A simplified approach to transportation system planning

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Introduction

The increase of passenger and goods transportation demand, both in urban or suburban and in intercity settings, has caused a notable growth of research activities in transportation science, technological, infrastructural, and organisational topics are involved in this field of research. This paper deals with transportation planning, with specific regard to public transport service supply, and it proposes a simplified approach to supply planning, suitable to case studies when no investment in infrastructure is envisaged. The interest in a simplified approach is motivated by the excessive burdensomeness of traditional planning methods, if compared with some particular problems. The proposed methodology is not intended to be opposite to the traditional one when a complete planning problem must be faced, but it can be useful when the cost of planning activities is expected low.

The Traditional Approach

This section resumes the fundamental aspects of traditional approach in transportation planning, as they can be found in literature [1], [2]. According to such an approach, it is firstly necessary to define the transportation system considered, i.e., the set of elements which contribute to producing and consuming transportation supply. Then, the transportation system can be divided into an internal subsystem, that is the subsystem to which planning activities are devoted, and an external subsystem which includes external human activities that give rise to transportation needs; the latter is taken into account only in terms of interactions with the former. The internal subsystem can be divided into the subsystem of transportation demand and the one of supply. There is a correlation between demand and supply, which can modify each other.
to a great extent, in order to model such a correlation, it is convenient to introduce a system of demand-supply interactions. The logical structure so far described can be represented by Figure 1.

Because of their importance in planning activity, the above-mentioned subsystems deserve a precise definition. Transportation supply is defined as the set of physical, organisational, and regulative factors which determine the features of transportation supply. Models of supply systems are usually based on a group of links which describes the topology of the transportation network and on functions which define how traffic flow is affected by level of service and other supply variables.

Transportation demand is defined as the number of passengers which need to travel from a place called Origin to another place called Destination during a fixed time interval. As it can be found in [2], transportation demand for a fixed route does not correspond to the passenger flow of the same route (a route is here intended to be a couple Origin node-Destination node); in fact, it is impossible to estimate transportation demand for a route where no transportation supply is provided. A demand model is defined as a mathematical function that can be applied in order to evaluate the number of passengers which need to travel from an Origin place to a Destination in a fixed time interval; demand models, or functions, may be stochastic or deterministic. As passenger travel demand involves human factors, such as behavioural factors and habits, it is difficult to estimate transportation demand precisely in a deterministic sense. As a consequence, two different approaches have been developed in technical literature to this scope: the deterministic approach yields the number of passengers which travel from A to B as a mean value of a percentage of a population. The stochastic approach yields the probability that a passenger may travel along a route as a function of socio-economic variables related to the passenger and of the level of service. Logit, Nested Logit, and Probit are examples of models based on the stochastic approach.
Models of interactions between transportation demand and supply aim at simulating mutual effects existing between transportation supply and mode or route choice of passengers; choices result from the interactions between the flow of passengers who consume the supply of a transportation system and the effects, both internal and external, that derive from such a consumption [3], [4].

On the basis of the definition of fundamental transportation system elements, it is possible to describe the planning process:

1. a model of transportation supply must be built in order to take into account:
   - topology of transportation network;
   - frequency and schedule of service;
   - infrastructure;
   - operating policies of the system, personnel management;
2. a transportation demand model must be built according to the following procedure:
   - on the basis of the socio-economic variables of the considered geographical context, it is necessary to define zones which produce or attract a flow of passengers, the considered geographical context is therefore subdivided into several zones, for each zone, a node must be defined, connected to other nodes through links corresponding to the flow of passengers;
   - according to the attractiveness of the zones and to their capability of producing transportation needs it is possible to build Origin/Destination matrix, possibly time-variant;
3. for each link between two nodes, the flow of passengers can be estimated through the following procedure:
   - the attractiveness of each mode operated on the considered link can be evaluated by applying choice models,
4. the flow of passengers can be obtained as a product of total transportation demand between the considered nodes, and the probability that a mode be chosen by generic passenger.
5. on the basis of passenger flows, that have been evaluated for each mode and for each route, it is possible to assess revenues and the effectiveness corresponding to alternative decisions concerning transportation planning. Passenger flows may vary as a function of the perceived cost of transportation supply, for instance because of traffic congestion.

The calibration of a mode-choice model represents a critical procedure of the methodology above described. The calibration process needs a statistical analysis to be performed on the considered geographical context. This need may cause some difficulties. A direct statistical analysis makes it necessary:

a) to prepare an adequate questionnaire, with unmistakable, well-focused questions;
b) to select a significant sample;
c) to process the answers, in order to estimate the values of the attractiveness of all the modes.

A well-designed poll must obtain information about different alternative solutions, in order to avoid the need of a second, successive poll in case
intervents different from the previous ones should be envisaged. Costs of such a planning process result to be high, and they are economically justified only if transportation planning involves the realisation of new infrastructures, that requires high investments.

The Simplified Approach

As it was suggested in the previous section, the simplified approach is proposed in order to supply a decision support model when a transportation planner, or a general decisor, has to operate in a hard constrained budget framework, i.e. whenever any infrastructural intervention is unwanted. Under that condition, it is authors' opinion that the classic methodology seems to be too expensive to be applied with respect to the revenues that could be collected. Let us take a look at the assumptions of this alternative approach: they are the infrastructure, the fleet, and the number of the employees invariableness. On the other hand, no one supposition about the mode of transport, or about the origin - destination couple is needed. The simplified approach is suggested in order to support decisions on timetables improving, changing the company expenses only in terms of variable costs (energy consumption, worn of rolling-stock). The results of the application of this alternative approach are provided as a list of trips that should be added to the present timetable, in order to satisfy the demand for transportation on a given origin - destination pair, if rolling-stock and employees are available to the transportation company.

The simplified approach aims to evaluate if a mode of transport should attract some of the unsatisfied demand for transportation, by scheduling new trips, given an origin - destination pair, a demand model, and a supply system. In order to make this approach applicable, the distribution function of the demand for transportation (static or time variant) is supposed given for all the modes of transport that provide the transportation supply on the origin - demand pair case study; let \( D_R(t) \) be the mathematical or graphic representation of this distribution function.

In a graphic context, the time is represented on the horizontal axis, whereas on the vertical axis the first order derivative with respect of time of the demand for transportation is drawn \( D_R(t) \) represents the first order time derivative of the number of people which intend to act a displacement from \( O \) to \( D \) (where \( O \) and \( D \) indicate, respectively, the Origin and the Destination of the trip and \( R \) means a path connecting \( O \) to \( D \)); this number of people is expected to desire to leave from \( O \) at time \( t \). In the next figure, a graphical example of the just exposed hypothesis is shown:
Let us consider the following expression: \( \int D_{RI}(t) \, dt \); it represents the number of passengers which would like to travel from O to D, and that intend to leave from O during the time interval \([t, t+\delta t]\). Suppose that the transportation mode M is in the supply system; if a trip \(c\), which is performed by the M mode on the R path, leaving from O during the time interval \([0, t^*]\) exists, it will attract some passengers, or better, it could satisfy some of the demand for transportation represented by \(D_{RI}(t)\) according to a relationship \(f_{MRc}(t)\) that, from now on, the authors will name the trip fulfilment function; the trip fulfilment function is expected to behave as follows:

\[
f_{MRc}(t) = \frac{1}{t^* - t}
\]

The expression \( \int_{0}^{+\infty} f_{MRc}(t) \, dt \) represents the number of passengers which travel using the \(c\) trip, which belongs to M mode, on the R path. The trip fulfilment function shows how a given trip, which leaves from O at \(t\) time, is
attractive for both passengers which intend to leave at that time, and for a number of users that would like to leave during the time interval \([0, t^f]\), as it was shown in the previous figure. It is also opinion of the authors that the trip fulfilment function reaches its maximum value in \(t^f\). \(f_{\text{MRC}}(t)\) shows, for each time instant \(t\), the first derivative, with respect of time, of the number of people leaving at \(t\) time; moreover, in its maximum value \(f_{\text{MRC}}(t)\) means the density function of the demand for transportation of mode \(M\), obviously limited to the path \(R\), if the supply is big enough to satisfy the whole demand for transportation of mode \(M\).

Suppose one has a transportation system which supply provides some trips (e.g.: 3), using means of transportation of \(M\) mode, during an assumed time interval (e.g., \([0, t^*]\)). Suppose also to plot, on a Cartesian co-ordinate system, both the total demand for transportation and the trip fulfilment functions of all the trips that have been considered.

![Figure 4: A superimposition of a demand distribution function with 3 trip fulfilment functions](image)

The interpolation of the different values that the trip fulfilment functions reach at time \(t_1\), \(t_2\) and \(t_3\) represents the demand for transportation of the \(M\) mode, with respect of \(R\) path, during the time interval case study \(([0, t^*])\), from now on, this particular demand function will be named \(D_{\text{Rt}}(t)\). The methodology suggested by the authors proposes to add some more trips, during the time interval case study, in order to fulfil the transportation demand that was not previously satisfied by the \(M\) mode supply. Note that this exceeding demand for transportation is travelling from \(O\) to \(D\) using other modes of transport (i.e., private cars).

**NOTE 1:** The vehicle, that has to be added into the transportation supply system, has to provide a number of seats which can be estimated taking into account both the definition time interval of the used trip fulfilment function, and the value of the function \(D_{\text{Rt}}^M(t)\) at instant \(t_{nc^*}\), where \(nc\) means the trip number.
NOTE 2: One more consideration is due to the fact that the passengers which catch a means of transport $c$, to reach $D$ leaving from $O$, are users of the system that perceive time $t \in [0, t_{cf}]$ as the best leaving time. In other words, a user $i$, having the expected leaving time $t^* \in [0, t_{cf}]$, will not make use of the means of transport $c$.

The Operational Procedure

In this paragraph, an operational procedure based on the simplified approach just described is presented. This procedure aims at determining the need of adding a trip on a given path, and, if this need seems to be concrete, it is devoted to estimate the capacity of the vehicle that has to provide this adding supply. The operational procedure can be summarised as follows:

1. to find, for a given path $R$ in a transportation system, the demand for transportation and the parameter set which identifies the trip fulfilment functions $f_{M_{Rc}}(t)$ of the mode of transport that has to be upgraded; the parameter set has to be estimated for all trips that leave from $O$ during the time interval $[0, t^*]$;
2. to detect a time interval $[t_1, t_2] \in [0, t^*]$ in which the transportation supply of $M$ mode does not seem to provide a number of seats enough to fulfil the demand for transportation; in other words, the aim of this second procedure is to find the time instants $t_1$ and $t_2$ that verify the following equation: where $C$ means the total amount of trips leaving from $O$ during the period case study (i.e., $[0, t^*]$);
3. to evaluate, with the basis of the acknowledge of $D_{Rt}(t)$ and $f_{M_{Rc}}(t)$, an interpolation of the max $f_{M_{Rc}}(t)$ ($c = 1, \ldots, C$), as to provide an assessment of the demand for transportation of $M$ mode $D_{Rt}^{M}(t)$;
4. to find a time instant $t$ which corresponds to the leaving time of the new trip, that has to be added to the $M$ mode timetable, while evaluating if there is the availability of a means of transport that may fulfil the $M$ mode demand for transportation, as it can be estimated on the basis of the approximate function $D_{Rt}^{M}(t)$ The choice of the transportation means has obviously to satisfy the constraints imposed by both the number of employees, and the company availability of means of transport;
5. if a time $t$, having the features shown in the previous step, has been found, then the decisor has to evaluate the total cost of the adding trip;
6. to assess the total income of the transportation company that derives from the addiction of the new trip in the timetable, this amount obviously depends on the number of people that are expected to use the new trip. If the expected income is considerable enough with respect of the total cost perceived by the company, then the trip is added to the scheduled timetable, otherwise it is suggested to look either for other trip leaving times in the period $[t_1, t_2]$, or for a different time interval.
Conclusions

The simplified approach that had been introduced in this paper aims to be an alternative to the methods that are usually present in the literature, and it is devoted to the organisation of the transportation supply whenever any intervention on the system infrastructure is neglected. This last consideration is very important, in that it allows to underestimate the influence of the transportation supply on the user behaviour, in order to work in a steady demand context. In fact, it is well known that any infrastructure change in the transportation system implies a strong alteration on the demand for transportation, and those variations should not be limited to a new modal division [5]. It is also important to put into evidence the fact that this approach is both transportation mode and trip unconstrained. Further studies are in progress in order to evaluate an analytical form of the trip fulfilment function, and to identify their parameters.

References