A Simulation Approach of Fare Integration in Regional Transit Services

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Abstract. The paper presents a general procedure, supported by a system of simulation models, to estimate the effects due to the implementation of an integrated fare system in regional transit services. The effects on users (demand level variations) and on transit companies (management revenues) are considered. In particular, the demand is assumed to be elastic with respect to the fare at the modal and path choice dimensions. The general procedure is applied to the transit system of an Italian regional area.

1 Introduction

In the last years, many regional and metropolitan areas successfully introduced integrated fare systems in transit services, due to the modifications of European and national legislations. The implementation of an integrated fare system involves decisional implications concerning the necessity to activate comprehensible and easy usable fares for the user, to identify the management service revenues and their allocation among transit companies. The actual tendency is to move from non-integrated fare systems, where each transit company has his own fare structure and levels, towards integrated zone fare systems, where a common zone fare structure is defined, accepted and adopted by all transit companies operating in the area. A systematic description of fare integration experiences in transit services of some European metropolitan and regional areas is reported in [1], [2], [3].

Methods for designing integrated fare systems for transit services can be classified according to a "what if" (simulation) approach and a "what to" (optimization) approach (Figure 1).

In the first case, many alternative fare system scenarios (zone partition and fare structure and levels) are exogenously defined on the basis of experiences or specific knowledge of the examined area. Such configurations are simulated through a system of simulation models and compared with the support of some evaluation indicators. In the second case, fare system scenarios are generated automatically by means of an optimization model, which is usually composed by a zone partition model and a fare level model. The solutions of the optimization

F. Geraets et al. (Eds.): Railway Optimization 2004, LNCS 4359, pp. 200–218, 2007.

model are analyzed and evaluated through an iterative procedure. Both approaches have, in a general case, the minimum fare increment for the users and the minimum revenue reduction for the transit companies as objectives. The decision variables are the zone partition of the area and the fare structure and levels, and the constraints are given by the territorial integrity of the zones, some thresholds for maximum variations of fare levels and revenues, or fare monotonicity (increasing fares with trip length).

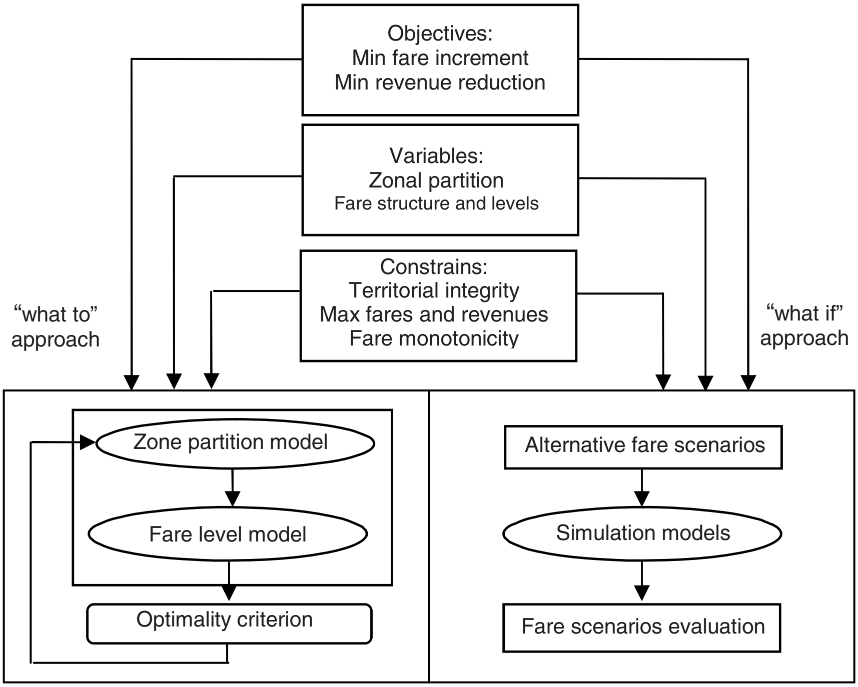

Fig. 1. "What to" and "what if" approaches for integrated zone fare system design

Some work based on the "what if" approach are proposed in [4] and more recently in [5], [6] and [7]. In the latter publications a procedure for management revenues estimation deriving from the definition of alternative fare systems in a regional area is proposed. Some work based on the "what to" approach are focused to the optimal definition of a zone fare system, with the objectives to minimize fare increments for the users and revenue reductions for the operating companies ([8], [9], [10], [11], [12] and [13]).

In all the above work the effects of the implementation of an integrated zone fare system are simulated and evaluated, assuming rigid demand.

The paper presents a general procedure, which uses a system of simulation models to estimate the effects on users (demand level variations) and on transit companies (management revenues), due to the implementation of an integrated fare system in regional transit services. In particular, the demand is assumed to be elastic with respect to the fare at the modal and path choice dimensions.

The paper is organized in three sections. In the first section, the general procedure for the simulation of fare systems and the system of simulation models for the estimation of demand levels and management revenues in a regional area are presented. The second section describes an application of the procedure to the Province of Reggio Calabria (Italy); the effects deriving from the definition of different fare systems have been simulated and compared in terms of demand levels and management revenues. Finally, the third section reports the conclusions and the research perspectives.

2 General Procedure for Fare Systems Simulation

The proposed procedure, based on the “what if” approach, allows to simulate the effects of the implementation of an integrated fare system in regional transit services on users (in terms of demand levels) and on transit companies (in terms of management revenues).

The procedure is presented according to the scheme shown in Figure 2 and involves specifications of a supply model, a fare model (it is separated from other components of the supply model), a demand model, a transit assignment model and a revenues model.

The starting step concerns the definition of the integrated fare system scenario, simulated through a fare model. Road facilities and transit services are simulated through a supply model. The demand can be simulated through a system of models that, from user specific, level-of-service and cost attributes (fares), provides modal origin-destination (O/D) matrices. At this point, the modal demand levels are evaluated with reference to prefixed constrains (i.e., minimum thresholds given by the demand levels in the current transit system modes), described in detail below. If such constrains are not satisfied the fare system scenario can be modified, otherwise modal O/D matrices are assigned to the network through an assignment model. Cost attributes are taken into account in the definition of systematic utility (or cost) connected to each path. So, it is possible to simulate the effects of a fare system scenario on the demand in the dimensions of mode and path choice. The assignment model (demand-supply interaction) gives back the flows (or loads) on each element of the network (link), that represent the input, together with fare matrices, for the revenues model. The estimated revenues are evaluated with reference to prefixed constrains (i.e., minimum thresholds of revenues/cost rates imposed from legislation, as in Italy). If such constrains are satisfied the procedure ends, otherwise, there is a new feedback to the starting step.

The decision variables are represented by the fare system (zone partition, fare structure and levels), assuming the network topology and performances to be constant. The objectives can be the minimum fare increment for the users and/or the minimum revenue reduction for the operating companies. The constrains are given by thresholds for demand levels and fare revenues, for example:

- estimated demand levels for every existing transit mode for the fare system scenario ($d^{T,S}$) must be not less ($\lambda \geq 1$) than demand levels for the current fare system ($d^{T,C}$):

$$d^{T,S} \geq \lambda d^{T,C} \tag{1}$$

- estimated fare revenues for the fare system scenario $(R)^S$ must be not less than prefixed thresholds of the revenues/costs rate (i.e., $\eta \geq 0.35$, as in Italy):

$$R^S \geq \eta MC \tag{2}$$

where: T, transit system; S, fare system scenario; C, current fare system; R, fare revenues; MC, operating management costs.

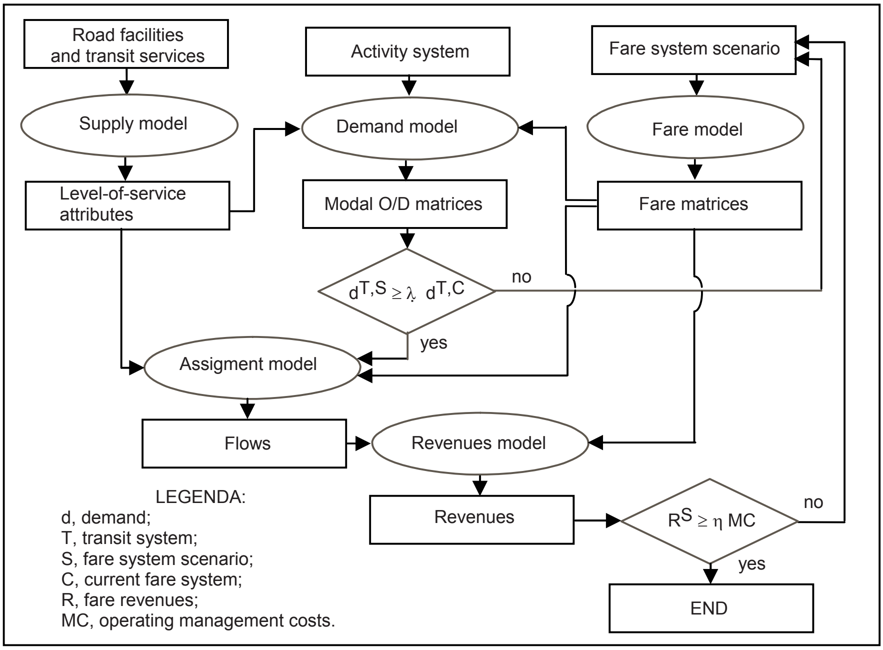

Fig. 2. Graphical scheme of the general procedure

2.1 Supply Model (Road Facilities, Transit Services)

Road facilities are modeled through a network model, composed by a topological graph. Transit low-frequency services (as in regional areas) are represented by a run-based supply model, where the graph is made up by a service sub-graph (timetable) and an access/egress sub-graph. Cost functions for links on the two sub-networks are assumed to be separable and not flow-dependent (not congested networks).

Different run-based supply models for low-frequency transit services are presented in [14], [15] and [16]. In this work, the mixed line-based/database supply model from [15] is considered. It uses a line-based network model together with a timetable database; in particular, it uses a line-based approach to describe the spatial service network topology in terms of routes, lines and stops and data associated to nodes and links to define runs on the network.

The run-based supply model is able to simulate each mode/service at a run level. It is also able to simulate a "mixed" mode, which is composed by two (or more) transit modes, through the explicit representation of intermodal transfer nodes. Two approaches exist in literature [7] to simulate intermodal transfers. According to the first one, a supply model is implemented, which is able to integrate all transport modes in a single network and to represent, through specific nodes and links, intermodal transfers. The network is quite complex and needs the definition of some criteria in order to prevent the choice of infeasible paths. According to the second one, a network is implemented for each transport mode. The connection between these networks is ensured by a fictitious origin and/or destination node in each of them, which represents the intermodal transfer nodes. So, the path on the mixed mode is composed from the path on the first network from the origin node to the intermodal transfer node (fictitious destination on the first network) and the path on the second network from the intermodal transfer node (fictitious origin on the second network) to the real destination (Figure 3). The network is less complex, if intermodal transfer nodes are not numerous and are explicitly defined. This second approach is adopted in this work for the representation of the mixed mode.

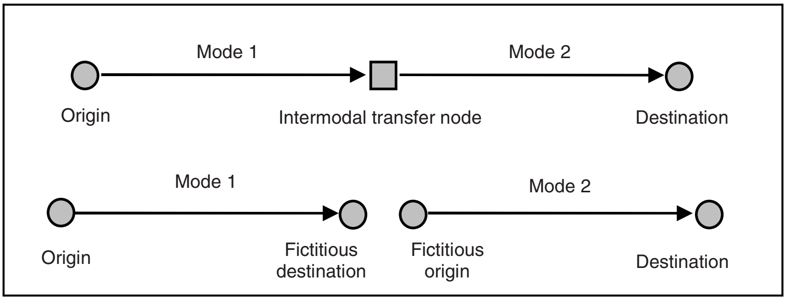

Fig. 3. Intermodal transfer node representation

2.2 Fare Model

The fare model is a component of the supply model, but it is separately treated here because cost attributes (fare) are the ones that change due to the implementation of an integrated fare system.

Different fare models can be specified to represent different fare systems. Generally, fare (p) is composed of an access fare to the service (p_0) and a variable on-board fare (p_v), which depends on the use of service. The last one has different specifications which depend on the fare structure. Fare models can be linear or non-linear; in the following some models are presented which are able to simulate different fare systems:

- constant fare model ($p_v = 0$):
$$p = p_0 \tag{3}$$
- distance (or time) fare model, when p_v depends on traveled distance (d) between origin and destination (or travel time t);
$$p = p_0 + p_v(d) \tag{4.a}$$
$$p = p_0 + p_v(t) \tag{4.b}$$
- zone fare model, when p_v depends on the number of crossed zone boundaries (n):
$$p = p_0 + p_v(n) \tag{5}$$
- origin-destination fare model, when fare depends on each origin-destination (O/D) couple; according to the service provided, distance, specific commercial strategies:
$$p = p_{\mathrm{O/D}} \in P_{\mathrm{O/D}} \tag{6}$$

where $P_{\mathrm{O/D}}$ is a fare matrix, having as elements fare associated to O/D couple.

Fare models (4) and (5) have a linear specification and simulate additive fares independent from O/D couple and path, while fare model (6) simulate a non-additive fare which depends on each O/D couple. In this work, only linear fare models are considered.

2.3 Demand Model

Transport demand can be obtained from a direct estimation, from model estimation, from traffic counts. Model estimation provides parameters estimation of the sub-models related to different choice dimensions and allows to forecast demand variations in short, medium and long term.

In this work, in order to simulate the effects deriving from the implementation of an integrated fare system, mode and path choices are explicitly simulated. To such purpose, modal and path choice sets and choice models are specified.

Modal choice set includes individual (car) and transit modes available for users for extra urban trips. Among transit modes, a mixed mode is dealt as a specific mode and is considered as a specific alternative in the choice set. Attributes (especially level-of-service attributes) related to mixed mode derive from the composition of attributes of the first mode from origin to intermodal transfer node and of attributes of the second mode from intermodal transfer node to destination. Such attributes are determined through network loading models with deterministic path choice for both transport modes.

Mode choice model is based on random utility theory ([17] and [18]); it provides O/D matrices for each transport mode.

Modal O/D matrices must be segmented into more detailed time-varying matrices, in order to be consistent to run-based supply model. Demand segmentation is performed according to users desired departure time (DDT) from origin and desired arrival time (DAT) at destination. Usually, DAT is related to home-living trips and DDT to returning trips.

In low-frequency transit systems, path choice set can be composed of selected paths, according to some criteria ([19] and [16]), which lead to the generation of a reduces set of feasible paths.

Path choice model (determinist or stochastic) is completely pre-trip and depends on the systematic (or perceived) utilities of each path equal to the opposite of the path costs. Such costs are equal to the sum of two components: additive costs and non-additive costs. The first ones derive from the sum of costs (generally time) of links of the path, while the second ones are specific of the path and/or the origin-destination couple.

Access/egress time, earliness/lateness arrive at stop, waiting time, boarding time, on-board time, alighting time are additive costs (in not-congested networks), while fare can be an additive or not additive cost, depending on the fare systems (respectively linear or not linear). For linear fare structures (Eq. 4 and 5), it is possible to convert fare monetary cost in temporal cost, assigning the access fare (p_v) to the boarding link and the variable on-board cost (p_v) to the (or some) on-board links. For non-linear fare structures (Eq. 6), fare cost represents a non-additive path cost that can be considered only after the explicit enumeration of all paths.

2.4 Transit Assignment Model

In low-frequency transit systems, where all runs must be explicitly simulated, transit assignment of demand flow to the network must be performed through a dynamic schedule-based approach, which allows to obtain disaggregate results in terms of on-board loads on each vehicle. Different transit assignment models based on schedule-based approach are proposed in literature ([15], [19], [20], [21] and [16]). For not-congested networks, transit assignment is simulated with a whit-in day dynamic network loading model which allows to simulate at each time load on links representing services.

2.5 Revenues Model

Management revenues are estimated through revenues models which differ according to the fare system, that can be linear or not and can operate in an integrated context or not ([5] and [6]).

Table 1 presents revenues models for different fare systems. Models (8) and (12) are applicable having as input demand flows ($d_{\mathrm{O/D}}$), while models (7), (9), (10) and (11) are applicable after performing the transit assignment and, generally, need as input demand flows ($d_{\mathrm{O/D}}$), flows (f) on some links, the two components of the fare model (p_0 and p_v).

Model (7) is applicable for revenues calculation for a not integrated constant fare system, simulated by equation (3). Model (9) is related to a not integrated distance linear fare system (Equation 4); it needs as input, for every run (r), flows on boarding links (f_{tr}), flows on on-board links (f_{br}), additive link fare associated to each on-board link depending on link length (p_{vr}). Model (10) is referred to an integrated distance linear structure and it does not require flows on boarding links. Model (11) is applicable for integrated zone linear fare systems and needs as input flows on on-board link crossing zone boundaries (f_{w}) and additive variable fare associated to each on-board link crossing zone boundaries (p_{vw}).

Table 1. Revenues models and required inputs

Fare system	Integr.	Input	Model	
Constant	No	p_0, f_{tr}	$\sum_{\mathrm{r}} \sum_{\mathrm{t}} p_0 f_{\mathrm{tr}}$	**(7)**
	Yes	$p_0, d_{\mathrm{O/D}}$	$p_0 \sum_{\mathrm{O/D}} d_{\mathrm{O/D}}$	**(8)**
Distance	No	$p_0, p_{\mathrm{vr}}, f_{\mathrm{tr}}, f_{\mathrm{br}}$	$\sum_{\mathrm{r}} \sum_{\mathrm{t}} p_0 f_{\mathrm{tr}} + \sum_{\mathrm{r}} \sum_{\mathrm{b}} f_{\mathrm{br}} p_{\mathrm{vr}}$	**(9)**
	Yes	$p_0, p_{\mathrm{vr}}, d_{\mathrm{O/D}}, f_{\mathrm{br}}$	$p_0 \sum_{\mathrm{O/D}} d_{\mathrm{O/D}} + \sum_{\mathrm{r}} \sum_{\mathrm{b}} f_{\mathrm{br}} p_{\mathrm{vr}}$	**(10)**
Zone	Yes	$p_0, p_{\mathrm{vw}}, d_{\mathrm{O/D}}, f_{\mathrm{w}}$	$p_0 \sum_{\mathrm{O/D}} d_{\mathrm{O/D}} + \sum_{\mathrm{w}} f_{\mathrm{w}} p_{\mathrm{vw}}$	**(11)**
O-D	Yes	$p_{\mathrm{O/D}}, d_{\mathrm{O/D}}$	$\sum_{\mathrm{O/D}} p_{\mathrm{O/D}} d_{\mathrm{O/D}}$	**(12)**

t, boarding link; w, on-board link crossing zone boundaries; b, on-board link; r, run; $d_{\mathrm{O/D}}$, demand flow on O/D couple; f, link flow.

3 Application to the Province of Reggio Calabria

The general procedure is applied to the transit system of the Province of Reggio Calabria, located in the south of Italy. The general objective, in this case, is the simulation of effects on users and on fare revenues deriving from the modification of a season-ticket (monthly ticket) for users who travel systematically inside the Province for work and study purposes. In particular, two fare systems are simulated:

- the current not integrated distance fare system, where each company sells its own monthly ticket (the price depends on traveled distance between origin and destination) to users not valid for services provided for other companies (users which make modal/service transfers need to buy multiple tickets);
- an integrated zone fare system, where companies sell a monthly ticket (the price depends on the number of crossed zone boundaries between origin and destination), valid for all services/modes connecting origin and destination.

The steps for the application of the procedure are: supply representation, through the network graph (nodes for spatial location of bus stops and rail stations, links for spatial connection of nodes, intermodal transfer nodes) and the service timetable (temporal representation of runs: leaving time from the terminus and arriving/leaving time at stops/stations); fare system definition, through the specification and calibration of fare models simulating the two fare systems; demand estimation for each mode during an average working day and time-varying O/D demand matrices estimation, transit assignment of time-varying O/D demand matrices to the run-based network; revenues estimation.

3.1 Supply Representation

In the examined area, the road system is composed by local and regional roads, while a highway runs along the Thyrrenian coast. The total length of road network is 1097 kilometers. Many transit companies (27) operate in the area with 505 lines/day and 1344 runs/day, providing connections inside the province. Two transit modes are present: bus and rail, providing mono-class services. No intra/intermodal integration (fare and timetable) exists, however a small number of intermodal transfers are present in the major coastal towns. Rail lines run along the coast connecting all costal towns, while bus lines connect each other all coastal towns and hilly villages (Figure 4). Some characteristics of the two transit modes are described in Table 2.

A network graph for each mode provides the spatial representation of transit services, while timetable provides their temporal representation. Mixed mode representation is relatively easy, due to the small number of intermodal transfer nodes and the transit system structure (Figure 4). Therefore, mixed mode is derived from the composition of the rail mode (running along the coast) and of the bus mode (running from sea to mountains and vice versa). Four intermodal transfer nodes are defined (Reggio Calabria, Gioia Tauro, Melito Porto Salvo and Locri), where it is possible the transfer from bus system to rail one and vice versa. Intermodal transfer nodes are selected after an empirical evaluation of the number of bus and train runs stopping at each bus stop and rail station of the network.

Table 2. Bus and rail characteristics

	Bus	Rail
Network length [km]	1097	203
Number of stops	269	36
Number of lines/day	428	77
Number of runs/day	1132	212
Commercial speed [km/h]	56.5	36.2
Number of operators	26	1

3.2 Definition of Fare Systems

Two different fare systems are simulated. The first is a non-integrated distance linear fare system. A fare model is specified and calibrated in a previous study ([5] and [6]) and parameters (Table 3) are calibrated for the two existing modes (bus and train) for a monthly season-ticket:

$$p = p_0 + \chi d \tag{13}$$

Table 3. Parameters of the non-integrated linear distance fare model

Bus		Rail	
p_0 (€)	χ (€ /km)	p_0 (€)	χ(€ /km)
0.147	0.019	0.352	0.028

The second is an integrated zone linear fare system, in which zone fares are defined according to a previous zone partition. The fare model is specified as follows:

$$p = p_0 + \beta_n \tag{14}$$

Three fare levels scenarios are defined assigning different values to parameters p_0 and β, as shown in Table 4.

Table 4. Parameters for the integrated zone linear fare model

Scenario	p_0(€)	β(€/n)
1	0.35	0.40
2	0.45	0.50
3	0.55	0.60

The Province is divided in 33 fare zones with equal medium diameter of 10 km (Figure 4). Fare zones are designed in order capture the sea-mountain and coastal trips. Each zone has a convex shape and encloses one or more municipalities.

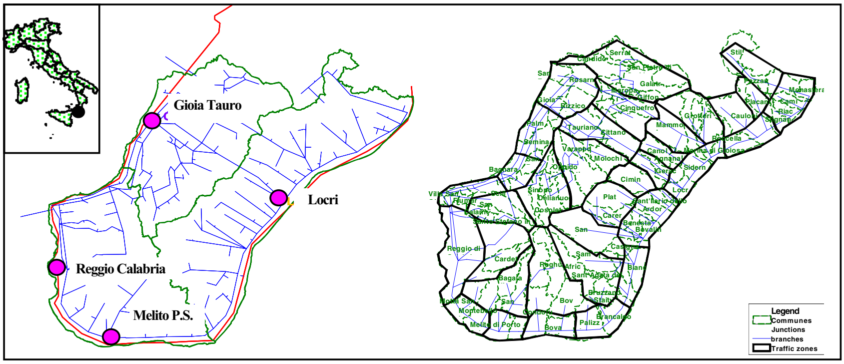

Fig. 4. Transit network and zone partition of the Province of Reggio Calabria

The specification and calibration of the fare models (13) and (14) allow to determine a fare matrix for each fare system, which is necessary in next steps concerning modal demand O/D matrices estimation and transit assignment of time-varying demand flows to the run-based network.

3.3 Demand Estimation

The area, with a population of 580000 inhabitants, has been divided in 97 traffic zones, corresponding to the municipalities. The city of Reggio Calabria is the main attraction/emission center and minor towns are located along the coast. The total daily O/D matrix of systematic extra urban trips in the area for all modes and two purposes (work and study) is provided by national statistics institute ISTAT in 1991.

A disaggregate mode choice model is specified and calibrated in order to split the total daily O/D among transport modes. Modal choice set is composed by four transport modes: car, bus, rail, mixed. The specified mode choice model is a multinomial logit:

$$p(\mathrm{m/od}) = \exp(V_{\mathrm{m/od}}) / \sum_{\mathrm{m'}} \exp(V_{\mathrm{m'/od}}) \tag{15}$$

with: $V_{\mathrm{m/od}} = \sum_j \beta_j X_{\mathrm{m}j}$, systematic utility function associated to mode m; β_j, parameters to be calibrated; $X_{\mathrm{m}j}$, attributes of mode m.

The systematic utility function is a linear combination of level-of-service attributes, defined in Table 5.

The values of attributes are average daily values for each O/D couple. Car on-board travel times are determined through a stochastic equilibrium assignment model. Cost for car mode is fuel cost, assuming a unit fuel consumption of 10 Km/liter and a unit fuel cost of 1 €/liter. Bus and rail on-board travel times are determined through a network loading model with a determinist choice of hyper path. Cost for transit modes (fare) is obtained from models (13) and (14) for each O/D couple (fare matrices). For mixed mode, three more average daily attributes are estimated: average headway between two runs (Inter), average daily intermodal transfer time (t_t) in the four transfer nodes, percentage use of rail mode (%rail).

Table 5. Attributes in the systematic utility function

Symbol		Definition
$t_{\mathrm{a/e}}$	[hour]	Access/egress time to/from the bus stop or rail station
t_b	[hour]	On-board travel time
C	[€]	Cost for the monthly season-ticket (bus, rail) or fuel cost (car)
Inter	[hour]	Average daily headway between two runs
t_t	[hour]	Average daily intermodal transfer time
%rail	[%]	Percentage use of rail mode in the mixed mode
ASA		Alternative specific attributes

Observed data are obtained from a survey executed during a working day at bus stops, rail stations and on-board. A random sample of more than 500 interviews with workers and students performed in a revealed preference way is available.

Model calibration is performed through the maximum-likelihood method. The results of two different specifications related respectively to work and study purposes are presented in Table 6.

Concerning the model related to work purpose, all parameters are negative (unless the %rail one), as expected, and statistically significant, as t-student statistics shows. The positive sign of %rail parameter expresses the users appreciation for the higher reliability and speed of rail services.

On-board and access/egress parameters respect the ratios that it is possible to find in literature. The value of on-board time is satisfactory, while the value of access/egress time seems to be slightly high, due to the relative high average distances of the access terminal to the service from the origin (and of the final destination from the egress terminal). Finally, the goodness of fit statistic is acceptable ($\rho^2 = 0.482$).

Table 6. Parameters calibration of modal choice models for work and study purposes

		Model			
Mode	Attributes	Work		Study	
		β	*t*-statistics	β	*t*-statistics
Bus	$t_{\mathrm{a/e}}$	−1.437	−12.8	−3.687	−13.5
	t_b	−0.477	−8.0	−1.775	−13.1
	C	−0.054	−4.9	−0.408	−12.7
	Inter	−0.030	−8.0	−0.026	−6.6
	ASA	−0.749	−12.0	- - -	- - -
Rail	$t_{\mathrm{a/e}}$	−1.437	−12.8	−3.687	−13.5
	t_b	−0.477	−8.0	−1.775	−13.1
	C	−0.054	−4.9	−0.408	−12.7
	Inter	−0.030	−8.0	−0.026	−6.6
	ASA	−1.147	−16.4	−0.883	−16.7
Mixed	$t_{\mathrm{a/e}}$	−1.437	−12.8	−3.687	−13.5
	t_b	−0.477	−8.0	−1.775	−13.1
	C	−0.054	−4.9	−0.408	−12.7
	Inter	−0.030	−8.0	−0.026	−6.6
	t_t	−0.922	−3.4	−0.458	−2.5
	%rail	1.737	2.8	- - -	- - -
	ASA	−3.977	−7.4	−3.533	−14.2
Car	t_b	−0.477	−8.0	- - -	- - -
	C	−0.054	−4.9	- - -	- - -
ρ^2		0.482		0.388	
V.O.T.(a/e)		25.75		9.04	
V.O.T.(b)		7.50		4.35	

As far as concern the model for study purpose, the access/egress and cost parameters are greater than the previous case. The values of the time are lower, as expected. Finally, the goodness of fit statistic is less than the previous one ($\rho^2 = 0.338$).

The two specified and calibrated modal demand models are applied to estimate the daily O/D demand matrices for the three transit modes with the current fare system (not integrated linear distance) and for the three fare scenarios of the integrated zone linear fare system. The results are presented in Table 7. The first observation is that mixed mode in all cases attracts an extremely small number of users; this is due to the lack in the area of any modal/service integration, that make transfers very burdensome. Transit daily demand for current distance fare system is equal to 23128 pax/day. Transit daily demand for scenario 1 ($p_0 = 0.35€; \beta = 0.40€/n$) of zone fare system is 23438 pax/day; while, for scenarios 2 ($p_0 = 0.45€; \beta = 0.50€/n$) and 3 ($p_0 = 0.55€; \beta = 0.60€/n$), demand is respectively 23136 pax/day and 22805 pax/day. Table 7 reports also the demand for each mode and percentage demand variation related to the current fare distance system.

Table 7. Modal demand for each simulated fare systems

			Demand [pax/day]			
Fare system			Bus	Rail	Mixed	Total
Distance		Abs	15067	7681	380	23128
Zone	1	Abs	15262	7780	396	23438
		$\Delta\%$	+1.29	+1.29	+4.21	+1.34
	2	Abs	15026	7724	386	23136
		$\Delta\%$	−0.27	+0.56	+1.58	+0.03
	3	Abs	14815	7621	369	22805
		$\Delta\%$	−1.70	−0.80	−2.90	−1.40

Abs = absolute demand values,
$\Delta\%$ = percentage demand variation related to current distance fare system.

In order to obtain time-varying O/D matrices to be assigned to the run-based network, the simulation period of an average working day (from 4:30 to 20:00) is discretized into 64 time-slices of 15 minutes. A desired arrival time (DAT) at destination and a desired departure time (DDT) from the origin are associated to each time-slice. Then, DAT and DDT distributions for each travel purpose (work and study), assumed to be rigid to the simulated fare systems, are obtained on the base of previous researches on the same area [22] and on a similar Italian regional area [23]. DAT and DDT distributions for work and study purposes are presented respectively in Figures 5 and 6.

In Figure 5, DAT distribution for work purpose has a morning peak value between 7:00 and 7:30 and has low values after 14:00, while DDT distribution has two peaks at 14:00 and 18:00. Figure 6 shows that DAT and DDT distributions for study purpose are very concentrated with peak values respectively at 8:00 and 13:00.

At this point, as home-living and returning trips are executed inside the average working day, each daily modal O/D matrix is equally divided into two sub-matrices for home-living trips and for returning trips. At the end, each submatrix is splitted into 64 time-slice O/D matrices for trip purpose, according to

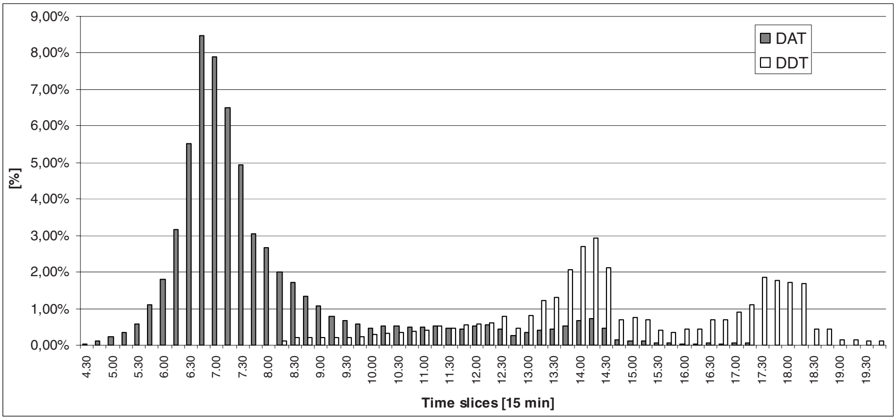

Fig. 5. DAT and DDT distributions for work purpose

distributions of Figures 5 and 6. For each simulated fare scenario, it is necessary to obtain totally 256 time-slice O/D matrices.

Concerning path choice simulation, path choice set is composed of paths selected according to some criteria related to DDT from origin, DAT at destination, maximum earliness and lateness accepted from users [19]. Systematic utility for each path is a generalized cost given from a weighted sum of time and monetary additive costs: access and egress times ($t_{\mathrm{a/e}}$), on-board time (t_b), boarding/transfer time (t_t), schedule penalty, fare (p). Generalized cost for path k (C_k) is specified, for a given DDT from origin, as follows:

$$C_k(\mathrm{DDT}) = \beta_{\mathrm{a/e}} t_{\mathrm{a/e}} + \beta_b t_{b,\mathrm{k}} + \beta_t t_{t,\mathrm{k}} + \beta_c p_{\mathrm{k}} + \beta_{\mathrm{EDT}} \mathrm{EDT}_k + \beta_{\mathrm{LDT}} \mathrm{LDT}_k \quad (16)$$

and for a given DAT at destination:

$$C_k(\mathrm{DDT}) = \beta_{\mathrm{a/e}} t_{\mathrm{a/e}} + \beta_b t_{b,\mathrm{k}} + \beta_t t_{t,\mathrm{k}} + \beta_c p_{\mathrm{k}} + \beta_{\mathrm{EAT}} \mathrm{EAT}_k + \beta_{\mathrm{LAT}} \mathrm{LAT}_k \quad (17)$$

with schedule penalties given by:

- EDT_k and LDT_k, Early Departure Time and Late Departure Time (difference between DDT and the scheduled departure time);
- EAT_k and LAT_k, Early Arrival Time and Late Arrival Time (difference between DAT and the scheduled arrival time).

Obviously, EDT_k and LDT_k attributes in (16) and EAT_k and LAT_k in (17) are mutually exclusive. Maximum earliness and lateness is 60 minutes for a given DDT/DAT both for work and study purposes. Fare for each path k (p_k) depends on the simulated linear fare systems (Eq. 13 and 14). It is obtained as sum of:

- access fare component (p_0), associated to the boarding link;
- variable on-board fare component (p_v), associated to the (or some) on-board links.

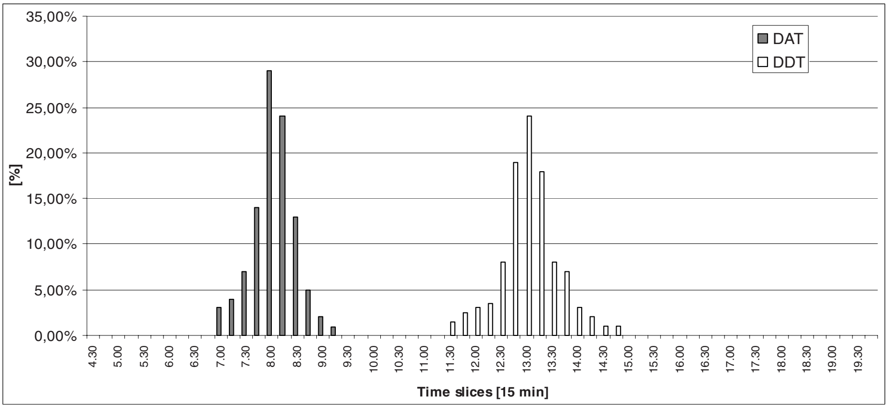

Fig. 6. DAT and DDT distributions for study purpose

Fare is, then, converted into generalized cost by means of β_c, which is represented by the inverse of value of time for users.

The values of parameters β for path attributes are presented in Table 8. They are obtained from values presented in [16], relating parameters of different time attributes to the on-board time parameter ($\beta_b = 1.00$). In order to penalize the number of transfers, parameter β_t is equal to 10.00, estimated from an aggregate calibration. The value of parameter β_c is equal to 8.00 (dis/€) for work purpose and to 13.80 (dis/€) for study purpose.

Path choice model is deterministic and fully pre-trip and provides the minimum shortest space-time path on the run-based network from each origin to each destination.

Table 8. Parameters for path attributes

Parameters		Work	Study
$\beta_{\mathrm{a/e}}$	[dis/min]	3.05	0.38
β_b	[dis/min]	1.00	1.00
β_t	[dis/min]	10.00	10.00
β_{EDT},β_{EAT}	[dis/min]	1.64, 1.70	2.92, 3.60
β_{LDT},β_{LAT}	[dis/min]	1.64, 1.70	2.92, 3.60
β_c	[dis/€]	8.00	13.80

dis = disutility

3.4 Transit Assignment

Transit assignment is based on a schedule-based approach on not congested run-based network. It is performed with the support EMME/2© software [24], which considers a minimum cost path algorithm on a space-time network. As space-time network can become very large, the algorithm generates dynamically the part of the network that is actually needed for the computations (instead of explicitly building the whole network). The algorithm computes paths either forward (starting from the origin), for trips with a desired departure time, or backward (starting from the destination) for trips with a desired arrival time, implicitly generating the minimum cost space-time path for each origin-destination couple ([24] and [19]).

3.5 Revenues Estimation

Revenues are calculated for each simulated fare scenario and each mode (bus, rail and mixed), considering as inputs loads on runs from transit assignment and fares from fare models (13) and (14).

Revenues are divided considering the access fare component (p_0) and the variable on-board fare (p_v). This last one is calculated according to model (13) for the not integrated distance fare system (with parameters from Table 3) and according to model (14) for the integrated zone fare system (with parameters from Table 4 for each simulated scenario).

Table 9 shows the results of revenues estimation. Total daily revenues for the not integrated distance fare system is equal to 26960 €/day. Total daily revenues for scenario 1 ($p_0 = 0.35$€; $\beta = 0.40$€$/n$) of integrated zone linear fare system is 19107 €/day, with a reduction of 29.10% related to the current fare system. Concerning scenarios 2 ($p_0 = 0.35$€; $\beta = 0.40$€$/n$) and 3 ($p_0 = 0.55$€; $\beta = 0.60$€$/n$), revenues are respectively 24550 €/day (−8.90%) and 28849 €/day (+7.00%). Revenues for mixed mode are always negligible, as expected.

Table 9. Daily revenues estimation for the simulated fare systems

			Revenues [€/day]			
Fare system			Bus	Rail	Mixed	Total
Distance		Access	3375	2719	109	6202
		On-board	14095	6458	204	20758
		Total	17470	9177	313	26960
Zone	1	Access	5307	2696	89	8002
		On-board	8069	3036	132	11105
		Total	13375	5732	221	19107
		Δ%	−23.40	−37.50	−29.40	−29.10
	2	Access	6762	3476	144	10238
		On-board	10015	4298	171	14313
		Total	16777	7773	315	24550
		Δ%	−4.00	−15.30	+0.60	−8.90
	3	Access	8203	4212	231	12415
		On-board	11978	4456	199	16434
		Total	20181	8668	430	28849
		Δ%	+15.50	−5.50	+37.40	+7.00

Δ% = percentage variation related to current fare system.

Figure 7 shows the percentage differences in daily revenues (*Δ*% revenues) and in daily transit demand (*Δ*% demand) between the three scenarios of the integrated zone linear fare system and the not integrated distance fare system one. Concerning scenario 1, revenues reduction is −29.10%, while transit demand increment is +0.50% (+119 pax/day). In scenario 2 there is a reduction of revenues of −8.9%, while transit demand is not changed. Finally, in scenario 3 there is an increment of +7.00% in revenues versus a reduction in transit demand of −0.8% (−182 pax/day).

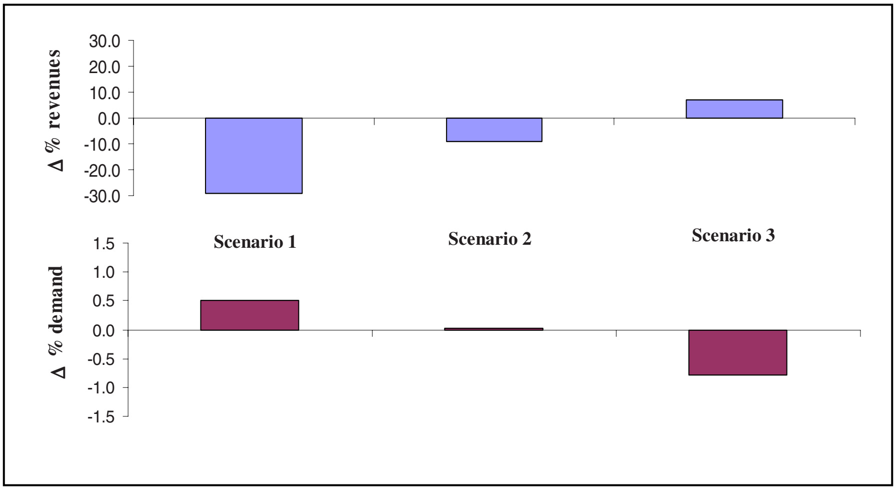

Fig. 7. Percentage differences in revenues and demand among the three simulated zone fare systems and the distance one

4 Conclusions and Research Perspectives

The paper presents a general procedure for the estimation of effects on demand and on transit revenues due to the definition of an integrated fare system in regional transit services. The necessary input data for a modeling approach are pointed out and some fare system models are specified. Finally, the procedure is applied to the Province of Reggio Calabria, Italy. Two fare systems are simulated and the results are highlighted in terms demand and revenues.

The procedure allows to simulate demand elasticity at mode and path choice dimensions, to simulate the effects of integrated linear fare systems and to explicitly simulate the mixed mode, composed by two transit modes, through the definition of intermodal transfer nodes. Non-linear fare systems can not actually be simulated, due to their non-additive nature. The simulation will be possible, using algorithms which are able to explicitly enumerate all paths on the network, which is now very costly, both in terms of CPU time and memory space.

Future research will concern the analysis of effects of integrated fare systems on other classes of users (occasional), a deeper analysis on demand with the support of stated preferences investigations, and a more disaggregate analysis of service revenues for each transit company. Moreover, it will be investigated the possibility to simulate integrated non-linear fare systems, by means of algorithms which are able to explicitate paths on the network.

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