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Reverse Assignment Formulation in Evacuation Simulation

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Abstract

To evaluate the performances of a transport system, many works in literature use traffic data (i.e. flow counts) observed on representative links of the transport network) together with transport model. The observed data are the input for the transport model update. Often the corrections in the costs are not accompanied by a corresponding correction in link flows and update in demand values in a whole methodology.
In this paper, we apply a method for calibrating the parameters of cost functions and demand parameters and/or demand update at the same time. The data input are a (initial) demand matrix, the link cost function (i.e., a function for each link set), the model for users choices simulation. The outputs are an updated demand matrix, the optimal parameters of cost functions and the link flows. The method is able to calibrate the cost functions and update the demand values when, in a particular situation, the transport system is subject to a sudden load, as happens in the case of an evacuation. The flows and costs are observed on some characteristic links (with cameras and probe vehicles equipped with GPS). An application on the route performance of a fleet of vehicles that evacuates some users is reported.

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Keywords: cost functions; demand update; constrained gradient algorithm; traffic assignment; route design.

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1. Introduction

The o-d matrix update, as in literature, consists on the update of demand values starting from observed flows. Using a consolidated method (i.e. least squares) the o-d matrix is updated with a cost functions established in advance. In the same way, the calibration of the link cost parameters, as in literature, consists on the optimization of the link cost parameters starting from observed travel times with demand established in advance.

The demand and the link cost have to be estimated in a whole method. The reverse assignment (Russo and Vitetta, 2011) overtakes this limitation updating the demand together with the estimation of the parameters of the supply model.

Figure 1 shows a compact flow chart of an iteration of the reverse assignment method. Starting from initial values of demand and supply (at time t) and considering observed costs and traffic counts in the interval (t, t + Δt], the reverse assignment is able to update it, forecasting their values in the interval (t, t + Δt]. In the new interval, the new system state is defined with new cost and demand values and parameters. In this way, the system evolves through successive rolling horizons (increasing the time by Δt), until the end of the simulation period.

During an evacuation, the demand increase due the sudden travels of the users. In this case, inside the time interval (t, t+Δt], a new demand matrix (evacuation demand) must be considered as input for the reverse assignment. This demand is added to the ordinary demand. Similarly, modifications can be happen in evacuation supply and it must be considered.

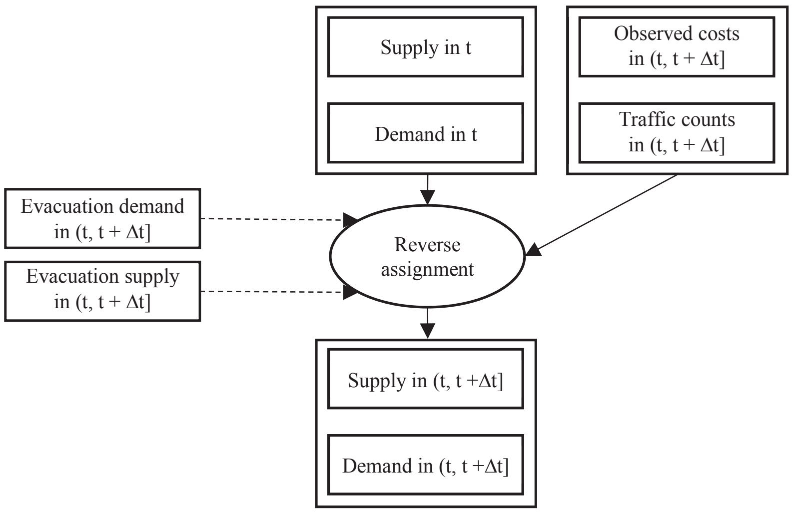

Fig. 1. Reverse assignment in evacuation

The assignment problem is proposed by Wardrop (1952) in static network and extended by Ben Akiva et al. (1987), Cantarella and Cascetta (1995) in dynamic network with within-day and day-to-day models. The demand can be updated from traffic counts (Cascetta and Nguyen 1988) with two approaches: demand values update (Fisk, 1988; Bell et al., 1996; Cascetta, 1984; Maher, 1983; Ben Akiva et al., 1985); parameters calibration (Hogberg, 1976; Cascetta, 1986; Cascetta and Russo, 1997; Yang et al., 2001). Travel cost functions calibration (i.e. Bureau of Public Roads, 1964) is made considering data collected by probe vehicles with static (Lehmann and Kwella, 1998) and dynamic approaches (Tavana and Mahamassani, 2000).

In emergency conditions, when need to evacuate a city (on a portion of the city) some modifications are introduced both in term of demand and supply.

(a) As in Figure 1, the demand increases, considering that new trips are added to those ordinary present. Beside these new demand entries, also the users with no autonomy in the journey (i.e. old persons, children …) must be considered.

(b) In addition, the supply can be subject to changes, for example with some roads unusable or closed by the authority and reserved; in this case, it is necessary to redesign the paths and the routes in the affected area.

(c) In relation to the people with no autonomy in the journey, it is necessary to engage a fleet of vehicles for this purpose.

In this context, a reliable knowledge of the transport network and its performances is crucial. The updated origin destination matrix and the fitting of the cost functions at the emergency conditions allow a simulation of the system in order to capture its changes.

In this paper, reverse assignment is applied to a real dimension network to update the demand and calibrate the cost functions. It allows obtaining basic values for developing a procedure for evacuation simulation of a city (or a portion of it). During an evacuation, both demand and supply can be subject to variation in their entity (i.e., some street are unavailable, some people needing to move simultaneously from an origin and a destination).

(a) Regarding the demand (Russo and Chilà, 2010), it is essential to have a reliable estimation of the ordinary and emergency demand; two origin-destination matrices have to be assigned to the supply. During evacuation conditions, the ordinary demand is incremented to consider the people that lead their location (house, work, school) to get a safe place and assigned to a network subject to some changes.

(b) Regarding the supply (Vitetta et al., 2008), there are several possible scenarios related to the type of emergency (flood, fire, man-made events). In relation to the simulation of emergency conditions, the network configuration can be different from the ordinary condition considering: damage derived from the hazardous events; optimization from public authority (minimum evacuation time and behavioural, technical and external constraints).

(c) Moreover, a set of users evacuated with rescue vehicles is considered. The routes of the vehicles are designed according with the aim to minimize the evacuation time. In the application section, some data (travel times) related to the routes are surveyed with a GPS. A comparison among the routes generated for a fleet of rescue vehicles with and without origin-destination matrix and cost function calibration is reported.

The highlights of the paper can be summarized as:

- demand values and cost function parameters are calibrated jointly using reverse assignment and it is applied in evacuation simulation;
- an application on a real dimension network is reported.

The paper is structured as follow: in Section 2 the basis of the reverse assignment are reported; in Section 3 an application to a real dimension network is reported, including an application of the reverse assignment and the design of the routes for a fleet of rescue vehicles during an evacuation; in Section 4 the conclusions are reported.

2. Reverse Assignment

The reverse assignment, initially proposed by Russo and Vitetta (2011) for ordinary condition, is able to obtain at the same time the parameters of cost functions and the origin-destination matrix of a static traffic assignment model. Starting from an initial origin-destination matrix and a set of parameters of the cost function, the optimization procedure (based on a constrained gradient algorithm) optimize it, in order to minimize the objective function defined as a distance measure between observed and estimated values. The reverse assignment problem can be formulated as a minimum problem as in equations (1):

minimize
$$z(\mathbf{d}_s, \boldsymbol{\alpha}, \boldsymbol{\beta}; \mathbf{d}_o, \mathbf{f}_o, \mathbf{c}_o) = z_1(\mathbf{d}_o, \mathbf{d}_s) + z_2(\mathbf{d}_o, \boldsymbol{\varpi}(\mathbf{X}, \boldsymbol{\alpha})) + z_3(\mathbf{f}_o, \mathbf{f}_s) + z_4(\mathbf{c}_o, \boldsymbol{\chi}(\mathbf{f}_s, \mathbf{Y}, \boldsymbol{\beta})) \quad (1)$$

where

$\mathbf{d}_o$, initial demand, with entry d_{or} the initial demand related to o-d pair r;

$\mathbf{d}_s$, updated demand, with entry d_{sr} the updated demand related to o-d pair r;

$\boldsymbol{\varpi}(\mathbf{X}, \boldsymbol{\alpha})$ is the demand function, with $\mathbf{X}$ system of attributes and $\boldsymbol{\alpha}$ vector of demand parameters;

$\mathbf{f}_o$, observed flow, with entry f_{oi} the observed flow on link i;

$\mathbf{f}_s$, estimated flow, with entry f_{si} the observed flow on link i;

$\mathbf{c}_o$, observed cost, with entry c_{oi} the observed cost on link i;

$\chi(\mathbf{f}_s, \mathbf{Y}, \boldsymbol{\beta})$ is the estimated cost function vector, with entry $c_{si} = \chi(f_{si}, \mathbf{y}_i, \boldsymbol{\beta})$ on link i and $\mathbf{Y}$ is a matrix where the generic column $\mathbf{y}_i$ contains the infrastructural characteristics relative to the link i and $\boldsymbol{\beta}$ is the estimated vector of cost parameters;

z_1 is a measure of the distance between the observed demand and the estimated demand values;

z_2 is a measure of the distance between the observed demand and the modelled demand values;

z_3 is a measure of the distance between the observed flow and the estimated flow;

z_4 is a measure of the distance between the observed cost and the estimated cost.

The function $\mathbf{z}(.)$ in equation (1) is composed by four parts, taking into account the problem values to update. The z_1, z_2, z_3 and z_4 can be evaluated considering a distance measure to compare respectively initial and estimated vectors (i.e. an Euclidean distance).

The objective function could consider also some of the four distance functions. Several specifications could be considered for the demand function $\boldsymbol{\varpi}(\mathbf{X}, \boldsymbol{\alpha})$ and a cost function $\chi(\mathbf{f}_s, \mathbf{Y}, \boldsymbol{\beta})$. In the application, for simplicity sake, we suppose that only the demand values are updated (the z_2 function is not consider).

For simplicity sake, in the application a BPR cost function (Bureau of Public Roads, 1964) is considered. For a generic link i, the link cost $c_{si} = \chi(f_{si}, \mathbf{y}_i, \boldsymbol{\beta})$ is:

$$c_{si} = \chi(f_{si}, \mathbf{y}_i, \boldsymbol{\beta}) = (y_{i1}/\beta_1)\,(1+\beta_2(f_{si}/(\beta_3\, y_{i2}/\, y_{i3}))^{\beta_4}) \tag{2}$$

where

y_{i1} is the link length ($\mathbf{y}_i = [y_{i1}, y_{i2}, \ldots, y_{ij}]$);

y_{i2} and y_{i3} the green time and the cycle at final node of the link;

β_1, β_2, β_3, β_4 cost function parameters calibrated in reverse assignment ($\boldsymbol{\beta} = [\beta_1\, \beta_2\, \beta_3\, \beta_4]^T$).

The reverse assignment procedure considers a Constrained Gradient Algorithm (CGA) to evaluate simultaneously the demand values and the parameters of the cost function. Figure 2 reports a diagram flow that explains this method.

Starting from initial values of costs ($\mathbf{c}_o$), flows ($\mathbf{f}_o$) and demand ($\mathbf{d}_o$) and considering the supply configuration an assignment is performed in order to evaluate costs and flows ($\mathbf{c}_s$, $\mathbf{f}_s$). Hence, a norm of the $\mathbf{z}(.)$ function is evaluated ($\|\mathbf{z}\|$) and tested. The test consists on a comparison among the initial values $\mathbf{c}_o$, $\mathbf{f}_o$ and $\mathbf{d}_o$ and the forecasted values $\mathbf{c}_s$, $\mathbf{f}_s$ and $\mathbf{d}_s$. If the test fails, the CGA allows evaluating new values for cost parameters and demand. The outputs are the estimated demand vector $\mathbf{d}_s$ and the parameter vectors $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$.

Note that in the solution procedure, at each iteration, traffic assignments are performed with the actual demand values and link cost parameters.

3. Application

The test application is made considering a real dimension network (Figure 3), constituted by 444 links, 188 nodes and 12 centroids. The graph represent a portion of Reggio Calabria, a city in the south Italy, with about 180000 inhabitants (Istat, 2011 statistic). The considered area includes schools, the university, two hospitals and many public offices.

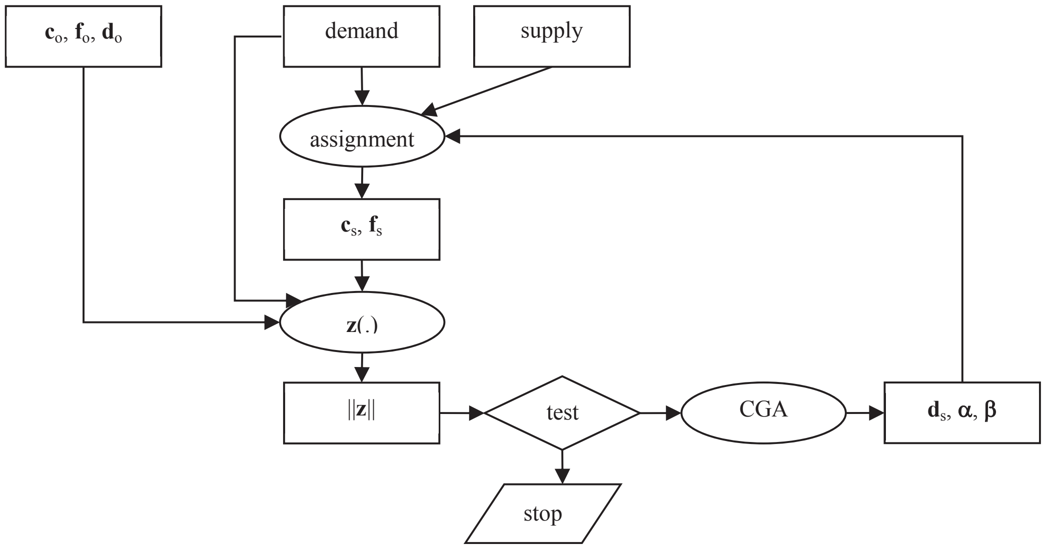

Fig. 2. Reverse assignment procedure

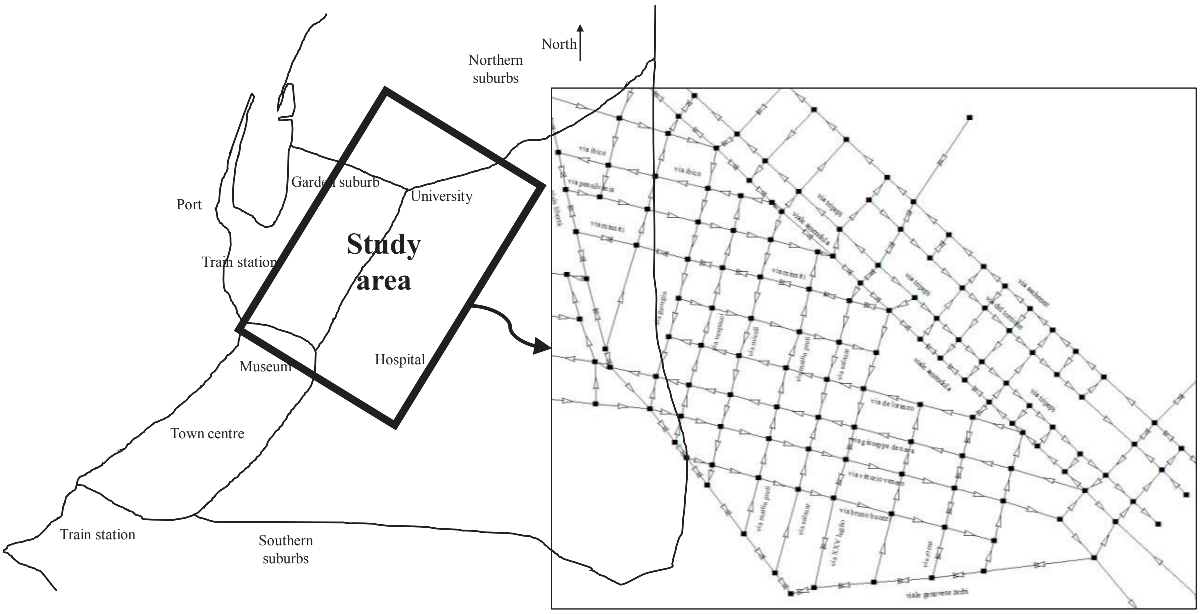

Fig. 3. The area of Reggio Calabria and the graph of the study area

The demand matrix, results of some survey in the study area, have as mean 111.5 users/hour, as standard error 9.76 users/hour. The total ordinary demand is 16056 users/hour. The value max of travels among the origin destination pairs is 907 users/hour; the minimum is 104 users/hour.

Reverse assignment

To perform the reverse assignment procedure, a survey on a sub-set of representative network links was made, related to travel time and flow. The flows are collected on a business day in the morning rush hour. Similarly, the travel times are collected with a probe vehicle equipped with a GPS.

Table 1 reports some indicators related to the surveyed data compared with those forecasted.

Table 1 Comparing some surveyed and simulated flow and time values

		Observed values		Forecasted values	
	Number of links	Mean	Standard error	Mean	Standard error
Flow (veh/hour)	17	591	17	566	15
Time (sec)	73	14.7	2.5	18.0	3.2

The **z**(.) functions are evaluated using the minimum least square method and the Euclidean distance between the observed data and the forecasted values.

The initial demand is obtained by previous survey in the area; the cost function considered in the assignment is a BPR, as in Eq. 2.

To evaluate the effectiveness of the proposed procedure, three scenarios are compared:

1. only cost function parameters calibration;
2. only origin destination matrix update;
3. simultaneous cost function parameters calibration and origin-destination matrix update.

In Table 2 the parameter values, the value of the objective function and the mean and the standard error of the demand matrix are reported.

In the scenario 1., only the parameters of the BPR function are calibrated, considering the initial origin-destination matrix. The value of the objective function decreases.

In the scenario 2., the demand is updated, considering the initial cost function parameters (as in literature). The value of the objective function decreases, the means of the origin destination matrix decreases, however, its dispersion increases because the values are redistributed among the o/d pairs according to the flows.

In the scenario 3., both the function parameters calibration and origin destination matrix are made. Comparing it with the scenarios 1. and 2., other values for the cost parameters and demand values are obtained. Comparing it with the scenario 1., the objective function and the o/d matrix mean decrease, the o/d matrix dispersion increases. Comparing it with the scenario 2., can be note the small reduction of objective function and o/d matrix mean.

Table 2. – Comparing evaluation scenarios

Variables		Initial values	Scenario 1	Scenario 2	Scenario 3
Cost parameters	$\boldsymbol{\beta} = [\beta_1\beta_2\beta_3\beta_4]^T$	$[20{,}0\ 1\ 525\ 3]^T$	$[19{,}9\ 0{,}05\ 890\ 2{,}7]^T$	$[20{,}0\ 1\ 525\ 3]^T$	$[20{,}3\ 0{,}06\ 519\ 2{,}4]^T$
Demand	e_{od}	111,50	111,50	98,15	97,54
	se_{od}	9,76	9,76	14,54	14,47
Objective function	z ()	46,7	9,3	9,2	9,1

e_{od}: origin-destination matrix mean in veh/h, se_{od}: origin-destination matrix standard error in veh/h, β_1 in km/hour, β_3 in veh/hour

<u>Route optimization in emergency conditions</u>

In term of supply, it is assumed that some links are unavailable in the traffic assignment, because the simulated events affect their use.

In term of demand, it is assumed that to the ordinary demand (obtained with reverse procedure) must be added to the evacuation demand; in the simulation, the evacuation demand starts from 4 zones (centroids) in the town centre and reach the safe zone in the suburb. The origin-destination matrix mean is 140 vehicles with standard error 18.9 vehicles.

The changes in supply and demand cause a change in the performances. In this way, the travel time for ordinary and evacuated users changes, and the travel time for emergency vehicles changes. It is interesting to evaluate how a good evaluation of origin destination matrix and cost function parameters affects the optimization of the route of some rescue (emergency) vehicles moving into the affected area. The effects of a peak demand entering in the transport system are analysed in Vitetta et al. (2007).

During an evacuation, there are some users with no autonomy in the journey and they needs help to leave their position; in this simulation we assume twenty-three users to evacuate with some emergency vehicle. A fleet homogeneous vehicles is assumed available to transport the users. The optimization of the routes followed by the vehicles is a combinatorial problem hard in solution, developed initially for freight transport (Dantzig and Ramser, 1959) and then extended to other fields (Polimeni and Vitetta, 2011). Most of the solution methods are based on heuristics approaches (Russo et al., 2010; Polimeni et al., 2010), but in some cases exact algorithms are applied (Fisher, 1994).

The routes are optimized for each designed scenario (1., 2. or 3.); the optimization variable is the travel time evaluated in the (congested) network. Table 3 shows some results, considering also the operation time (needing for picking-up the users) at each stop. In each scenario, four routes are generated, the total time range from 11880 seconds (about 3 hours) to 17100 seconds (about 4.7 hours), while the travelled distance range from to 8000 metres to 13200 metres. The values difference demonstrates in this specific application case the importance of the use of a reverse assignment procedure for route optimization in emergency conditions. It is clear that the objective function in scenario 3 is the best due the simultaneous cost function parameters calibration and origin-destination matrix update. We want to emphasize that are not so interested in the final value of the objective function, but are interested in the good estimation of the total evacuation time that means the increase of rescued people.

Table 3 – Comparing routes in different scenarios

Scenario	Routes	Travel time + operations (s)	Travel distance (m)
1	1	4860	3700
	2	4380	3400
	3	3780	2900
	4	4080	3200
	Total	**17100**	**13200**
2	1	4260	4000
	2	2880	2800
	3	2640	2600
	4	2760	2600
	Total	**12540**	**8100**
3	1	4080	4000
	2	2700	2700
	3	2540	2600
	4	2580	2600
	Total	**11880**	**8000**

4. Conclusions

In this paper, a method for simultaneously calibrate the parameters of a cost function and update an origin destination matrix form surveyed data (travel time and flow) is applied. Starting from a survey on some representative links of a network, a reverse assignment procedure is applied in order to calibrate a cost function (in our case a BPR function is choice, but other functional forms are evaluable) and to update the origin destination matrix. The reverse assignment results are compared with those obtainable with classical origin-destination matrix update and with only the cost function calibration.

This application was conducted on a real dimension network. Moreover, to extend the procedure, it is assumed that, for a hidden event, an area of the city has to be evacuated: considering a peak demand, the travel time in the network are re-calculated. A route optimization problem is solved to design the routes of some vehicles that move on the network to pick-up some users with no autonomy in the journey needing help to evacuate the area.

Possible future developments could be the calibration of other cost functions and the application in time-dependent networks.

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