AN INTEGRATED APPROACH TO LOCAL PUBLIC TRANSPORT SERVICES AND EFFICENCY IN COMPANY MANAGEMENT. A MODEL APPLICATION

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Abstract

The design of public transport systems is a complex activity which develops on different levels. The process is made of different components, as the design of service levels and definition of service parameters, as planning bus routes, planning bus stops, setting frequency and time-tables. The process is based largely on customer satisfaction; therefore the design of the service will be demand-oriented. The service design has an effect on the cost of the service and therefore it is a constraint.

Experience shows that it is not conceivable to design a system which is budget – restrictions free, therefore it is not possible to fulfil passenger requirements without keeping in account the limits set by service production costs, that is offering a service which is conceived independently from company efficiency, or effectiveness.

In standard approaches, all the service data (i.e. timetable) is a given invariable data for the problem solving. The proposed approach intends to solve the problem of vehicle scheduling by considering the service data, defined in the first step, as a variable of the system; therefore, during the process of optimization of the vehicle scheduling, it is possible to modify the time table given as input, in function of the optimization of the company's business efficiency.

The approach presented in this paper is based on the consideration that the constraints set in the service planning phases, if considered rigid, are a strong limitation to the achievement of efficiency in the company business process.

Therefore in the phase of vehicle and crew scheduling, the constraints on the service data are relaxed, allowing small modifications to the time table.

Keywords: bus service design, Time table, vehicle scheduling, crew scheduling.

Presenting Author's biography

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1 Introduction and state of art

Public transport is based on a relation between demand and supply, as all transport systems. In the case of Public Transport, demand is influenced by many external factors, community mobility needs, social inclusion and collective transport demand patterns to name some, while supply, in an always more commercial orientated market, has to go by financial efficiency. The process in the programming phase, the design of service levels and definition of service parameters, as planning bus routes, planning bus stops, setting frequency and time-tables is based largely on customer satisfaction, therefore the design of the service is demand-oriented.

As a consequence, based on elementary economy rules, the service design has an effect on the cost of the service. Developing the desired service and respecting budget are the base conditions, and therefore it is not possible to fulfil passenger requirements without keeping in account the limits set by service production costs, that is designing the service independently from company efficiency, or effectiveness.

To this, it must be added that analyzing data in the Italian Public Transport market, it can be seen that over 70% of the sustained costs are for personnel.

In theory, the best bus service design model should consider all inputs and constraints, therefore optimizing the service which contemporarily achieves the goals of customer satisfaction and minimization of operative costs. Practically such a model would be computationally complex, and of difficult analytical definition. The modality which comprises reliable results with computational accessibility is an approach by successive steps. Firstly the service is designed with the layout of routes, bus stop locating, frequency and time table definition. Secondly, the service is designed by assigning vehicle to trips (vehicle scheduling), drivers to vehicles (crew scheduling), and to create work weeks for drivers (rostering). If it is used, a scheduling system adds real business value.

In the first step, the planning of the bus service, the methods used to minimize the objective function refer to aggregated parameters for the company production costs, in which the company's efficiency is a marginal contribute [1,2].

In the second step the characteristics of the operators company, as vehicle number, drivers, and operative costs have a central role in the assignment of the proposed bus service to the road [3,4,5].

In standard approaches, all the service data (i.e. time table) is a given invariable data for the problem solving. The proposed approach intends to solve the problem of vehicle scheduling by considering the service data, defined in the first step, as a variable of the system; therefore, during the process of optimization of the vehicle scheduling, it is possible to modify the time table given as input, in function of the optimization of the company's business efficiency [6].

The approach presented in this paper is based on the consideration that the constraints set in the service planning phases (first step), if considered rigid, are a strong limitation to the achievement of efficiency in the company business process.

Therefore in the phase of vehicle and crew scheduling (second step), the constraints on the service data (time table) are relaxed, allowing small modifications to the time table, where for small modifications we intend fluctuations of departure and arrival times at bus stops which do not affect or interfere with passenger demand.

The paper presents the service planning methodology, the simulation of a test network and real system adopting the proposed model. The parameters developed in the study and design phase are valued and verified in the application.

2 The proposed procedure

The proposed procedure (figure 1) is developed on the following phases.

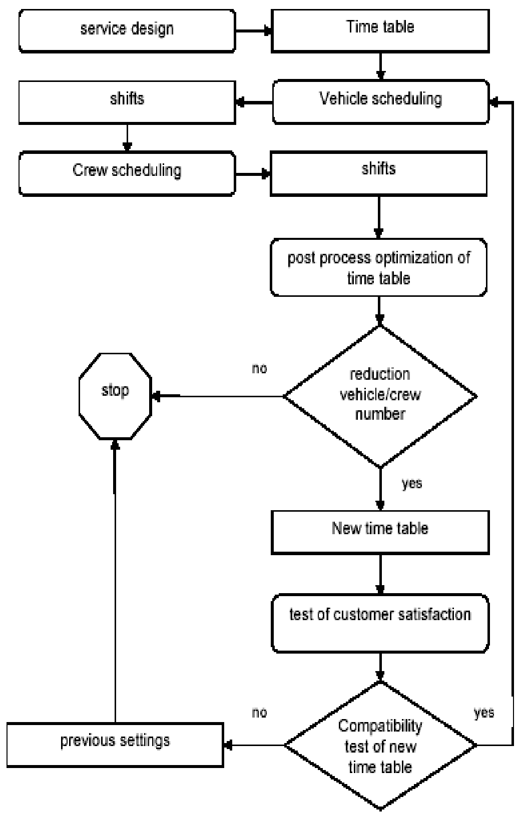

Fig. 1 proposed process scheme

Starting from the timetable which has been designed in the first step, the procedure researches the solution for a problem of vehicle scheduling which aims to obtain the scheduling of vehicles while optimizing company resources. Subsequently the problem of crew scheduling, assigning drivers to vehicles, is solved using models present in literature. The first solution obtained, is conditioned by the input time table, designed in the first step. From this first scheduling configuration it is possible to begin a post process of optimization of the departure time scheduling, aiming to reduce the use of resources, in terms of vehicle and crew employment. The procedure is set considering as an invariable constraint the customer satisfaction level required by contract, and develops a number of *n* iterations, until the number of vehicles and crew between two successive iterations converges.

In detail, for vehicle and crew scheduling it is necessary to generate, considering the constraints set, all the possible shifts and associate to each of them a relative cost C_i. Defined the matrix **A** of incidence runs/shifts, with runs r_i in rows and shifts S_j, *in* columns, it is assumed that the element a_{ij} is equal to 1 if the run r_i is covered from the shift S_j, 0 otherwise. It can therefore be formulated *a set partitioning* problem:

$Min\ \boldsymbol{C}^T \cdot \mathbf{x}$ with

$A \cdot x = 1$

$x_i \in \{0,1\} \quad \forall\ i$

where $\boldsymbol{C}^T$ represents the vector, the elements of which are the costs of the single shifts.

The solution to the *set partitioning* problem consists in finding a subset of columns (shifts) of the matrix A which portions at minimum cost the set of the rows (runs), so that each row of the matrix is chosen exactly in one shift [7].

The result obtained in terms of shifts is conditioned by a rigid constraint given from the timetable. With the proposed procedure we want to verify if a solution better than the solution found with the crew scheduling exists, obtained relaxing the rigid constraints of the timetable; it is therefore necessary to define a temporal slot within which it is possible to vary the departure time of some runs, aiming to reduce the number of shifts, without worsening the service level offered to the user.

3 An application of the procedure to a test network

In order to expose the whole process of the service program, here expressed in terms of vehicle scheduling and crew scheduling, an application is developed for a test network.

Let us consider the network in figure 2, with three centroids, 7 nodes (of which 4 are bus stops) and two bus lines. Pair 1-2 is connected by line A1, (for pair 2-1 A2), pair 1-3 is connected by line B1 (for pair 3-1 B2), pair 2-3 is connected with transfer in node H using lines A and B.

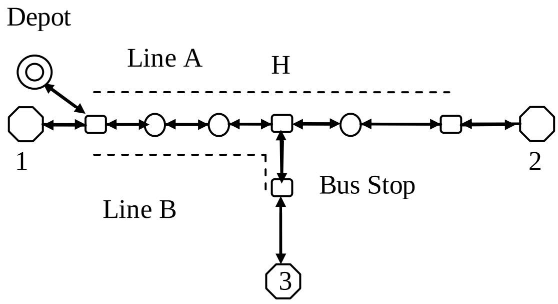

Fig. 2 The test network

The travel time on line A is assumed equal to 20 minutes, while that on line B is assumed equal to 15 minutes.

Assuming that such service has already been planned, and the timetable for lines A1, A2, B1, B2 shown in table 1 is relative to the time slot between 7.00 and 9.15.

Tab. 1 Timetable of the planned service.

Line	Run	Departure	Arrival
A1	1	7.00	7.20
A1	2	7.20	7.40
A1	3	8.05	8.25
A1	4	8.55	9.15
B1	1	7.45	8.00
B1	2	8.15	8.30
B1	3	8.40	8.55
A2	1	7.25	7.45
A2	2	7.55	8.15
A2	3	8.35	8.55
A2	4	9.25	9.45
B2	1	8.20	8.35
B2	2	8.35	8.50
B2	3	9.00	9.15

In the hypothesis of a single depot, for this network, the vehicle shifts of minimal "cost" necessary in order to carry out the runs of this service can be easily calculated. The three shifts and the runs bound to each are shown in table 2.

Once the vehicle shifts have been set, the crew schedule is assigned. This is a very delicate phase, because it is subject to many constraints, which often depend from current legislation and/or local agreements between companies and workers unions.

Tab. 2 vehicle schedule

Vehicle shift	Line	Run	Departure	Arrival
1		Trans. depot	7.15	7.20
1	A1	2	7.20	7.40
1	A2	2	7.55	8.15
1	B1	2	8.15	8.30
1	B2	2	8.35	8.50
1	A1	4	8.55	9.15
1	A2	4	9.25	9.45
1		Trans. depot	9.45	9.50
2		Trans. depot	6.55	7.00
2	A1	1	7.00	7.20
2	A2	1	7.25	7.45
2	B1	1	7.45	8.00
2	B2	1	8.20	8.35
2	B1	3	8.40	8.55
2	B2	3	9.00	9.15
2		Trans. depot	9.15	9.20
3		Trans. depot	8.00	8.05
3	A1	3	08.05	8.25
3	A2	3	8.35	8.55
3		Trans. depot	8.55	9.00

In the present case the main hypotheses considered are the following: a driver can begin or finish the shift in correspondence of the depot, or a terminus which is within an acceptable walking distance from the depot; a shift cannot last more than 6 hours, and eventual overtime which can be at the most an hour, and between one run and the other the driver must have a break of at least 5 minutes.

Once the hypotheses are set, the best crew scheduling, reported in table 3, can be calculated. For the test network, it is obtained that 5 drivers in service are strictly necessary. To calculate staff on service the number is increased considering members off duty for rest in the week and holidays in the year, and reserve to cover absent members off duty for illness, leave or other.

Once the calculation process of the vehicle shifts and the crew shifts has been carried out, the aim set is to verify if there can be an improvement modifying the timetables, sliding on the time axis the beginning of the shifts, looking for a more favourable solution in terms of operating costs, and therefore to reduce the number of the crew shifts.

Tab. 3 crew schedule

Crew shift	Vehicle shift	Line	Run	Depart.	Arrival
1	2		Trans. depot	6.55	7.00
1	2	A1	1	7.00	7.20
1	2	A2	1	7.25	7.45
2	2	B1	1	7.45	8.00
2	2	B2	1	8.20	8.35
2	2	B1	3	8.40	8.55
2	2	B2	3	9.00	9.15
2	2		Trans. depot	9.15	9.20
3	1		Trans. depot	7.15	7.20
3	1	A1	2	7.20	7.40
3	1	A2	2	7.55	8.15
4	1	B1	2	8.15	8.30
4	1	B2	2	8.35	8.50
4	1	A1	4	8.55	9.15
4	1	A2	4	9.25	9.45
4	1		Trans. depot	9.45	9.50
5	3		Trans. depot	8.00	8.05
5	3	A1	3	8.05	8.25
5	3	A2	3	8.35	8.55
5	3		Trans. depot	8.55	9.00

It can be easily seen in table four that if shift 1 were to be anticipated 5 minutes, and equally shift 3 were to be anticipated 5 minutes, the service could be carried out with only three crew shifts.

Clearly the new shifts must respect the time-space constraints assumed previously: in fact a shift can be aligned with an other only in the case in which the arrival terminus of the previous one coincides with the beginning terminus of the successive one, and if there is an interval of at least 5 minutes (and not greater than 30) between the two shifts, and the duration of the new shift must be smaller or equal to the maximum duration adopted in the crew scheduling. It is necessary also that the new shifts are coherent with the vehicle scheduling, so not to modify the company efficiency in the vehicle scheduling.

Tab. 4 “slid” timetable with new crew scheduling

Crew shift	Vehicle shift	Line	Run	Depart.	Arrival
1	2		Trans. depot	6.50	6.55
1	2	A1	1	6.55	7.15
1	2	A2	1	7.20	7.40
1	2	B1	1	7.45	8.00
1	2	B2	1	8.20	8.35
1	2	B1	3	8.40	8.55
1	2	B2	3	9.00	9.15
1	2		Trans. depot	9.15	9.20
2	1		Trans. depot	7.10	7.15
2	1	A1	2	7.15	7.35
2	1	A2	2	7.50	8.10
2	1	B1	2	8.15	8.30
2	1	B2	2	8.35	8.50
2	1	A1	4	8.55	9.15
2	1	A2	4	9.25	9.45
2	1		Trans. depot	9.45	9.50
3	3		Trans. depot	8.00	8.05
3	3	A1	3	8.05	8.25
3	3	A2	3	8.35	8.55
3	3		Trans. depot	8.55	9.00

It is obvious that for the company to be able to carry out the service with only three crew shifts would represent a remarkable achievement on economic terms, considering that the cost of the staff in transport companies represents over 70% of the total cost.

To verify the effects that the “sliding” of the crew shifts, and therefore of the timetables, has on the users is more complex, as it is necessary to proceed to an explicit verification of the effects on the customers of the new timetables obtained for the service. The verification can be carried out using a model for the calculation of the attributes of level of service induced on the customers by the modified timetables.

It is necessary to use an assignment model of the schedule-based approach, which allows, by means of the explicit representation of the timetables of the runs (diachronic network), to estimate the effects produced from variations of the timetable. The application of the assignment model, both in the case of the initial timetables, and in the case of the modified timetables in the phase of post-optimization, allows, by the means of the calculation of specific indicators (total waiting time spent at bus stops, variation of the penalty of early arrival/delay endured, etc), to estimate the goodness of the found solution [8].

The assignment model must allow the users present at the bus stop to choose the run which allows them to arrive as soon as possible and, in the case of more combinations of runs which allow to arrive at destination at the same time, it is preferred the one which requires the minor number of transfers.

For the application of the model it is also necessary to know the transport demand between the different pairs origin/destination and the temporal distribution of the same in the considered period. For a high frequency urban transport system a uniform distribution of the arrivals of the users to the stops can be assumed.

Assuming a deterministic model, it is estimated for every pair o/d the set of paths chosen from the users in the two timetable configurations (initial and post optimization) and subsequently some indicators in order to estimate the effects on the user.

The application of the model to the test network, assuming the transport demand between the pairs o/d, shown in table 5, has allowed to calculate the total waiting time spent from the users at the bus stops for the two different timetables.

Tab. 5 Origin/destination demand (users/hour)

Origin	Destination	Value
1	2	28
1	3	14
2	3	12
2	1	20
3	1	24
3	2	12

The obtained values of the total waiting time, equal respectively to 7904 and 7920 minutes are nearly identical and demonstrate that the improvement of the efficiency of the service, with a remarkable reduction of the crew shifts, has not determined a decrease in the service level offered to the users.

4 An application of the procedure to the transport system of the city of Reggio Calabria

The entire procedure has been applied on the public transport system of the city of Reggio Calabria, Italy, a city with a basin of 230.000 inhabitants on a surface of 252 sq km. The transport service covers 3.173.000 bus*km/year and is structured on 35 lines, which carry an average of 35.000 pax/day.

The company runs the service on a single depot scheme; it has developed recently a new service plan designing new routes, lines and timetables. Different configurations of network and timetables were drawn, choosing the one which, on equal bus*Km, offered the customers the better service level. Transport demand has been estimated, on the base of surveys, and the schedule-based approach models have been applied so to allow to assign the transport demand to the various configurations of assumed networks and timetables.

The scenarios are based on the common hypothesis: two main terminals localised on the edge of the city centre, in which the lines from North and South have terminus. The two terminals are therefore connected between each other by means of a high frequency line which crosses the entire city centre. Vehicle and crew scheduling has been carried out using a commercial software, which allows to estimate 68 vehicle shifts and 143 crew shifts

The detailed analysis of these shifts and timetables was developed resorting to the use of a heuristic algorithm which allows to evaluate for each pair of turns the possible improvements, choosing the ones which give the highest contribute, in regards to all the constraints set. The algorithm is based on a Greedy technique, and the obtained solution depends on the chosen path, and the final solution is not necessary the best, even though it is surely better than the initial one.

The variations of the of departure times of some runs has concurred therefore to join pairs of shifts, for a total saving of 12 crew shifts, equal to the reduction of 7.74%, correspondent to an annual cost of approximately 360.000 euro.

The assessment of the effects on the users, applying the assignment model to the new timetable (scenario B), has supplied the values of the total waiting time spent by the customers at the bus-stops similar to those of the initial configuration (scenario A): 602226 minutes for the scenario B and 602121 minutes for the scenario A, equal to a variation percentage of 0.02%.

The service plan was rearranged in accordance with the new configuration of shifts, agreed with the workers unions, and in use from the month of September 2007.

5 Conclusions

In the paper a focus has been set on the problem of integrating the design phases with the programmed service, also in regards to the service financial efficiency. It has been verified as the results of the design of the vehicle and crew scheduling can be improved adopting small modifications to the programmed service.

At the same time it is done so that there is no reduction in the service levels. A procedure has been introduced which has been applied on a test network, and on a real case for a medium size city network.

The results obtained in the applications show a reduction, respecting the constraints set, in the necessary crew number on the network service, therefore allowing a reduction of production costs maintaining equal service levels.

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