Design and Control of a Public-Transportation Service Contract.

Feasibility Study Summary.


1. Introduction and structure of the Study.

From the end of the 20th century up to today, some changes occurred in the organization of Public Transport (PT) services in Europe and specifically in Italy. Local governments, while keeping the political responsibility of PT services, more and more often are turning to the market to provide transport services in outsourcing, entrusting the management of the service to an Operator. At the same time, local governments are establishing Public Transport Agencies (PTA), also called “Authorities”, whose duties include service planning, service awarding procedures and drafting of the contract of service which describes the conditions for PT provision by the Operator.

This Study, which has been conducted within the EPTA European Project – Interreg IVC, focuses on the case of the city of Bologna, but the analysis could be extended to many other cases, where the service is provided according to a model Agency-Operator.

This Study includes two main sections, which are closely linked:

- the first one (see. Chapter 3) analyses the relationship between the Agency and the Operator, according to a model of game theory and studies the equilibrium conditions;

- the second one (see Chapters 4 and 5) describes a control procedure through which the Agency may verify the performance of the Operator, with respect to the fulfilment of its contractual obligations. The proposed control procedure, in turn, is a necessary input for the calculation of the balance of the game, because the Operator chooses the level of accuracy (or “truth”) of its performance report, also depending on the effectiveness of the controlling procedure.

An optimized controlling procedure allows the Agency to carry out its work at minimum costs and with the greatest possible accuracy. It also helps to define a condition of equilibrium in which the Operator gets incentives if it respects its contractual obligations on performance and reporting activities.
The optimal control procedure is defined with the use of techniques applied to a combinatorial optimization problem of integer linear programming. Although the resulting problem is difficult both from the theoretical point of view ("NP-hard") and from the practical point of view, the computational study demonstrates that it is possible to find efficient optimal or near-optimal solutions.

The conclusion of this Study (see Chapter 7) is that the proposed methodology can be used to adjust the main parameters of the contract – as the fines and the minimum investment to get the desired behaviour by the Operator – provided the control is done according to an optimized procedure.

In the specific case of Bologna (see Chapter 6 and 7), the Agency awarded a six-year Contract of Service (extendable by three more years), which allows the Operator to collect about 150 million euros/year, including public funding and revenues from tariffs and traffic. The Operator, as foreseen in the Contract of Service, has to monitor its own performance and to provide the data to the Agency. If the Operator does not achieve the requested objectives – in terms of number of kms made with respect to the planned ones – the Agency shall sanction it; the Operator is also sanctioned, and in a more consistent way, if he provides to the Agency deliberately falsified data on its performance.

One of the limits of this kind of Contract is the asymmetry of information between the Operator and the Agency, because the Operator has direct access to information concerning its performance, while the Agency receives the information only by the Operator. Without an adequate control process, the Operator would not have an incentive to ensure the provision of the contracted service levels and to correctly report its level of performance to the Agency.

Currently the Agency performs some controls on the service, but these controls are not systematic, because they are mainly based on complaints received by the users. In these cases, the Agency sends an employee to check specific bus stops. The Agency is then interested to standardize the controlling procedure, with the aim to evaluate the performance of the Operator and validate the current contract. This activity will help the Agency to refine the structure of the contract, if necessary, and to improve the structure of the fines in the next one.

2. Literature overview and Good Practice transferability.

The Study contains three viewpoints and perspectives: the game that encodes the contract, the case study about the public transportation system in Bologna, and the mathematical programming approach used to optimize the control problem.

For each of them it was made an in-depth study of the scientific literature, throughout the last 30 years. For a specific list of the articles and the studies please refer to the integral version of the Study.

With regard to the transferability of Good Practices it is one of the main objectives of the EPTA Project. 35 Good Practices have been identified and divided into 7 groups, corresponding to the 7 Pillars of EPTA – Regulation, Planning, Tendering/Awarding,

---

1 Linear programming is a branch of operations research that is concerned with studying resolution algorithms for linear optimization problems. A problem is said to be linear if both the objective function and the constraints are linear functions. A problem is an integer linear program problem if the variables are constrained to be integer values.
Integration, Promotion, Management and Control. This Feasibility Study is related to the pillar Control, and the Good Practice "C3 - A system to monitor and control the performed service of the PT Operator" was transferred and adapted to Bologna.

This Good Practice derives from the experience of ATR, the Agency of Forlì-Cesena. Since Forlì-Cesena is a Province of the Emilia-Romagna Region and PT legal framework is mainly based on a regional basis, SRM and ATR move within the same legal framework, and the Good Practice could be completely applicable to Bologna case.

In 2006, ATR created and certified a system to control PT service in his province: some employees from ATR go to specific bus stops and check if buses pass and the Operator regularly provides PT services. The number of services per month to be controlled and the bus stops where controllers have to perform their activity is defined by specific software, created for this purpose.

The PT Service in the province of Forlì-Cesena consists of 756,000 services per year, and the statistically significant sample has been calculated in 1,250 services per years, equal to the 0,17% of the whole Service.

In the last few years, ATR developed also a monitoring system based on AVM (Automatic Vehicle Monitoring): buses have been equipped with a GPS receiver and a system communicating with a Central Office, in order to know the location of all buses in real-time, and verify if some problems - such as delays, service not performed, etc. - happen. A specific tool provides a report with information about all services, and automatically highlights differences between planned and performed services.

Since in Bologna the situation is a bit different than in Forlì-Cesena, this Good Practice has been adapted and improved.

First of all, the number of services provided in Bologna is three times then in Forlì-Cesena: this means that the number of significant services to be controlled is higher, and consequently the cost to perform controls will be higher as well.

Then, it is useful to make a consideration about the AVM system: in Forlì-Cesena, until a few years ago, buses were owned by the Agency, and it could install and manage directly the AVM system. In Bologna, on the contrary, the Operator owns buses and this is a constraint for the Agency, which cannot manage directly the AVM. Furthermore some lacks of performance cannot be revealed by AVM. In fact, although in Bologna buses are already equipped with GPS devices, the most common service quality deficiency in Bologna is that buses do not wait enough time at bus stops to allow passengers to get in (because the bus is running late); that event cannot be identified by a GPS-based tracking system. In addition, drivers could be tempted to switch off the GPS to avoid the control, claiming that the device is malfunctioning – this is difficult to verify if it was malfunctioning or not, and this could lead to unpleasant controversies.

Given these reasons, SRM prefers to control activities through its own employees, visiting bus stops and buses, because this kind of control is much more accurate and can involve many other aspects of quality such as cleanliness, drivers’ courtesy, etc.

The target of this Feasibility Study will be the improvement of the human control system created by ATR, so that it could fit better with local situation in Bologna.

3. Modelling the relationship between the Agency and the Operator through the Theory of Games.

The main objective of the Agency is to maximize user’s satisfaction, by ensuring the
correct provision of planned service\(^2\). The secondary objective is to create a legal framework where the Operator could be honest and could provide reliable information about its performance.

The relationship between the Agency and the Operator is modelled as a multi-period game between the two actors. Firstly, the Agency establishes the details of the contract, and then the Operator decides how much to invest in the provision of the PT service. Later, the operator chooses how to report information concerning its performance, while the Agency chooses how many efforts to use in controlling the Operator. The game is divided into the three following steps:

1. the Agency defines the value of the fines for service deficiencies. For each expected service that is not provided, and the Operator declares its lack, a fine \(f\) will be applied to the Operator. For each service that is not provided and the Operator does not report its lack, the Operator receives a higher penalty \(F\) (if the Agency is able to discover it). If the value of \(F\) is too high, the Operator could not pay it and force the Agency to terminate the contract, in this case the Agency will have to organize a new tender to select a new Operator. This result is clearly extreme and undesirable. Also, there is a (small) chance that a service that was reported as provided by the Operator, and which was inspected and detected as missing by the Agency, was instead really provided, but has not been observed for some reasons (it was in late, it took a different route, the controller has not observed it, etc.). The possibility of imperfect detection, together with the problem that would arise from having to organize a new tender, imposes a reasonable limit on the value of \(F\). In the first step, it was assumed that the value of \(F\) is defined by the Agency externally to the game, as a result of his legal and organizational knowledge. In a second step, the values of fines \(f\) and \(F\) were calculated as a result of the balance of the game;
2. the Operator chooses how much to invest in the provision of the PT service (this includes investment on new buses, fleet management, salaries paid to drivers, etc...), and more specifically on the quality of service, that is the percentage of services that are actually provided compared the planned services. This percentage may also be considered as the probability that the Operator provides a certain service;
3. the Operator decides how many services it will not report correctly (his "level of truth"). At the same time, the Agency decides the budget to invest in control activities. Since the control is made by controllers on site, this is an intensive activity and the budget consists mainly of the salaries paid to employees. The control procedure defines a function that relates the budget to the probability that a service is controlled.

4. The control procedure.

The control is performed by a limited number of controllers (usually three or four) on behalf of the Agency: controllers go to bus stops and check on site if a specific service is provided. It is also possible, with a long waiting time, to verify whether the frequency of the service corresponds to the planned one.

Since high frequency lines, in urban areas, carry most of the passengers, the procedure defined in this section focuses on the control of these lines. Although the procedure has been designed considering high frequency lines, controllers are also asked to record low frequency services at the bus stop (urban and/or sub/extra urban services).

\(^2\) We refer to a service as a bus run on a specified line at a specified time of the day. Instead a line is the route in the transportation network that buses take.
Given a budget for the control activities, the target is to maximize the number of collected information. The procedure selects the bus stops to visit every day, depending on the time available and on the stops controlled in previous periods. The procedure, in fact, creates different routes every day, because the Agency wants to diversify the bus stops controlled in order to have a complete picture of the services provided by the Operator. As a result, the number of information that can be collected at a bus stop depends also on when this bus stop has been visited the last time: the profit of stops and lines controlled recently is reduced, and as a result there is more probability to cover the entire network. This also makes it more difficult for the Operator to foresee where controllers are. Finally, the proposed procedure gives the possibility to force a visit in some specific lines or bus stops, for example when there are complaints by users on a specific bus stops.

Starting from the existing public transport network, the procedure extracts a graph that includes all the stops (nodes of the graph) and the possible links (arcs of the graph). The set of nodes includes the office of the Agency, in which the controllers have to start and to conclude their activity. Each bus stop is associated with one or more weights representing the time that a controller can spend at it, which corresponds to a profit. The profit is the number of information that may be collected during this time and depends mainly on the number of lines that pass by the stop.

The optimization problem related to the maximization of the profit has a structure that includes both aspects of Vehicle Routing and Set Covering, since the target is not only to maximize the number of the “visited” stops, but also the number of different lines controlled.

The product of the optimized procedure is a path on the graph (and consequently on the public transport and road network) for each controller, which maximizes the profit associated with the control at bus stops and the number of controlled lines, taking also in account that the path of each controller does not exceed a specified length of time. In the specific case of Bologna, as it will be described in Chapter 6, all paths must start and end at the office of the Agency.

5. The algorithm.

In this section they will be describe the components of the algorithm used to solve the integer linear programming model at the basis of the control procedure introduced in the previous section. The model is solved through a Branch-and-Cut algorithm implemented in IBM-solver CPLEX 12.

The model used for the specific case of the city of Bologna should consider a graph with 1,104 nodes and 28,742 arcs. However, it is too large to be handled by the solver without ad-hoc and heuristics procedures; in particular, the solver cannot find feasible

---

3 The problem has a structure similar to a Prize-Collecting routing problem. Arcs have a cost, which is proportional to the time spent in moving from a node to another (during that time the controller will not have the possibility to control any service, and in some way he will be “wasting” his time). Nodes have a prize, corresponding to the value of the information that can be collected in that node. In this problem, the objective is the maximization of the value obtained from the sum of the prizes of the nodes minus the costs of the arcs.

4 The Vehicle Routing Problem is a kind of problem in the area of operations research. These problems deal with all aspects of vehicle fleet management in logistic fields.

5 The Set Covering Problem is a classical problem in combinatorial calculation, computer science and complexity theory, the study of which has made a fundamental contribution to the development of the whole science of optimization algorithms.

6 The Branch-and-cut is a method used in operations research for solving integer linear programming problems.
solutions for the problem. For this reason, writing ad-hoc algorithm to find good solutions was the right choice to solve the problem successfully. The algorithm is based on the selection of a subset of nodes and on the reduction of the original graph into a smaller graph, which allows identifying good feasible solutions, whose distance from the optimal solution (unknown) can be assessed by re-mapping these solutions on the original graph.

6. Case study: the control methodology applied to the case of Bologna.

In this section, the discussed methodology is applied to the case of the city of Bologna. The case study focuses on 29 high frequency urban lines, with a maximum average waiting time between two consecutive services equal to 30 minutes. These lines cover 1,104 stops and serve 82% of the total passengers of the PT service.

The graph used as input for the model was extracted from the real PT and road network. This graph consists of two kinds of arcs:

- arcs representing bus connections;
- arcs representing pedestrian connections, used to connect all pairs of bus stops that are not already connected by existing bus lines and short enough to be walked;

and it is shown in the following figure.

Concerning the case study, the contractual fines related to the regularity of the service have been analysed. The Contract of Service foresees a standard monthly regularity $\geq 99.0\%$, which is equal to the ratio between provided services and planned services, as well as foreseen in the schedules and as delivered to PT users. A planned service is a specific service, scheduled and communicated to users, departing from the bus terminal and/or arriving at it. If the standard is not reached, a fine amounting to EUR 250 $f$ could be applied for each decrease of one unit to the second decimal digit.
The contract also foresees that if SRM discovers incomplete or incorrect reports, it can apply a fine up to 25,000 EUR for each element of disagreement between the Operator’s report and control of SRM. If untruth report is discovered, the SRM may apply a fine up to 250,000 EUR (F) for each mendacious report.

The values of parameters used in the model, that are the profits collected for each bus stop or line controlled, were established on the basis of the recommendations of the Agency in order to prefer the control of lines with most users.

7. The relationship between the optimized control and the game.

The final section of this study analyses the relationship between the game and the controlling procedure.

Regarding the optimization of the equilibrium conditions of the game, it was assumed that the budget invested by the Agency on control activities could determine the probability that a specific service is controlled, according to a specific function. When, instead, this function is determined solving the optimization model, it is possible to evaluate empirically the function point by point. In fact, for each scenario, it is estimated the total number of hours dedicated to the control (which is the main component of the budget) and the percentage of controlled services is determined by solving the model.

The figure shows the probability of control of a specific service as a function of the total budget of dedicated hours per day and the number of controllers (two, three and four). The main conclusion is that the total number of working hours is the most important element, while how these hours are distributed among controllers is much less important.

The optimized control procedure has been compared with a “human” control procedure, obtained replicating the behaviour of a controller who chooses path and bus stops to visit on the basis of his knowledge of the city and of the service. The result is that the optimized procedure is able to increase by 50% the number of controlled services in the same time, when the control activity does not exceed 12 hours per day and by 30%.

when the control activity lasts more than 12 hours per day.

Finally, the analysis of the game described in Section 3 has been extended beyond the current situation, considering the value of the fines as a result of the balance of the game itself and not as an input for the problem. In order to keep it usable, the game is modelled by considering the average values of different parameters characterizing the service. Some of these parameters cannot be modified in order to evaluate different scenarios, because the whole network and the function that determines the probability of control should be modified as a consequence. For the parameters that can be modified, however, different scenarios have been considered. The average parameters used to model the service are:

- number of lines;
- hourly frequency;
- hourly cost of the driver (driving cost);
- duration of a service;
- hourly cost of the bus to have a minimum service provided (for at least 90% of planned service);
- hourly cost of control activity (in charge of the Agency);
- total number of users waiting at a bus stop which are involved by a missing service
- cost of time.

Once these parameters have been defined, the solution of the theory of game model will provide equilibrium values for:

- fine \( f \) and \( F \);
- percentage of service to be controlled;
- hours per day to dedicate to control activities.

The first column of the table below shows the baseline scenario.

Six different scenarios have been evaluated, keeping each time all parameters unchanged but one (this one is reported in the heading of columns).

The value of the fine \( F \) does not change through the scenarios. In the modelling of the game, in fact, \( F \) depends only on the effectiveness of the control procedure (which is constant in this analysis because it is optimized) and on the cost the Agency should support in case of anticipated contract end or bankruptcy of the Operator (evaluated in 200,000 EUR). The optimal value of \( F \) varies proportionally to the changes of this cost, and we have, for example, \( F = 219.000 \) EUR for a doubled cost for anticipated contract end.
<table>
<thead>
<tr>
<th>Basic scenario</th>
<th>Cost of time</th>
<th>Cost of time</th>
<th>Driver's cost</th>
<th>Involved users</th>
<th>Involved users</th>
<th>Bus cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of lines</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hourly frequen ce (1/h)</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Involved users</td>
<td>50</td>
<td>60</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Driver’s hourly cost (EUR)</td>
<td>40</td>
<td></td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration of a service (h)</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bus hourly cost (EUR)</td>
<td>20</td>
<td></td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Controller’s hourly cost (EUR)</td>
<td>46</td>
<td></td>
<td>34.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total number of services</td>
<td>2,088</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost of time (EUR)</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine F (euro)</td>
<td>109,464</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine f (euro)</td>
<td>2,087</td>
<td>2.792</td>
<td>3.310</td>
<td>2.181</td>
<td>2.253</td>
<td>1.900</td>
</tr>
<tr>
<td>Service to be controlled %</td>
<td>1,91</td>
<td>2.55</td>
<td>3.02</td>
<td>1.99</td>
<td>2.06</td>
<td>1.74</td>
</tr>
<tr>
<td>Control activities (h)</td>
<td>6,5</td>
<td>10</td>
<td>12</td>
<td>7</td>
<td>7</td>
<td>5,5</td>
</tr>
</tbody>
</table>