Comparing Route Deviation Bus Operation with Respect to Dial-a-Ride Service for a Low-Demand Residential Area

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Abstract— **Flexible transit services, such as Route Deviation Bus, or RDB, match the features of fixed-haul traditional transit and demand-responsive service. They have been proven to be efficient on the grounds of both cost and performance in many low-density residential areas. This paper deals with a special form of advanced public transport operations, which is known by different names, such as route deviation line, point deviation bus line, corridor deviation line and checkpoint dial-a-ride. We present the results of a design analysis performed on a real network using a model proposed for the Route Deviation Bus problem, which is based on mixed integer linear programming. The study network is located in Campi Bisenzio, a small town in the surroundings of Florence (Italy). This urban area is characterized by a low level of the transit demand for the major part of the day. Two decades ago, the traditional line-haul system has been replaced with a mixed advance request and immediate request Dial-a-Ride system. In this paper, first, the RDB problem is briefly summarized. Second, the model is applied to the real case of Campi Bisenzio and the results drawn from the model application are shown in comparison with the existing on-demand service management as a mixed operations Dial-a-Ride system. We simulated the RDB service operating in the actual scenario and then we compared the two different operations modes, calculating their respective values in a set of performance indexes. In such a study case, the existing mixed Dial-a-Ride operations mode results are better than the switching to a route deviation bus service. However, this result seems to be highly influenced by the particular frame of the underlying street network. Nevertheless, we can view the obtained results as a meaningful trial performed on a real scale that highlights boundaries and better defines the application domain of the more frequently applied new RDB service operations for the low transit demand management. Finally, our results show that a route deviation strategy is more suitable to accommodate rejected requests, that is, those for which it is impossible to schedule the call, than any Dial-a-Ride strategy.**

Keywords - Flexible route design and planning; Route Deviation Bus operations; Dial-a-Ride transit systems; Integer programming.

I. INTRODUCTION

There are some transport systems that serve a low demand in time and/or in space. In such cases, the optimal service strategy must be suited in a way as to follow the demand.

Many types of transport systems operate under the so-called “demand responsive” manner. Among them, there is the route deviation system, also called Route Deviation Bus, or RDB, line. The RDB system consists of a number of tracks pertaining to the main route, and of other tracks pertaining to deviations. Passengers can be grouped in three different clusters: in the first cluster there are passengers boarding at main route stops that come before the deviate stop; the second cluster groups passengers alighting at main route stops that follow the deviate stop; the third cluster counts passengers at the deviate stop.

Such a classification leads directly to understanding that every objective function for the RDB problem must have at least two terms: the first one is the disutility that deviations impose, as an extra in-vehicle time, on passengers of the main route; the second one is the amount of benefit attained from those passengers that use deviated stops. The operating mode of RDB will be reviewed in short in the following section.

Major advantages of a route deviation service include:

- Increasing of the area served by a vehicle ;
- Better service productivity, through reducing empty vehicle trips;
- Improving system accessibility, by shortening walking distances.

However, this flexibility has an upper bound in terms of increase of the timetable adherence variance for base line, or main route, stops. Nevertheless, until now and as far as we know, the RDB problem has received little research contributions as mathematical model formulation when compared to the fixed line-haul problem. Studies of route deviation systems are reported in Bredendiek and Kratschmer [1], Filippi et al. [2], Daganzo [3], Pratelli and Schoen [4]. More recently, Qui and coworkers [5] identify as demi-flexible operation the policy group between flexible and fixed-route transit systems. Shen et al. [6] proposed a two-stage model to minimize the total cost of a flexible transit service operating as a demand responsive connector system with on-demand stations. The review made by Ronald and co-workers [7] investigates the application of an agent-based approach for simulating demand responsive transport systems. Lu et al. [8] presented a flexible feeder transit routing model suited for irregular-shaped networks. Lee and Savelsberg [9] investigated a flexible transport system known as a demand responsive connector, which transports commuters from residential addresses to transit

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hubs via a shuttle service, from where they continue their journey via a traditional timetabled service. Finally, Papanikolaou et al. [10] compiled a critical overview of the literature on the modeling issues related to flexible transit systems at strategic and operational levels.

Diana et al. [11] compared the performance in terms of the distance traveled of a conventional fixed-route transit system and of a demand responsive service. Different models were proposed to study the design of feeder transit services by comparing a demand-responsive service and a fixed-route policy [12].

The main task of this paper is to offer to transit planners an experimental contribution to make their choice between specific transit services for flex-route policy. Moreover, because many traditional fixed-haul transit systems in low-demand areas are switching to flex-route services, this paper intends to help towards the choice between alternative flex-route transit strategies suited for situations that have a low and sparse user demand.

The paper is organized as follows. In Section II, the RDB operations are described, while in Section III, the RDB problem is depicted in its mixed integer linear programming formulation [4]. In Section IV, an actual on-demand transit service scenario has been simulated as an RDB operating mode and then compared to the real mixed operations Dial-a-Ride system management. Section V ends the paper with a comment about the resulting comparison evidence based on the respective value set of performance indexes.

II. The Route Deviation Bus Operating Mode

The RDB, or demand-responsive service on set routes, is a transversal transit system that distributes and collects passengers in the crossed blocks supporting the main, or fixed, routes along radials and arterials.

RDB operation has been proposed and applied in order to enhance effectiveness of line-haul transit during off-peak periods, as well-suited service for small towns or as a component of a larger integrated transit system [13][14].

One of the main elements of such a system is the so-called equipped bus stop, or terminal, which accepts user subscriptions and makes the bus deviate from its main route (Figure 1).

Indeed, the terminal core is a control unit, which interfaces other local devices, such as “detour traffic lights”, keys and displays. The user interface is a graphic screen, usually LCD display, plus few functional keys, which guide the user in his/her choice of menus. The calling terminal also informs users about the timetable and lines of the urban service, the expected time of arrival of the next bus and delays.

Periodically, each terminal consults the “detour traffic lights” and updates its forecast time-of-passage table with the new received data.

After having read the time of passage on the screen, the passenger may insert a coin or a smart-card to confirm his reservation. The terminal stores the subscriptions and sends a switching signal to the proper detour traffic light. There are two such detour traffic lights on the base route, one for each direction, close to the “detour point”.

When a detour point is active, the control system sends a message to the on-coming vehicle, which informs the driver about the need of making a deviation. When the bus reaches the equipped bus stop, data are reset in the control system. This operation closes the cycle and detects whether or not the reserved service was actually given. The control system can record vehicle passages at detour points and at on-call terminals, so it can compute the actual mileage day by day.

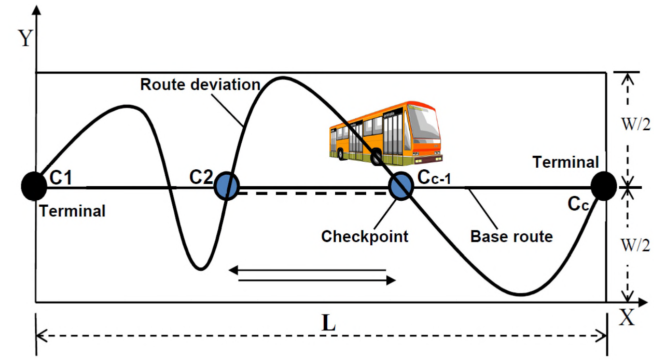

Figure 1. Route deviation bus policy.

III. The RDB Problem

Let us consider the problem faced by the bus route planner when designing a bus route with optional stopping, as described in the previous sections.

In this section, we shall deal with a simplified model and we will describe in brief a mathematical programming model, built in order to help the decision maker. We assume that a bus route has been designed regarding to the main stops served by the bus route. What remains to be decided is the location of the optional bus stops whose are served on a demand basis. A trade-off has to be found between the interest of passengers located at these extra bus stops, and the augmented travel time suffered both from passengers on the bus whose route is deviated, and from passengers waiting for the bus at regular stops downstream the deviation.

We assume, for simplicity, that the bus route has the characteristics of a “feeder” line (i.e., many-to-one), that is supposed to be true for all the stops, except for the last one where no passenger leaves the bus. This way, we do not need origin/destination matrices and we can base our model just on the (expected) passenger demand at each bus stop.

The bus route with regular and demand stops is formalized as a directed graph, with two types of nodes – those corresponding to regular stops, and those associated with optional demand stops – and three kinds of arcs: the arcs corresponding to the normal bus route, the arcs corresponding to deviations whose are actuated by passenger demand, and arcs associated to links whose passengers not served by a demand bus stop have to cover on foot. Figure 2 shows a simple deviation bus line layout with 7 normal stops, numbered from 1 to 7 and identifies the location of 3 possible optional stops: A, B and C.

The main decision concerns whether to activate or not the optional stops in A, B, C. If the route planner decides to

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serve, e.g., optional stop A, then a bus on the main route will deviate from node 2 to node A, and then to node 3 only if a demand in node A is detected. Otherwise, the bus route corresponds to the regular arc 1-2. On the other hand, if the route planner decides not to serve node A, then passengers potentially located at node A will have to walk from node A to the nearest fixed stop, which is here assumed to be node 2. The arc corresponding to pedestrian mode is the dashed one in Figure 2.

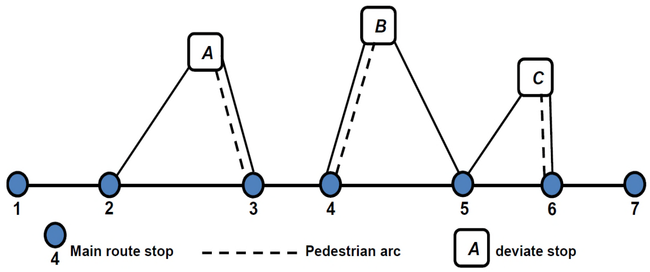

Figure 2. Basic graph layout of a route deviation bus line [4].

From the point of view of mathematical modeling, there are several issues arising from the problem above. The first issue has been already coped with and concerns origin/destination pairs. A second issue concerns cost computations. This model assumes that to each arc corresponds a unit cost proportional to the distance between the endpoints of the arc (an alternative could be to use an estimate of the travel time). The distance is augmented for the arcs corresponding to pedestrian flow, in order to give an estimate of their “perceived” distance. The travel time should be used; but in such a case, is also required to make a correction as time perceived in different ways, and depending on whether the passenger is walking or waiting for the bus. An aggregate measure of cost has been obtained by multiplying each unit cost by the flow, i.e., by the expected number of passengers on that arc.

IV. THE ROUTE DEVIATION BUS MODEL

In the optimal RDB design model based on a mixed integer linear programming problem, Pratelli and Schoen [4] consider the problem faced by the bus route planner when designing a bus route with optional stopping, as previously described. For sake of simplicity, the RDB model is herewith briefly resumed, and the interested reader is addressed to the original paper [4].

The service area is divided into segments by some regular stops along the base route, identified by 1, 2 … N (Figure 1). It is assumed that a bus route has already designed with its main stops. A trade-off has to be found between the interest of passengers located at these extra bus stops, and the augmented travel time suffered both from people on the bus whose route is deviated, and from passengers waiting for the bus at regular stops downstream the deviation. As said before, the bus route is like a “feeder” line, i.e., many-to-one, and in the last stop no passenger leaves the bus. Therefore, it does not need of any o/d matrix, and the RDB model is based just on *In(i)* and *Out(i),* number of users boarding and alighting the bus at stop, respectively. *M* is the bus capacity; *Q* is the maximum feasible deviation distance from the main route, on each side; *t(i,j)* is the time associated to any single user boarded on the bus traveling on arc *(i,j)*; *t*(i,j)* is the time on foot for a user walking from location *i* to *j*.

In each ride, the bus must visit all the regular stops. The total aggregated travel time T_0, obtained when the bus makes no deviations outside the base line, is given by (1):

$$T_0 = \sum_{i=1}^{n-1} t(i,i+1)\, f(i,i+1) \tag{1}$$

Demand is constant during the design period, even when it is associated to regular stops and deviate stops. The decision variables are binary-valued variables, defining both the decision or not of placing a deviated stop at some location, and the entities describing of flows along the different arcs. The decision variables are:

- $\delta(d_i)=1$ representing the decision to place a deviated stop at location d_i; $\delta(d_i)=0$, otherwise;
- *f(i,j)* is the flow variable related to the amount of users on board of the bus travelling along arc *(i,j)*;
- *f*(i,j)* is the flow variable of the number of users walking on foot from location *i* to regular bus stop *j*.

The RDB objective function to minimize has the following form:

$$\begin{aligned} \min Z = {} & K_b\left[\sum_{i=1}^{n-1}\left(t(i,i+1)f(i,i+1)+t(i,d_i)f(i,d_i)+t(d_i,i+1)f(d_i,i+1)\right)-T_0\right] \\ & +K_f\left[\sum_{i=1}^{n-1} t^*(d_i,i)f^*(d_i,i)\right] \\ & +K_w\left[\sum_{m=2}^{n}\sum_{i=1}^{m-1}\left(t_i(i,d_i)+t(d_i,i+1)-t(i,i+1)\right)I_n(m)p_{di}\delta(d_i)\right] \end{aligned} \tag{2}$$

Each one of the three terms in square brackets in the objective function (2) above, is to represent:

a) the total surplus travel time perceived by users boarded on the bus, which is defined as the total aggregated time elapsed on board during deviations;

b) the total travel time perceived by users who have to reach on foot a regular stop from the locations, which are not served by any deviate stop;

c) the augmented waiting time suffered by users at bus stops located downstream of the deviations caused by an upstream deviation: at bus stop *m* there are *In(m)* users waiting.

Each term in (2) is multiplied by a time weight coefficient: K_b, K_f and K_w, which respectively consider the different time perceived by users when traveling in vehicle, walking and waiting [3]. A deviation at regular bus stop *i* can only occur if the decision is taken of serving the deviated bus stop, $\delta(d_i)$ = 1, and either at least one passenger

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is waiting at d_i, or a passenger on the bus just before stop i asks to be alighted at the deviated stop.

Probability p_{di} that a route deviation will actually occur during a time slot Δt is given by $p_{di}=1 - \exp[(\alpha_{di} + \beta_{di})\ \Delta t]$, given that both the process of passengers arriving at a deviated stop with rate α_{di}, and the process of requests to be alighted at deviated stops with rate β_{di}, form two independent Poisson' processes [4].

A set of constraints is defined to reproduce the relationships between the different flows and the decisions whether to activate or not deviated bus stops. The three constraints, $f(i,d_i) \leq M\delta(d_i)$, $f(di,i+1) \leq M\delta(d_i)$, $f^*(di,i) \leq M(1-\delta(d_i))$, impose the two logical conditions that a deviated arc have a positive flow only and only if the corresponding deviate stop is activated and, conversely, there is a positive flow of walking users only and only if the deviate stop is not activated. Flow conservation both at regular and deviate stop is represented by constraint $f(i-1,i) + f(d_i-1,i) + f^*(d_i,i)+In(i) = f(i,i+1) + f(i,d_i)+Out(i)$ and constraint $f(d_i,i)+ In(d_i) = f(d_i,i+1)+ f^*(d_i,i)+ Out(d_i)$. Randomness in bus route deviation is referred by $f(i,d_i) \geq p_{di}[f(i-1,i)+ f(d_i-1,i)+ f^*(d_i,i)+ In(i) - M(1-\delta(d_i)]$.

The latter, it is a logical constraint, and it is referred to randomness in bus route deviation. If $p_{di} > 0$ is the probability of at least one user waiting at deviated stop d_i, and the decision is taken to activate that deviated stop, then users entering node i will be divided into two streams: one on the deviated arc (i,d_i) and proportional to p_{di}; the other one on the fixed line arc $(i, i+1)$ and proportional to $(1- p_{di})$. A practical upper bound is imposed on max length, or max time, of any deviation. There is a last constraint, $g \leq \Sigma\delta(d_i) \leq G$, imposing that the total number of deviated stops to be activated must lie between a minimum number g and a maximum number G.

Finally, the RDB model results in a mixed integer linear programming problem, or MILP [15]. The above MILP has been implemented in the mathematical high level language AMPL [16] and the computational tests were run on a common PC using CPLEX solver.

V. Application Network and Framework

The town of Campi Bisenzio is located in the metropolitan area of Florence, central Tuscany (Italy). Campi Bisenzio (Figure 3) is a small town with a high density populated historic center, and some sparsely residential and industrial activities in its surroundings, along two opposite streamlines oriented to North and South, respectively. The rounded relevant land-use data are: 29 sqkm of municipal area; 35,000 inhabitants; average population density of 1,200 inhab/sqkm.

Therefore, transport demand is sparse and characterized by a high variability rate in time and space. There are several road links with quite different geometries. In such a condition, it is very difficult to serve transit demand by conventional line-haul operations, and flexible-route service looks the most proper choice. Since 1998 the previous three fixed line-haul transit service was replaced by a new Dial-a-Ride system conceived for mixed mode operations, named Personalbus. Today, the Personalbus service covers all the municipal area, even reaching zones that never were served by the previous fixed line-haul transit system. Personalbus is a demand-responsive door-to-door transit system, which operates in a Dial-a-Ride mixed mode, i.e., managing both advance requests and immediate requests.

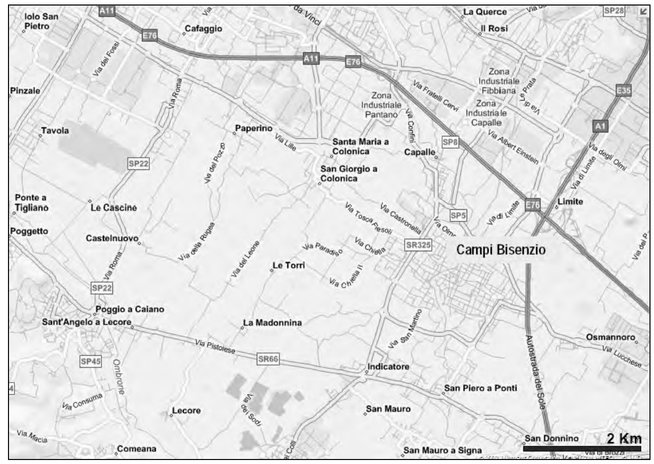

Figure 3. Map of the service area.

The core of Personalbus is the so-called Travel Dispatch Centre, or TDC, located at the ATAF headquarter, the main urban transit company of Florence. All the travel requests are collected, processed and managed by specific software, which solves for vehicle routes and dispatching for day-by-day basis on the stops as requested by patronage. The TDC is suited to manage:

- telephone travel requests, coming from user's house or directly from equipped stops; each travel request may be formulated into two ways. The first is in advance (e.g., the day before) or on systematic base (e.g., every Monday at 9:00 a.m.). The second is immediate, when the request is at least 15 minutes before travel starting;
- automatic travel request collecting and managing by its related insertion into the current optimal vehicle dispatching and scheduling plan;
- in-vehicle communication for driver instructions on the new vehicle route required by the accepted travel request(s).

Users call by phone the TDC and ask for booking their trip, specifying both desired departure and/or arrival time and location of stops for pick-up and drop-off. Then, TDC operator inputs data and runs the vehicle routing and scheduling software, giving to the user the corresponding answer to his/her trip request, in real time. At this point, a negotiation phase on the user's specified service times can eventually start between the TDC operator and the user. The first desired times can be corrected in order to meet both optimal system operations and tolerable user needs. Booking phase ends with definitive acceptance or refusal by the user of proposed trip solutions.

TDC's operators are able to manage the immediate requests negotiating with the user for the best pick-up time,

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which can span into a time window of ±20 minutes centered on the user preferred time. This avoids any flat refusal of the user by the transit company. At the most, it is the user who gives up his/her trip, but it happens very rarely.

Finally, it is useful to underline that time negotiation is possible because the Personalbus patronage, as usually happen in any demand-responsive system, have a "relaxed" travel time utility function. This last is quite different from a "tight-to-time" travel time utility function characterizing systematic users of conventional fixed-haul transit systems.

The success obtained by Personalbus is clearly showed in Figure 4, where is represented the patronage evolution in the first 5 years of starting up, from middle 1998 to 2002 [17].

Moreover, the value of the last year recorded patronage of the previous existing three fixed line-haul service is also depicted in Figure 4, and it is about many thousands less carried on by the flexible line one.

The monthly patronage ranges on 9,700 passengers carried on average, with peaks around 13,000 passengers per month (Figure 4). As said above, Personalbus Travel Dispatch Centre has to cope with both off-line and on-line requests, i.e., both advance requests and immediate requests. Table I shows a typical requests resume recorded in two weeks on Fall beginning.

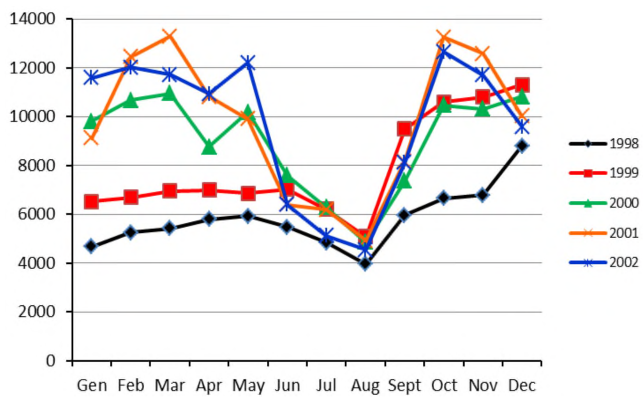

Figure 4. Personalbus monthly patronage from 1998 to 2002 [17].

From the values reported in Table I, it is fairly clear that the advance requests are almost prevalent in respect to the immediate requests. Due to this evidence, one can note that the service should be regular to some extent, instead fully demand-responsive. Moreover, data drawn from practice monitoring on user disposability to negotiate for immediate requests have revealed that shifts of plus or minus 20 to 30 minutes from the desired time are quite well accepted. This last fact gives force to the concept that demand-responsive system users have a perception of travel time fully different from line-haul system users, more and more linked to tight schedules.

These considerations have led to evaluate the hypothesis of a new transit system, operating in a mixed-mode between line-haul, for higher regular demand related to advance requests, and demand-responsive operations, for lower randomly demand related to occasional immediate requests. Roughly speaking, the new transit system to evaluate is the RDB bus system.

TABLE I. TWO TYPICAL TRIP REQUESTS WEEKS ARRIVED TO TDC.

	Total Requests	Total On-Line	% Advance	%Immediate
25 Sept	120	38	0.76	0.24
26 Sept	124	52	0.70	0.30
27 Sept	124	52	0.70	0.30
28 Sept	127	45	0.74	0.26
29 Sept	126	58	0.68	0.32
30 Sept	41	47	0.47	0.53
02 Oct	124	41	0.75	0.24
03 Oct	120	56	0.68	0.32
04 Oct	136	47	0.74	0.26
05 Oct	147	47	0.76	0.24
06 Oct	123	55	0.69	0.31
07 Oct	38	48	0.44	0.56

A. Comparison Indexes

Statistical data on costs are not available, therefore the comparison has been performed between the present DRT system service, i.e., Personalbus, and the proposed RDB system operations, through two comparison indexes, which are defined in respect to some relevant performance requirements:

$$\Delta W\% = \frac{T_{w,o} - T_{w,s}}{T_{w,o}} \times 100 \tag{3}$$

$$\Delta P\% = \frac{P_{att} - P_{RDB}}{P_{att}} \times 100 \tag{4}$$

Following Johnson et al. [18], the first index, $\Delta W\%$, represents the percentage variation of maximum waiting time at regular stops, and the symbols at the right member of expression (3) are: $T_{w,o}$ maximum observed waiting time of Personalbus; $T_{w,s}$ maximum waiting time resulting for the new RDB solution at hand.

The second comparison index, $\Delta P\%$, represented by expression (4), is the percentage difference between the actual satisfied demand, P_{att}, and the amount of demand, P_{RDB}, that the new RDB solution could satisfy.

B. Solving for the new RDB system network

Data recorded by Personalbus TDC have referred to compare the actual Dial-a-Ride mixed mode service operations to the new proposed RDB system operations. Basic data are related to each vehicle per day as bus mileage, daily effective service time, number of served requests, carried passengers per link, boarding and alighting passengers per stop.

The computational goals have been restricted to one representative operations period, which has selected in a test month with a satisfied patronage of 3,700 passengers. Real data are used to determine the frequency call at each stop.

The highest frequency call stops are used to build the main network "skeleton" leading to two fixed lines, namely Line 1 and Line 2, crossing the whole service area (Figure 5). Line 1 terminals are the industrial and commercial park of S.Angelo a Lecore (zone 8) and the railway station of Pratignone (zone 1). Line 2 terminals are the large interchange parking of motorways A1 and A11 (zone 3) and the residential zone of S.Donnino (zone 11) characterized by single-family detached housing. Each one of potential deviate stops has been placed as the centroid of a group of Personalbus stops not belonging to Line 1 nor Line 2 regular stops. These are stops characterized by low call frequencies, generally less than 0.15÷0.25. Therefore, the frequency call assigned to any potential deviate stop, i.e., deviation probability, was the weighted average frequency of the group, using number of calls of each stop as weight. This way, the result was in 13 deviate stops covering the whole area to serve.

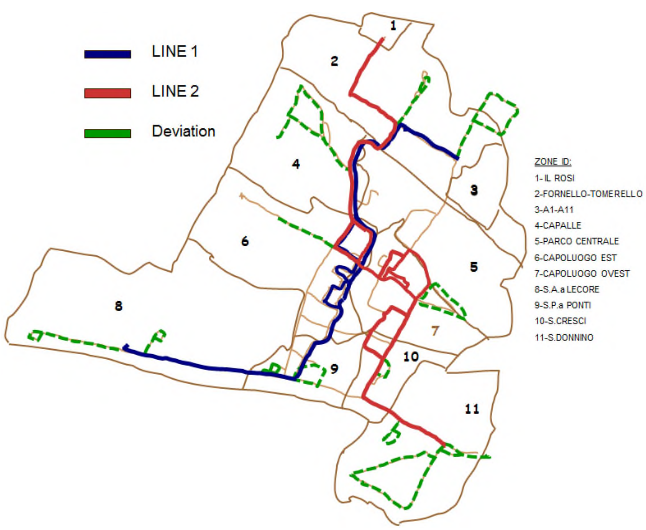

Figure 5. Layout of the new RDB network

Data related to Personalbus patronage was adapted to the new situation and an o/d matrix was obtained for the two RDB lines, respectively. Users having origin located on one line and their destination placed on the other line, were split assigning each of them to the closest stop common for both RDB lines.

At this point, a proper RDB problem was solved for each one of the two RDB lines, given both a minimum of 4 and a maximum of 7 deviate stops. The values for time weight coefficients in the objective function (2) were assumed in $K_b = 1.0$, $K_f = 2.5$ and $K_w = 2.2$. Definitive results showed the following issues:

- Line 1: Base line length is about 6.5 Km. Different combinations were analyzed, beginning with a number of 7 deviate stops to a number of 4 deviate stops. There are eight potential deviate stops on Northbound direction, and nine on Southbound direction. The RDB problem drops off the potential deviate stop located at the Pratiglione railway station, when solved for less than seven deviate stops. This is an obvious drawback highlighting the difference between theoretical and practical solutions.
- Line 2: Base line length is about 7.2 Km. As above, different combinations were analyzed including from 4 to 7 deviate stops. There are fourteen potential deviations in both directions. The theoretical solutions for less than 6 deviate stops not include the deviation associated to zone 4, where is located an important shopping center.

Both Line1 and Line 2 require a number of three vehicles dispatched on service for a period of 12 hours on a weekday (instead of six vehicles actually dispatched by Personalbus). Depending on the number of included deviate stops, there are different average vehicle headways, or frequencies, on regular stops for each of the two lines, respectively.

TABLE II. COMPUTED RDB SERVICE VALUES FOR THE TWO LINES.

Line 1	**Route travel time**	**Lost demand** (pax/m)	**Headway** (minutes)	**Deviation utility ratio**
Zero-Devs	1h 00' 26"	354	20	---
4 Devs	1h 43' 44"	193	35	0.72
5 Devs	2h 02' 54"	93	41	1.05
6 Devs	2h 12' 44"	53	45	1.20
7 Devs	2h 26' 29"	1	50	1.43
Line 2	**Route travel time**	**Lost demand** (pax/m)	**Headway** (minutes)	**Deviation utility ratio**
Zero-Devs	1h 14' 53"	354	25	---
4 Devs	1h 47' 44"	193	36	0.44
5 Devs	2h 09' 12"	93	43	0.72
6 Devs	2h 14' 56"	53	45	0.80
7 Devs	2h 37' 28"	1	53	1.09

Table II shows, in respect to different RDB solutions, the obtained values of average route travel time, monthly component of actual users not served by RDB, i.e., lost demand, and vehicle headway. In Table II are reported the values of no deviations situation, i.e., zero-devs, to reproduce the borderline case of line-haul operations.

In Figure 6 and 7, respectively, are depicted the same values of lost demand per month, and headway of Line 1 and Line 2 solution instances. It is trivial to notice that as the number of designed deviations increases, on one side the route travel times and headways also increase, and on the opposite side, the lost demand values obviously decrease.

Personalbus acts as a doorstep service and, therefore, an alternative RDB system operation needs the highest number of available deviate stops in order to keep the large part of the actual patronage. On the contrary, one must take into account of the transit company point of view, both in terms of efficiency and costs.

The high number of deviations implies both dispatching of many vehicles to maintain acceptable frequencies, and increasing in vehicle idle times, and lowering of user tolerability due to several deviations made upstream.

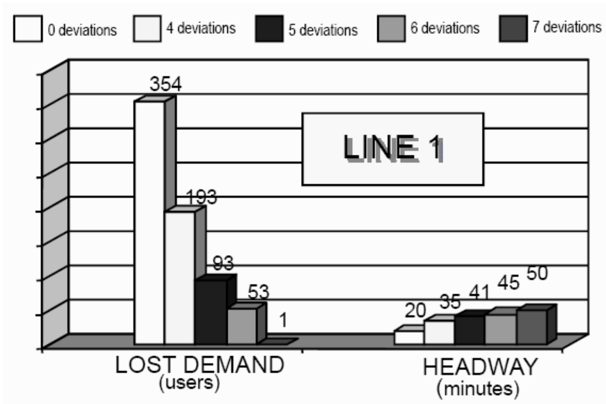

Figure 6. Lost demand and bus headways for Line 1 in the different instances of RDB operations.

Figure 7. Lost demand and bus headways for Line 2 in the different instances of RDB operations.

The last column of Table II shows the values of deviation utility ratio, which has been used since some decades as rule-of-thumb in many flexible-route deviation system evaluations and programs, as said by Johnson and co-workers [18].

It is generally assumed that stable deviation route system operations are possible if the ratio remains under 1 when calculated as:

$$DUR = \frac{Deviation\ \ pick-up\ \ time}{Line-haul\ \ time} \qquad (5)$$

Line 1 have feasible deviation utility ratios only in case of 4 deviate stops. While Line 2 shows all the evaluated instances feasible, except the one with 7 deviations.

Table III resumes the performance indexes of all RDB solved instances from 4 to 7 deviated stops, which are compared to the Personalbus ones. The values shown for RDB solutions, in Table III, are averages of the corresponding values related to each one of the two lines under examination. Moreover, it is clear that lower values of waiting times are referred to an RDB service with few deviated stops, say 55% less for 4 devs or 31% less for 5 devs, than Personalbus. Such RDB solutions also imply the highest losses of satisfied demand with respect to the present service situation, i.e., over 16% or 13% when compared to Personalbus, respectively.

TABLE III. COMPARISON RESUME OF PERSONALBUS IN RESPECT TO DIFFERENT INSTANCES OF RDB.

TYPE	**Freq.** (bus/h)	**Served demand** (pax/m)	**Max wait. time** (minutes)	**ΔW %**	**Lost demand** (pax/m)	**ΔP%**
PERSON ALBUS	---	3710	25.00	0	0	0
RDB 4 devs	2.55	3111	11.25	- 55	599	- 16.1
RDB 5 devs	2.05	3222	17.25	- 31	488	- 13.1
RDB 6 devs	2.00	3445	18.75	- 25	265	- 7.1
RDB 7 devs	1.75	3532	22.50	- 10	178	- 4.8

VI. CONCLUSIONS AND FUTURE WORK

Future mobility is challenged to bundle up transport demands to handle an increasing mobility caused by spatial sprawl, economic growth and suitable working time [19]. Flexible route and demand-responsive transport systems offer an opportunity to overcome these challenges for future public mobility for the preservation of personal mobility, especially in sparsely populated rural and residential areas [20][21].

In this paper, the RDB model has outlined as a MILP problem and applied to a real case. Computational results are drawn in the test area of Campi Bisenzio, a large residential area located in the surroundings of Florence (Italy), for a new RDB system operating with two base lines and different instances of number of designed deviate stops. Numerical comparisons through performance indexes highlight that the actual demand-responsive transit system, called Personalbus and operating under Dial-a-Ride mixed mode service, is quite better than changing to any one of the considered RDB flexible route system alternatives.

Nevertheless, the main computational results are likely linked to the poor resemblance to a “corridor” shape of the study-case network. This is a further detailed confirmation of some general findings previously obtained by Daganzo using analytical models [3].

In addition, the fairly considerable length of deviations to base bus route is also often resulted not favorably to deviation route operations development, as enhanced by the computed values of deviation utility ratio, i.e., DUR in (5), related to many among the RDB design alternatives taken into account.

Finally, the presented study-case leads to meaningful experimental findings on planning and application domain of demand-responsive transit systems requiring for RDB service operations. This paper is intended to offer to transit planners a preliminary experimental evidence in the field of flex-route systems. Future studies can also cope with developments to incorporate ITS technologies, advanced math tools and innovative smartphone applications.

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