.1%	5.0%	8.1%	6.2%	**17,6%**
heavy goods vehicles	15.4%	3.0%	7.4%	8.1%	8.5%	**14,6%**
light goods vehicles	10.2%	4.6%	7.4%	3.3%	3.3%	**9,8%**
total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Table 11

Naples fine particle emissions in 2011 (base scenario)

vehicle category	PM 2.5		PM 10	
	(tons/year)	%	(tons/year)	%
cars	90	26.3%	114	29.6%
motorcycles	13	3.8%	15	3.9%
buses	95	27.7%	100	26.0%
heavy goods vehicles	98	28.5%	104	27.0%
light goods vehicles	47	13.7%	52	13.5%
total	**333**	**100%**	**373**	**100%**

The car, which has a vehicle share of 78% (and a vehicles*km share of 70%), proves to be the transport mode which produces the highest rate of pollutants. Its percentage incidence is always greater than 50% for each greenhouse gas, with peak values of 79% for nitrogen dioxide and 64% for carbon monoxide. As regards fine particles, car flows emit about 90 tons/year of PM2.5 (about 26%) and about 114 tons/year of PM10 (about 30%).

Motorcycles, with a vehicle share of 17% (and a vehicles*km share of 13%), play a significant role as regards CO, CH4/VOC and NM/VOC emissions. In fact, they emit 5,913 tons/year of CO (about 26%), 956 tons/year (about 30%) of VOC and 44 tons/year of CH4/VOC (about 21%). The impacts on fine particle emissions are negligible. Indeed, motorcycle flows contribute less than 4% to PM2.5 and PM10 emissions.

Summing up emissions values for all the other transport modes (bus, heavy goods vehicles and light goods vehicles, with a vehicles share of 6% and a vehicles*km share of 18%), it should be pointed out that they emit more than 44% of CO2 and more than 42% of equivalent CO2. Buses and goods vehicles show similar emission percentages for all the considered greenhouse gases. From estimation results for fine particles buses and goods vehicles emit more than 70% of PM2.5 and more than 66% of PM10.

3. CONCLUSIONS

This paper and the compendium one (Part 1) discusses the importance of rationality in transportation planning and in particular in using quantitative methods (tools) for ex-ante evaluations. An ex-post evaluation was performed to quantify the “non-rational effects” of two transport policies applied in Naples (Italy), underlining the importance of the ex-ante analysis for sustainable transportation planning. The results of the research underline the importance in using accurate transport simulation models to improve the forecast reliability of the estimations (predictions) for transportation planning.

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