



A demand-based methodology for planning the bus network of a small or medium town

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Abstract

This work aims at developing a demand-based methodology for designing the bus network of a small or medium town. The proposed modelling tool adopts a multi-agent objective function which evaluates performance in the context of different stakeholders: the surplus of travellers (car and bus users); the bus service provider's revenues and operation costs. This approach was applied to an existing bus network, serving Trapani, which is a medium town in the south of Italy (Sicily), with 100000 inhabitants. The bus-based public transport system attracts only about 5% of commuter trips within Trapani (source: National Institute of Statistics, 2005). This paper reports on an analysis of the application of the proposed multi-agent modelling tool to two planning scenarios: the first is *short-term* and characterized by a budget constraint (slight changes in the availability of drivers and vehicles) and the second *long-term* with new investments in new buses to improve services and increase patronage. In both cases, the impact of the recent car park charging policy launched by the local administration was considered.

The decision variables for the optimisation procedure were route, service frequency and capacity of each bus line. A *random utility model* was employed to forecast the mode choices for trips within Trapani and the travel demand-supply equilibrium was obtained using the *DUE (deterministic user equilibrium) assignment algorithm*, for private transport, and the *hyperpath network loading algorithm*, for public transport.

The optimisation procedure led to a more efficient bus network characterized by increase in bus frequencies and a better performance in terms of reduced travel time, especially for trips bound for the "old town" in the morning. In addition, a higher number of origin-destination pairs were served, at the expense of the need to interchange between the inner more frequent and the outer less frequent services. This implied that the number of transfers from one bus line to another significantly increased.

Keywords: Urban public transport; Bus network design; Park pricing; Mode choice simulation.

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1. Introduction

This paper focuses on a methodological approach for planning the public transport service of a small or medium town, subject to demand management strategies such as car park charging. The proposed approach was applied to the urban area of Trapani, an Italian town (in Sicily) with 100000 inhabitants. The layout of the town centre can be described as “funnel”-shaped (see Figure 1, where the “old town” and the “Fardella” zone, the main commercial area, are indicated). The town suffers acute traffic congestion during the morning (7:30-8:30) and afternoon (17:30-19:30) peak-periods, which is exacerbated by insufficient car parking spaces. Recently in an attempt to resolve this problem, the Town Council adopted a car park charging plan which aims to increase the availability of parking areas for short-stay users and to persuade commuters to use more remote car parks or the park and ride facility provided at Ilio (see Figure 1).

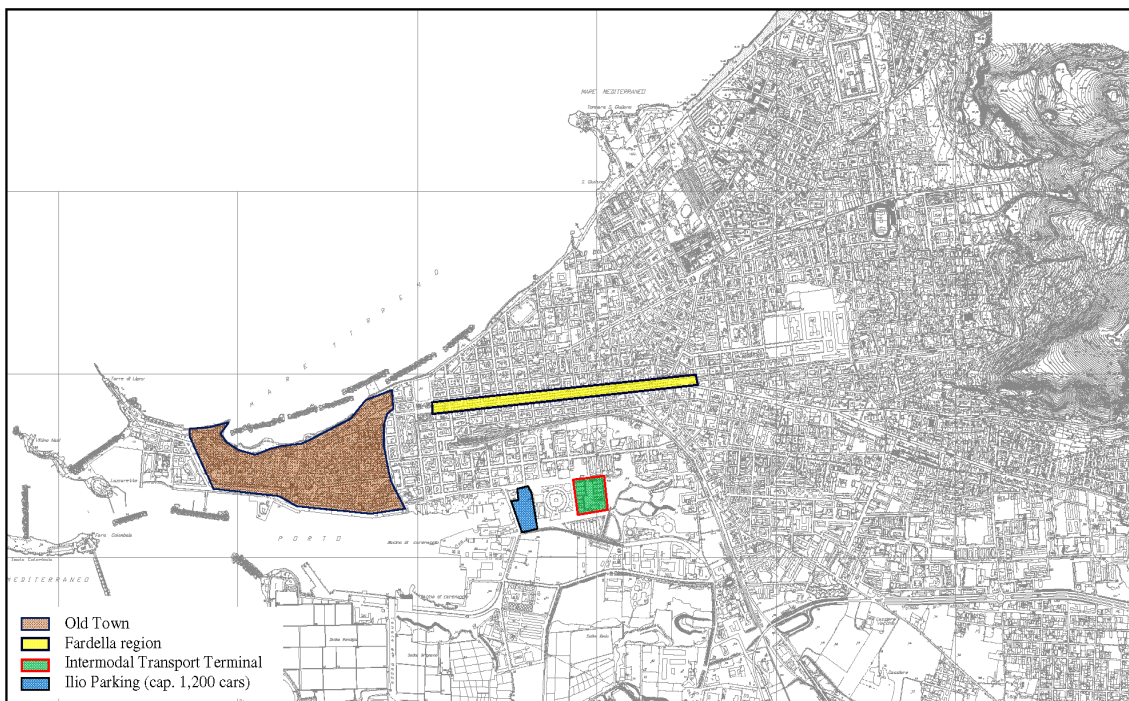


Figure 1: The centre of Trapani.

The existing public transport system consists of long, in terms of both distance and time, bus routes with low service frequencies implying a lack of competition; in fact, only about 5% of commuter trips within Trapani are served by bus (see Tables 1 and 2).

This paper in section 2 presents the state of the art of transit network design followed by a description in section 3 of the modelling framework; section 4 deals with mode choice behaviour modelling; section 5 highlights the characteristics of the bus network adopted as initial input for the design procedure; section 6 presents the analysis of the results along with some comments and finally in section 7 conclusions are drawn.

Table 1 exhibits service characteristics in terms of relative average speed and headway for central area compared to suburban and external lines.

Table 2 clearly shows the unpopularity of the bus as a commuting mode. This is due to the low values of service frequency and running speed.

Table 1: The current public transport service in Trapani.

Bus lines	Number of lines	Total number of buses	Total Length (km)	Average Length (km)	Average running time (min.)	Average speed (km/h)	Headway (min.)
"Old Town"	2	3	10	5	29	10.2	22
Suburban	8	16	106	13.2	120	13.1	38
External*	2	4	98	49.1	117	25.1	58

Note: * Linking Trapani to some nearby rural zones.

Table 2: The transport mode-based distribution of commuter trips in Trapani (7:30-8:30 a. m.).

Mode	(%)
Bus	5.5
Car	65.9
Motorbike	8.2
Other	20.4
Total	100.00

Source: National Institute of Statistics, 2005.

This paper presents an analytical framework to tackle the problems faced by the bus service provider in Trapani.

2. Background

The transit network design problem is usually formulated as a non linear optimisation problem with both discrete and continuous variables and associated constraints. The most effective solution approaches employ heuristic methods and evidence of this is presented below.

Ceder and Israeli (1993) adopted a mathematical programming-based transit network design approach which, as a first step, created a wide set of feasible routes in order to connect every node to all others. Next, the design procedure identified the minimum number of subsets of routes by solving a set covering problem and searched for the optimal subset through a multi-objective analysis.

Baaj and Mahmassani (1995) used an artificial intelligence heuristic algorithm which selected a given number of high demand origin-destination pairs and designed a starting network framework to connect these *o-d* pairs through the shortest routes. This initial network was progressively extended according to a node selection strategy based on trade-offs between performance measures and costs.

Ramirez and Seneviratne (1996) proposed an approach for route network design based on GIS applications. This assigned an impedance factor to each possible route and selected the set of routes minimising impedance.

Pattnaik et al. (1998) described a methodology for identifying optimal routes and service frequencies which employed a genetic algorithm. In particular, they implemented a two step procedure: first, a set of feasible routes was generated and then a genetic algorithm was used to select the optimum route configuration.

Soehodo and Koshi (1999) tackled the problem of designing transit routes and frequencies by formulating a programming problem that takes into account, in addition to traditional aspects such as minimal frequency and fleet size constraints, private car user costs, transit passenger crowding, transfer time and inconvenience.

Bielli et al. (2002) illustrated another approach for designing a bus network by using a genetic algorithm. They proposed a model that, at each iteration of the genetic algorithm, performed demand assignment on each network of the current set of derived solutions (feasible networks) and calculated performance indicators based on the assignment results.

Carrese and Gori (2002) developed a bus network design model consisting of two stages. In the first, the model constructed the transit network through heuristic procedures based on flow concentration, in the second stage, it identified the main and feeder lines.

Yan and Chen (2002) adopted a method for network design (routes and timetables) that optimised the relationship between bus service supply and traveller demand, through the construction of two time-space networks, which considered both a fleet and a passenger flow network.

Lee and Vuchic (2005) developed an iterative design strategy that optimised a starting network which consisted of the shortest routes connecting all the origin-destination pairs. This procedure eliminated the less efficient routes by taking into account mode choice behaviour.

Montella and Gallo (2002) proposed a methodology based on a repeated interaction between the analyst, who modified routes according to a feedback on the variation of the passenger occupancy factor and the demand-supply ratio, and an automated procedure, which was used for optimising bus line frequencies. Moreover, they assumed a fixed-demand for public transport and allowed for the trade-off between service provider's costs and user's costs.

The research described in this paper was inspired by Montella and Gallo, but presents some additional features by explicitly taking into account commuter mode choice and consequently adopts a multi-agent objective function consisting of the perceived utility of travellers (car and bus users) as well as the bus transport operator's revenues and operation costs in the performance measure used in the optimisation.

The next section details the proposed modelling framework.

3. Modelling framework

In order to design the future bus network of Trapani, the multi-agent objective function is defined as:

$$Arg \max_{\mathbf{R}, \mathbf{F}} \sum_{o-d} TP_{Bus} \cdot D_{o-d}^{Bus}(\mathbf{R}, \mathbf{F}) - C_{Bus} \cdot \sum_j F_j \cdot L_j(\mathbf{R}) + \sum_{o-d} \beta_C^{-1} \cdot S_{o-d}(\mathbf{R}, \mathbf{F}) \cdot D_{o-d} \quad (1)$$

Subject to

$$F_{min} \leq F_j \leq F_{max} \quad \forall j \quad (2a)$$

$$\sum_s S_{js} = 1 \quad \forall j \quad (2b)$$

$$S_{js} = 0/1 \quad \forall j \quad \forall s \quad (2c)$$

$$\sum_j n_{js} \leq NB_s \quad \forall s \quad (2d)$$

$$\sum_s S_{js} \cdot Cap_s \cdot F_j \geq D_j^{\max} \quad \forall j \quad (2e)$$

$$D_j^{\max} = \arg \max_{hi} D_j^{hi} \quad \forall j \quad (2f)$$

$$D_j^{hi} = \sum_{o-d} D_{o-d}^{Bus} \cdot A_{o-d}^{hi,j} \quad \forall j \quad (2g)$$

$$D^{Bus} = \hat{D}^{Bus}(\mathbf{R}, \mathbf{F}) \quad (2h)$$

$$D^{Car} = \hat{D}^{Car}(\mathbf{R}, \mathbf{F}) \quad (2i)$$

where,

TP_{bus} - one-way trip bus ticket price (euros). This was computed by dividing the monthly ticket price by 44 trips per month.

D_{o-d}^{Bus} - demand for public transport (passengers/hour) referring to origin-destination $o-d$ pair. This was estimated through a mode choice random utility model and was valid for the morning peak hour (7:30-8:30).

\mathbf{R} - vector of the various bus routes.

\mathbf{F} - vector of the various bus service frequencies (buses/hour).

C_{bus} - public transport average cost (3.5 euros/bus-km). This was estimated in accordance with the balance sheets (2005-2007) of the company supplying bus services in Trapani.

F_j - service frequency of bus line j (buses/hour).

L_j - length of bus line j (km).

β_c - coefficient associated with the monetary cost attributes of the mode choice random utility model (euros⁻¹).

$S_{o-d} = \ln \left[\exp(V_{o-d}^{Car}(\mathbf{R}, \mathbf{F})) + \exp(V_{o-d}^{Bus}(\mathbf{R}, \mathbf{F})) \right]$ - commuter surplus (maximum perceived utility) for origin-destination $o-d$ pair (dimensionless).

$V_{o-d}^{Car(Bus)}$ - systematic utility relative to the "Car" ("Bus") alternative and link $o-d$ (dimensionless).

D_{o-d} - total travel demand for pair $o-d$ (travellers/hour) consistent with the morning peak hour.

$F_{max(min)}$ - maximum (minimum) level of bus service frequency ($F_{min} = 2$ buses/hour; $F_{max} = 15$ buses/hour).

S_{js} - binary variable that is 1 if the type s bus is assigned to line j , 0 otherwise.

n_{js} - number of types s vehicles assigned to bus line j .

NB_s - total number of available types s buses.

Cap_s - maximum number of passengers both standing and sitting in a type s bus.

D_j^{\max} - maximum number of travellers using bus line j during the 7:30-8:30 hour.

D_j^{hi} - number of travellers using bus line j on line arc hi of the bus network during 7:30-8:30.

$A_{o-d}^{hi,j}$ - binary variable that is 1 if bus line j is included in the optimal hyperpath to move from origin o to destination d and line arc hi is part of the whole $o-d$ route, 0 otherwise.

$D^{Bus(Car)}$ - demand vector for bus (car) that consists of the various origin-destination flows (travellers/hour) and results from the application of the mode choice random utility model.

\hat{D}^{Bus} - demand vector for the “Bus” option, obtained by a hyperpath deterministic network loading of D^{Bus} (Cascetta, 2001; Ortùzar and Willumsen, 1994).

\hat{D}^{Car} - demand vector for the “Car” option that stems from a DUE assignment of D^{Car} (Cascetta, 2001; Ortùzar and Willumsen, 1994).

Thus, this objective function considers the interests of different stakeholders, namely the bus service provider’s revenues and operation costs and the car and bus users’ surplus.

In detail, consistent with a bilevel optimisation approach, we solved two nested problems:

- an *upper level problem*: that consists of maximising the objective function through the bus network routes, considering, for each line, the bus occupancy factor variation (passengers/vehicle)¹ and the ratio of demand (passengers-km) to supply² (seats-km)³;
- a *lower level problem*: that aims to maximise the objective function through the bus service frequencies and set the capacity of each line depending on the availability of vehicles and drivers and the demand for public transport. The latter is forecasted by a random utility model which simulates the competition between bus and car.

In order to solve the problem defined by (1), we employed a step-by-step design algorithm (see flow diagram presented in Figure 2). At each iteration a network configuration, that is better than the previous one, is generated, for the morning rush hour of a working day (7:30-8:30)⁴, by first solving the upper level problem followed by the lower level one. The resulting bus network is tested against the variation of the bus occupancy factor and the demand-supply ratio, so that if some bus lines show unsatisfactory values of these indicators, their routes can be modified and a new iteration of the bilevel optimisation process can be performed.

¹ This analysis allows the planner to gear supply to demand; for example, if a bus line presents a section with a very low occupancy factor, this part of the line path should be eliminated.

² It is calculated as follows: *Bus Capacity* (seats/bus) \times *Service Frequency* (buses/hour) \times *Bus Line Length* (km).

³ From the point of view of efficiency, a condition of equality between supply and demand would be the best solution.

⁴ Within this time window, commuter trips are prevalent, as emerges from the output of a survey conducted by the authors on the bus service demand in Trapani (Amoroso, Migliore, Catalano and Galatioto, 2008): in detail, during 7:30-8:30, the authors found out that students and workers travelling by bus are 525, while the total demand consists of 868 users.

By way of example, consider a bus line which presents a section of route with a high bus occupancy factor and another one with a low value of this indicator. The bilevel optimiser will provide two lines characterized by different service capacities.

At the first step, the method was applied to an initial proposed bus network, with routes set to improve the current level of service efficiency.

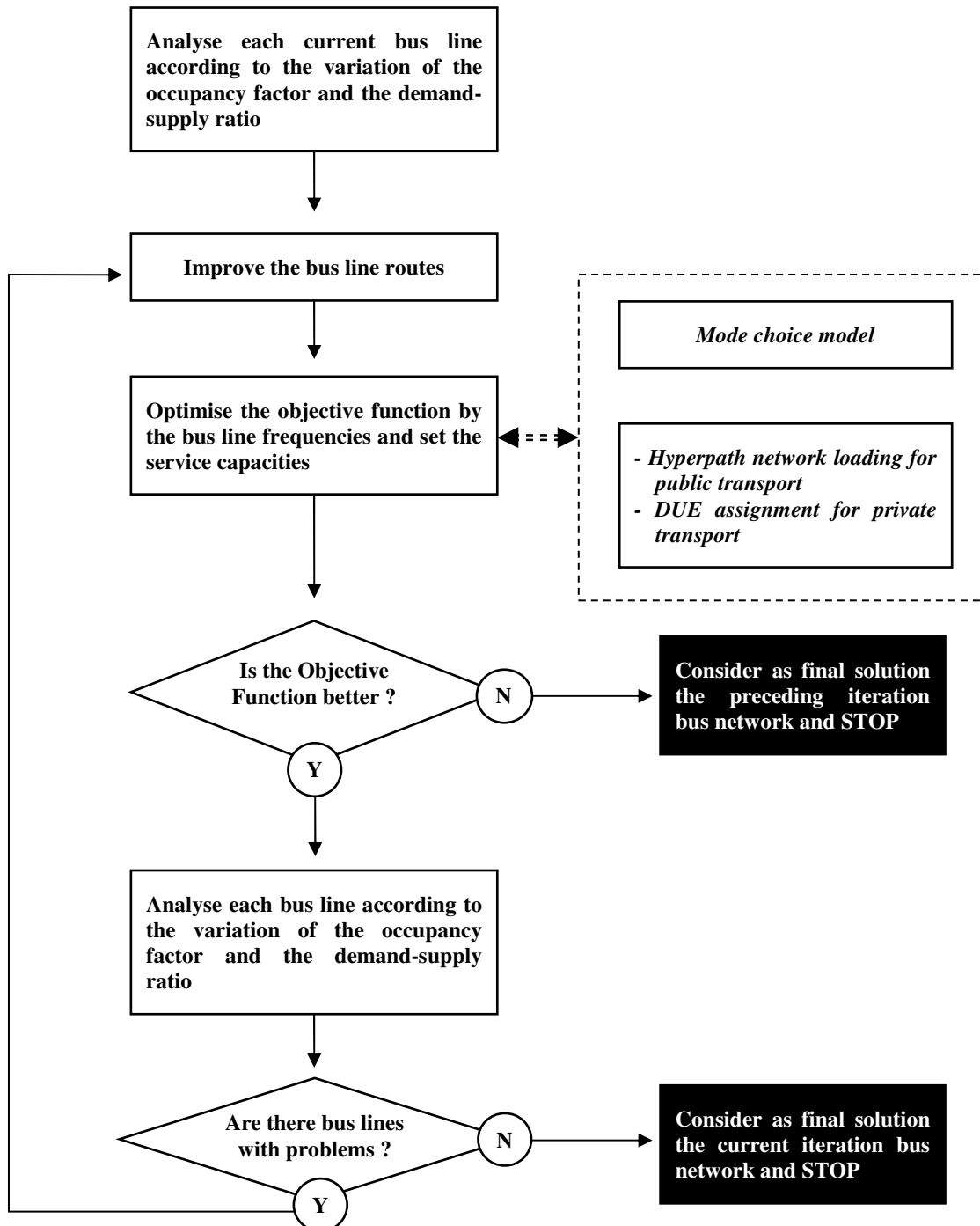


Figure 2: The bus network design algorithm.

4. Mode choice behaviour modelling

The transport mode choice behaviour for commuter trips within the urban area of Trapani was simulated using a multinomial logit model based on Ben Akiva and Lerman (1985). The following formulations refer to the one-way trip systematic utility functions associated with the alternative transport modes and containing only the attributes that proved statistically significant based on *t*-ratio.

$$V_{CAR} = \beta_{T_{TRAVEL}} \cdot T_{TRAVEL} + \beta_{C_{TRAVEL}} \cdot C_{TRAVEL} + \beta_{T_{PARKING}} \cdot T_{PARKING} + \beta_{CAR} \cdot CAR \quad (3)$$

$$V_{PUBLICTRANSPORT} = \beta_{T_{TRAVEL}} \cdot T_{TRAVEL} + \beta_{C_{TRAVEL}} \cdot C_{TRAVEL} \quad (4)$$

where,

V_j : systematic part of the alternative *j* utility function;

T_{TRAVEL} : one-way trip travel time (minutes);

C_{TRAVEL} : one-way trip travel cost (euros);

$T_{PARKING}$: parking time (minutes);

CAR (1/0): alternative specific attribute for the “Car” option;

$\beta_{T_{TRAVEL}}, \beta_{C_{TRAVEL}}, \beta_{T_{PARKING}}, \beta_{CAR}$: coefficients.

For car, the travel time attribute is the sum of the time spent moving from one’s own house to the trip starting point, the time spent moving from the trip start to the trip end and the time to reach the destination from the parking lot (trip end). For public transport, the travel time variable consists of the following elements: the time spent walking to and from stops, the waiting time at the bus stop, the in-vehicle time and, in the case of an interchange between two services, the transfer time, with a component of walk and wait. In the case of car, the travel cost variable consists of the following components: the travel cost derived by multiplying the cost per kilometre by the distance travelled and the fixed cost for park. For public transport, the travel cost is based on the season (monthly) ticket price for a bus user in Trapani.

The logit model was calibrated by adjusting (Cascetta, 2001) coefficients drawn from a previous study (Catalano, Lo Casto and Migliore, 2007)⁵, so as to consider the specific characteristics of the transport system of Trapani defined by an analysis of the data set collected from a recent survey on mode choice behaviour in Trapani. Table 3 shows the adjusted model parameters, while Figure 3 presents, for the existing bus services, the comparison between the flows of passengers derived from the survey and the flows from the logit model for the morning peak period (7:30-8:30 a.m.)

⁵ We refer to a work concerning the calibration of a demand model for predicting the modal split of the urban transport demand in Palermo, under a future scenario characterized by the availability of car sharing and car pooling.

Table 3: Estimation results for the multinomial logit model.

Attribute	Adjusted Coefficient	t-ratio	P value
T_{TRAVEL} (min.)	-0.03	-9.33	0.00
C_{TRAVEL} (€)	-0.29	-10.58	0.00
$T_{PARKING}$ (min.)	-0.11	-8.09	0.00
CAR (1/0)	2.96	11.63	0.00

Notes: ρ^2 (constants only) = 0.04; Value of time (T_{travel}/C_{travel}): 5.40 €/h.

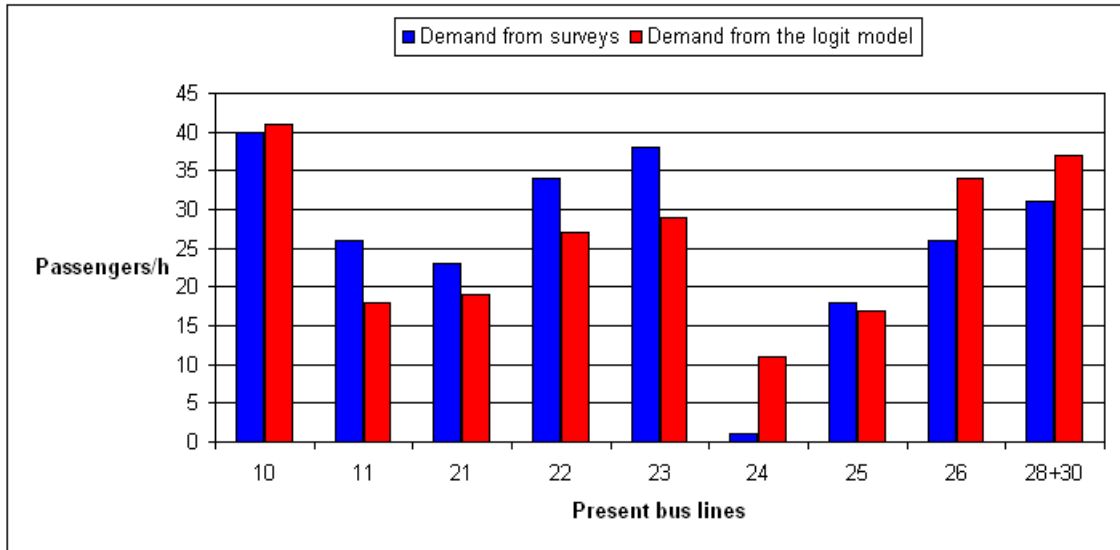


Figure 3: Comparison of the public transport demand from surveys with that derived from the logit model.

Under the bus frequency optimisation process, for every origin-destination pair, the modal split was determined using the model described above, whose attributes were estimated as follows:

- the time spent travelling by car from the trip start to the trip end was quantified by a DUE assignment of the origin-destination matrix which represented the private transport demand of Trapani.
- The parking time was estimated at 3 minutes based on a previous study concerning the park demand-supply system of Trapani (Amoroso, Migliore, Catalano and Galatioto, 2007).
- For the town centre area subject to the car park charging policy, the time taken to reach the destination from the parking lot was calculated taking into account the parking spaces that, under the aforesaid policy, commuters will be able to use either paying nothing or paying long-stay fares.
- The travel cost of one-way trip by car was estimated by assuming the perceived cost of 0.1 € per kilometre (fuel consumption). This perceived cost was multiplied by the length of the optimal route identified through a DUE assignment procedure.
- The cost of parking was determined in accordance with the parking policy recently launched by Trapani Town Council.
- The waiting time at the bus stop (or at bus stops if travellers use bus-bus interchange) was computed by multiplying the headway by 0.7. In this way the

distribution of passenger arrivals was simulated under the assumption that the bus service is not perfectly regular.

- The in-bus time was quantified by a hyperpath deterministic network loading of the origin-destination matrix representing the public transport demand of Trapani.
- The public transport cost per one-way trip was estimated on the basis of the season ticket price for a commuter using the bus service in Trapani. This was assumed to be 0.7 euros estimated by dividing the monthly ticket price by an expected usage of 44 trips.
- The time spent walking to and from stops or parking lots and the waiting time were doubled, since in real life their impact on passenger is greater than the in-vehicle time.

The simulation of public transport demand was carried out based on the following assumptions: students and elderly using the bus have no alternative; car users working or studying inside the town centre, where the described parking policy will be in force, will be induced to use the free parking facility at Ilio (see Fig. 1) and ride with bus⁶; commuters and students coming from other satellite towns by train walk or use bus services to reach their destination. Hence, these three groups of users represent an exogenous demand for bus transport.

5. The initial solution of the bus network design problem

As stated above, at the initial step, the planning algorithm was applied to a base bus network whose paths were designed to increase efficiency by improving the average ratio of demand (passengers-km) to supply (seats-km). An “All or Nothing” assignment of the origin-destination matrix representing the total transport demand of Trapani⁷ was performed to identify the principal trip generation and attraction zones of the study area as well as the routes preferred by users. Figure 4 gives the current public transport network in Trapani and Figure 5 illustrates the initial designed bus network. This network consists of the following elements: a *leader* bus service (line 1) with a high capacity serving the town centre and the parking area for car-bus interchange; one service (line 2) connects the park and ride facility with the “old town”; another service (line 3) penetrates the “old town”; two *feeder* services (lines 5 and 6) link the developing suburban area in the south of Trapani with the town centre through a transfer to the *leader* line; three services (lines 4, 7 and 8) connect the suburban area in the north of Trapani with the town centre and the park and ride facility and lastly three external services that were drawn from the present public transport system and were not changed, because they represent a minimum standard public transport service for nearby and small rural areas under the municipal administration of Trapani.

Finally, compared to the current situation, the base bus network requires only three additional buses and drivers to be assigned to the internal lines.

⁶ The estimation of such a demand derives from a previous study that led to the park pricing plan for Trapani centre (Amoroso, Migliore, Catalano and Galatioto, 2007).

⁷ In relation to the 7:30-8:30 morning peak hour of a working day (2007).

6. Computational results

The above methodology was applied to two future scenarios:

- a *short-term* scenario based on the budget constraint that, at each iteration of the transit network design algorithm, for the lower level problem, the variation of the difference between bus service revenues and operation costs remained positive with respect to the preceding iteration:

$$\sum_{o-d} TP_{Bus} \cdot [D_{o-d}^{Bus, t}(\mathbf{R}^t, \mathbf{F}^t) - D_{o-d}^{Bus, t-1}(\mathbf{R}^t, \mathbf{F}^{t-1})] - C_{Bus} \cdot \sum_j (F_j^t - F_j^{t-1}) \cdot L_j \geq 0 \quad (5)$$

where t represents a generic iteration of the step-by-step bus network design algorithm. For the definitions of other variables see section 3.

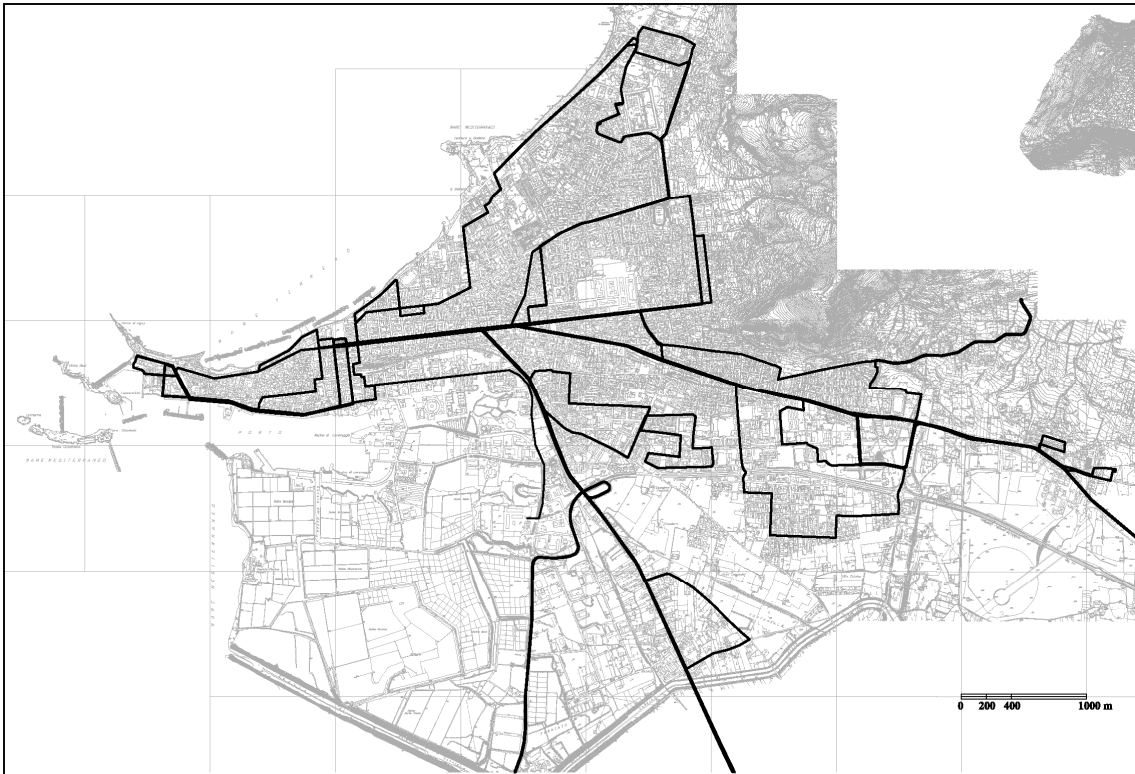


Figure 4: Current public transport network of Trapani.

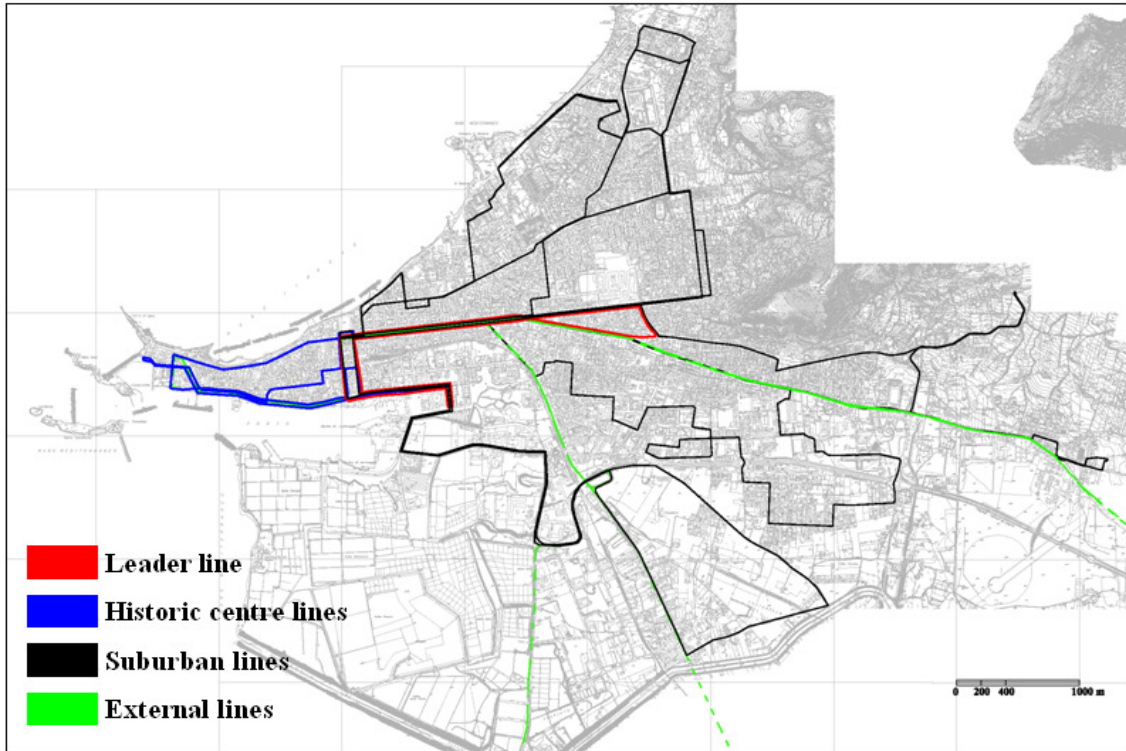


Figure 5: Initial solution of the bus network design problem.

- a *long-term* scenario taking into account the possibility of new investments in vehicles and human resources by relaxing the budget constraint to restrict the deficit margin to the value of 300 euros during the morning rush hour. This represents an estimate of the subsidy required for public transport that could be met from the charges derived from the parking policy introduced in Trapani centre. Using the same definitions as above, the corresponding budget constrain for the *long-term* scenario is:

$$\sum_{o-d} TP_{Bus} \cdot [D_{o-d}^{Bus,t}(\mathbf{R}^t, \mathbf{F}^t) - D_{o-d}^{Bus,t-1}(\mathbf{R}^t, \mathbf{F}^{t-1})] - C_{Bus} \cdot \sum_j (F_j^t - F_j^{t-1}) \cdot L_j \geq -300 \quad (6)$$

This threshold of 300 euros was obtained considering that, according to the above park charging plan, during the week and for 10 hours daily, 1542 car parks in the town centre can be used paying a fixed fare of 0.8 euros/hour and assuming that on average a revenue generating parking lot is used for 5 hours a day. An additional assumption was that one third of the annual revenues are invested in improving the quality of urban public transport by increasing the capacity for the main services during the morning⁸.

Under the *short-term* scenario, the base bus network resulted in the optimal one, whilst the *long-term* simulation required eleven additional buses (and drivers)⁹ assigned

⁸ The survey conducted on the urban public transport of Trapani in 2007 (Amoroso, Migliore, Catalano and Galatioto, 2008) pointed out that the demand for bus services falls sharply in the afternoon time: about 4380 users during the 6:00-14:00 period against about 1320 users during the 14:00-19:00 period.

⁹ 28 vehicles and drivers for the internal bus lines instead of 17 at present.

to regular services, without modifying the initial routes. Tables 4, 5 and 6 illustrate the future scenarios on the bus service of Trapani in comparison with the present situation.

The first comment on the outcomes concerns the possibility of investments: under the *long-term* scenario, the model suggests that the additional financial resources should be spent on global development of the public transport supply, so as to achieve a headway of less than 10 minutes, for both the leader and historic centre services, and of 20 minutes for the suburban lines.

The second, as can be seen in Tables 4, 5 and 6, under the *short-term* and *long-term* scenarios, a rise of 110-120% in the demand for public transport mainly due to the parking policy implementation is forecasted. In relation to the very inefficient lines serving the developing suburban area in the south of Trapani¹⁰, the average ratio of demand to supply increases considerably from the current value at 0.14 to 0.20 in the short term and 0.18 in the long term; consequently, the efficiency improves. Furthermore, with respect to the current scenario, the average origin-destination transit time is reduced by 6.4% and 15% in the short term and in the long term respectively. The biggest performance improvement occurs for trips into the “old town”: in this case, the average o-d transit time is reduced by 19% under the *short-term* solution and by 27% in the other case.

Finally, the model application leads to a 5% rise of the number of *o-d* pairs served, at the expense of the number of *o-d* connections implying a transfer from one bus line to another (interchange), which increases by 77%.

Table 4: The current bus network of Trapani (7:30-8:30 a.m. peak hour).

	Bus lines¹¹								
	10	11	21	22	23	24	25	26	28
Length (km)	4.4	5.6	10.5	10.2	10.0	18.8	14.3	8.7	19.3
Running time ¹² (hour)	28	30	49	50	51	72	59	43	83
Bus line demand ¹³ (passengers/hour)	127	90	131	102	146	29	85	63	95
Number of buses	2	1	2	2	2	1	2	2	3
Frequency (buses/hour)	4.3	2.0	2.5	2.4	2.4	0.8	2.0	2.8	2.2
Headway (minutes)	14.0	30.0	24.5	25.0	25.5	72.0	29.5	21.5	27.7
Supply (passengers/hour)	146	100	233	223	224	42	228	265	206
Max demand (passengers/hour)	72	56	67	57	84	25	42	35	50
(Demand x km) / (Supply x km)	0.30	0.48	0.20	0.14	0.26	0.33	0.08	0.08	0.08
Total demand = 868									
Number of served origin-destination pairs = 1040									
Number of served origin-destination pairs implying a transfer = 300									
Average origin-destination travel time (minutes) = 47									
Average origin-destination travel time to reach the historic centre (minutes) = 48									
Average origin-destination travel time to reach the main commercial area (minutes) = 41									

¹⁰ The number of which is reduced by the design procedure: from lines 24, 25, 26 and 28 at present to lines 5 and 6 under the project.

¹¹ Excluding the external lines that were not changed (see section 5).

¹² Including the time for driver break.

¹³ Passengers using bus-bus interchange are considered to estimate the demands for both bus services used.

Table 5: The optimal bus network for Trapani under the short-term scenario (7:30-8:30 a.m. peak hour).

	Bus lines							
	1	2	3	4	5	6	7	8
Length (km)	8.1	7.5	3.8	10.7	11.1	13.3	13.1	14
Running time (hour)	48	35	25	50	51	49	55	56
Bus line demand (passengers/hour)	674	592	183	110	163	81	161	162
Number of buses	5	3	2	2	2	2	2	2
Frequency (buses/hour)	6.29	5.12	4.79	2.40	2.35	2.45	2.19	2.14
Headway (minutes)	10	12	13	25	26	25	27	28
Supply (passengers/hour)	688	579	144	228	224	144	208	203
Max demand (passengers/hour)	373	552	134	110	88	71	92	117
(Demand x km) / (Supply x km)	0.23	0.34	0.48	0.20	0.17	0.23	0.19	0.33
Objective function (euros) = 158838								
Δ Revenues - Δ Running costs (euros) = 0								
Logit model-based demand (passengers/hour) = 320								
Car-bus intermodalism demand (passengers/hour) = 797								
Students and elderly (passengers/hour) = 662								
Train-bus intermodalism demand (passengers/hour) = 39								
Total demand = 1818								
Number of served origin-destination pairs = 1095								
Number of served origin-destination pairs implying a transfer = 530								
Average origin-destination travel time (minutes) = 44								
Average origin-destination travel time to reach the historic centre (minutes) = 39								
Average origin-destination travel time to reach the main commercial area (minutes) = 37								

Table 6: The optimal bus network for Trapani under the long-term scenario (7:30-8:30 a.m. peak-hour).

	Bus lines							
	1	2	3	4	5	6	7	8
Length (km)	8.1	7.5	3.8	10.7	11.1	13.3	13.1	14
Running time (hour)	48	35	25	50	51	49	55	56
Bus line demand (passengers/hour)	693	597	203	131	168	85	176	170
Number of buses	7	4	3	3	3	2	3	3
Frequency (buses/hour)	8.81	6.83	7.19	3.6	3.53	2.45	3.28	3.21
Headway (minutes)	7	9	8	17	17	25	18	19
(Demand x km) / (Supply x km)	0.17	0.26	0.35	0.18	0.12	0.24	0.14	0.24
Objective function (euros) = 158929								
Δ Revenues - Δ Running costs (euros) = - 292								
Logit model-based demand (passengers/hour) = 389								
Car-bus intermodalism demand (passengers/hour) = 797								
Students and elderly (passengers/hour) = 662								
Train-bus intermodalism demand (passengers/hour) = 39								
Total demand = 1887								
Number of served origin-destination pairs = 1095								
Number of served origin-destination pairs implying a transfer = 530								
Average origin-destination travel time (minutes) = 40								
Average origin-destination travel time to reach the historic centre (minutes) = 35								
Average origin-destination travel time to reach the main commercial area (minutes) = 34								

7. Conclusions

This paper has demonstrated the feasibility of a novel transit network design methodology by optimising a real size bus network, which serves Trapani, a medium town in the south of Italy (Sicily), with 100000 inhabitants and a low demand for public transport.

The proposed method consists of an iterative design strategy that optimises a base (current) network using a feedback algorithm based on the variation of the bus occupancy factor and the demand-supply ratio, explicitly allowing for mode choice behaviour.

Moreover, the model, by adopting a multi-agent objective function (reflecting both travellers and bus service provider), designs bus service routes, frequencies and capacities, for two planning scenarios: a *short-term* scenario characterized by a budget constraint (slight changes in the availability of drivers and vehicles) and a *long-term* scenario which considers the possibility of new investments in service quality. In both cases the impact of the parking policy recently agreed by the local administration is taken into account.

The simulation of public transport demand was carried out based on the following assumptions: students and elderly using the bus have no alternative; car users working or studying inside the town centre, where the described parking policy will be in force, will be induced to use a free parking facility outside the centre and ride with bus; commuters and students coming from other satellite towns by train walk or use bus services to reach their destination.

The optimisation procedure yielded a more efficient and effective bus network which required 77% increase in bus-bus interchange and characterized as follows: higher ratios of demand to supply particularly for the services linking the developing suburban area in the south of Trapani with the town centre; a better performance in terms of travel time, especially for trips into the “old town”; a higher number of *o-d* served pairs, but at the expense of the number of *o-d* connections implying a transfer from one bus service to another, which increases significantly. As regards the demand “captured” by the optimised transit system of Trapani, it mainly consists of individuals using the park and ride facility outside the centre: 797 passengers/hour, while the total demand is of 1818 passengers/hour under the *short-term* project and 1887 passengers/hour under the *long-term* scenario.

We did not deal with the problem of optimising the external lines that at present connect Trapani with the nearby rural zones, characterized by a “weak” travel demand. So, a development direction of this research could be to compare the proposed solution with the possibility of linking Trapani by bus to dispersed areas of residences perhaps also considering innovative approaches based on dial and ride and other bespoke services.

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