Abstract

Nowadays, urban population is witnessing a rapid growth and henceforth its mobility. City infrastructures and economic resources may not follow at the same rate as the increasing mobility. So often, projected increase in transport needs goes beyond projected expansion of transit network capacity. This asymmetry between transportation supply and demand is unmistakable: congestion, unpleasant travelling conditions and other phenomena that comes with are already witnessed in the public transit system.

Public transport performance is constrained not only by its availability but also by its capacity. Actually, the capacity of a transit line is defined by the operating frequency as well as the physical capacity of each vehicle. The relationship between loaded demand and capacity contributes to the setting of comfort levels in particular and the quality of service in general. To simulate these phenomena in an assignment model describing the users’ route and mode choices, the transportation supply should be subject to several constraints: capacity of the vehicles (sitting and standing places), boarding and alighting movements, and the lines and network load (operating frequency of each line).

Till recently, in most case studies including new transportation projects, crowding was not taken into account in transport modelling, while congestion should be integrated in simulation, particularly in the objective of effective traffic management. In this paper the studied approach includes three parts. The first part consists of a literature review of French and International existing researches on the influence of crowding in public transport and how it is modelled. The second part describes the adopted crowd-methodologies in our cases studies. The third part outlines the results of three case studies. A conclusion provides a synthesis of the compared results and recommendations.

The results are based upon three selected projects conducted by SYSTRA: (1) The extension of the current Metro network and restructuring the bus network in Baku (Azerbaijan); (2) The feasibility study of the Guayaquil (Ecuador) cable line taking into...
account the existing transit networks (BRT and Bus); (3) The assignment model of Saint-Etienne’s (France) public transit (TER – regional train-, Tram, Bus and Coach) with accurate simulation of passenger trips and capacity constraints. The crowd-model aims at achieving iteratively a balance between loaded demand and capacity. Three approaches are tested for the three projects. First, by adjusting the travel time alone, then by revising the waiting time and finally by combining the two previous approaches. This benchmark highlights indeed some phenomena, such as traffic breakdowns for instance, related to congestion in comparison to a reference scenario without capacity constraints. However, the results show complex spatial and temporal behaviors making their interpretation sensitive.

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Keywords: assignment model; capacity constraints; congestion; crowding; crowd-model; mobility; passenger trips; quality of service; traffic; transit network; stated preferences survey; route choice; modal choice

1. Introduction

Today, the urban population, accounting for 54% of the world population¹, is growing rapidly and continuously. Cities have become so dense that the 21st century is described as the Century of the City. By 2030, this population should count for 8.2 billion (Stigson, 2004) with 41 megacities of 10 million inhabitants or more.

Actually, transportation and mobility have become much needed. Cities infrastructure, as well as current economic resources cannot keep pace with the same increasing mobility. Conscious of these challenges, many countries and regions worldwide have encouraged programs promoting public transport or sharing. However, the projected increase in transportation needs go beyond the planned expansions of capacity of the transportation system. This asymmetry between supply and demand for transport is a source of congestion, unpleasant traveling conditions and irregularity.

During the last decade, public transport witnessed a significant additional traffic. In Île-de-France, for instance, an increase of 20% was observed between 1990 and 2000 (Eric Kroes et al., 2013) and 29% between 2002 and 2012 (Union International des Transports Publics, 2014). Faced with this growth, the offered capacity is sometimes insufficient and does not meet the demand especially in peak hours. Infrastructure renewal, building or modernization are among the proposed solutions to overcome the lack of capacity. However, all these options require large investments from where the importance of a traffic assignment model which takes into account capacity constraints.

2. Objectives and research approach

The study reported in this paper presents the results of a research on the effect of congestion in public transport on users comfort and quality of service. The research approach used for this study consisted of three phases. First, an inventory of existing researches on comfort perception in public transport was conducted to analyze alternatives for congestion modelling. Second, two methods were selected and studied in detail. The first one was based mainly on stated preferences surveys, which aim at assessing congestion disutility by econometric methods. The second method models the congestion through an iterative process that allows the assignment model to adjust travel time on board according to crowd levels. The third phase consisted of applying those methods to three different case studies in order to evaluate the relevance of the selected methods.

This paper focuses on how to value comfort in traffic assignment models, and capacity constraints in simulating users modal and route choices.

3. Comfort in public transport, literature review and challenges

This section summarizes the findings of qualitative researches conducted on comfort in transit and the disutility linked to congestion. A benchmark of the state of the art in this subject, so far few studied, has been proved very useful to understand the overall context in which the concept of comfort and the impact of congestion on public transport users are positioned.

3.1. Comfort in public transport

In the process of decision-making, two questions systematically arise to the user of public transport. The first is a five-level question, which assesses the service availability (TCQSM, 2013). These levels are as follows:

- **Spatial availability at the origin and spatial availability at destination**: if the service is too far from the origin or the destination of travel, the transit option will not be maintained. For instance, the average walking distance to a bus stop is 400m and 800m to a metro station. Beyond these values, transit is no longer a viable option.
- **Temporal availability**: The frequency and length of the service determine its temporal availability.
- **Information availability**: transit users need to know where and when the transportation service is available and how to use it. This information must be available and accessible. Real-time information for instance, presents several advantages. Indeed, a study in the Netherlands showed that real-time information reduces the perceived waiting time for the Tramway by 20%.
- **Capacity availability**: it is the available capacity to ride, sit, move, stand and park a bike or a car…

If these five elements defining the service availability are checked, then arises the second question dealing with comfort and convenience (if transit is an option, would you use it?).

The most important aspects in comfort, from the user’s perspective, would be summarized in three parameters: crowding, reliability and travel time. In the following paragraphs, we focus on the crowding and its value.

Public transport becomes less attractive if the passenger should stand, especially for long distance trips and under heavily congested conditions. When the traveler is standing, it becomes difficult for him to pool his travel time for reading, working or just resting. Thus, the transit loses a potential of its attractiveness in favor of the private cars. In addition, congestion in public transport reduces the operability of the service since boarding and alighting movements take longer than expected. Besides, some harmful behaviors appear with congestion; people trying to block the doors to allow a few passengers to enter the vehicle and blocking seats, or placing personal belongings on the floor. In socio-economics of transport, time spent in transport is the predominant parameter in the upstream evaluation of projects. Whether for private car or public transportation projects, travel time is the common parameter to all transport means allowing their comparison. Numerous are the studies which aim at assessing the economic value of travel time spent in transit but few are which deal with the value of the comfort or congestion. In order to enhance transit attractiveness, comfort and crowd levels must be valued. In fact, because of the disutility linked to congestion and the eventual obligation to travel standing, the value of the perceived travel time increases considerably (OECD, 2014).

Congestion is a phenomenon that significantly influences the physical comfort of travelers (STIF, 2006), creating annoyances to the user who needs thus to ignore the psychological comfort and accept some disutility (loss of control over ones activities in the transit mean of transport, lack of privacy…). In addition, congestion generate behaviors reducing the sense of individual responsibility and leading to uncivil deeds (STIF, 2013).

A stated preferences survey was conducted by the STIF (Kroes et al., 2006) in order to better understand the characteristics of transit users’ choices. For the comfort/congestion, the results of the logit analysis showed that travelling standing (against travelling seating) for work or study purposes is equivalent to spending an additional five minutes of travel time when the service is regular and equivalent to 14 additional minutes if the service is irregular. Furthermore, these values increase considerably when passengers have to stand in congested trains to reach an additional travel time up to 27 minutes. On a 20 minutes trip, an estimation of perceived comfort penalty adds 10.9 minutes to travel time (Kroes et al., 2006).

3.2. The value of congestion in public transport

Limited knowledge is available about congestion in public transport and user’s perception of congestion, which are nevertheless among the most important aspects in assessing the quality of service and comfort.

Insufficient capacity may question the service availability. If for example, at the bus or the subway arrival there are no more seating or standing places, the service is no longer available for users who are present on waiting platforms. The lack of capacity on the platform increases the boarding time in proportion to the number of waiting users and varies subsequently the service frequency (Alexis Poulhes, 2011). Frequency is thus reduced and users are constrained to wait for the next service or to find another alternative to ensure their displacement. The higher is the load, the higher is the required parking time at docks and the degraded access and egress conditions for transit users (Ektoras Chandakas, 2012).

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Hensher and Li (2011) state that the value of travel time would increase with congestion and has to be taken into account in the generalized time. Wardman and Whelan (2011) found that not only standing passengers see their utility decrease but also seated passengers. This would be expressed in disutility formulation by a travel time multiplicative factor close to one for seated passengers, to 2.7 for standing passengers and to 1.7 for seated passengers in very congested conditions. This perception of congestion is also studied by Haywood and Koning (2011) who confirm that Parisians would be willing to travel an average extra 8 minutes in metro if it enables them to reduce crowd levels in peak hours to reach those in off-peak hours (in other words reducing crowd levels is worth around 1.5 € per trip).

To summarize, congestion is responsible for a significant disutility that increases generalized costs. Studies on this subject were mainly based on stated preference surveys to express the value of the disutility associated with congestion. Multiplicative or additive penalty coefficients are applied to travel time function in peak hours and according to travelling conditions (standing, sitting and in which conditions). These penalties may be calculated if necessary for each region, mode and level of congestion and can be used in forecasting socio-economic assessments.

The following table gives an estimation of the travel time multiplier based on eight levels of congestion (Eric Kroes et al., 2013) for various transit in Ile-de-France.

<table>
<thead>
<tr>
<th>Crowd level</th>
<th>All mode</th>
<th>Metro</th>
<th>Train + RER</th>
<th>Bus + Tram</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Seated</td>
<td>Standing</td>
<td>Seated</td>
<td>Standing</td>
</tr>
<tr>
<td>1</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>2</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>3</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>4</td>
<td>1.083</td>
<td>1.077</td>
<td>1.073</td>
<td>1.102</td>
</tr>
<tr>
<td>5</td>
<td>1.165</td>
<td>1.289</td>
<td>1.155</td>
<td>1.270</td>
</tr>
<tr>
<td>6</td>
<td>1.248</td>
<td>1.394</td>
<td>1.232</td>
<td>1.362</td>
</tr>
<tr>
<td>7</td>
<td>1.330</td>
<td>1.499</td>
<td>1.309</td>
<td>1.453</td>
</tr>
<tr>
<td>8</td>
<td>1.413</td>
<td>1.604</td>
<td>1.386</td>
<td>1.545</td>
</tr>
</tbody>
</table>

The best approach would then be to examine the applicable comfort/congestion penalties and their associated curve in accordance with the specifications and features of the modeled transit service. Some modes are designed to accommodate a large number of standing passengers whereas for other mode it is not appropriate for passengers to stand.

4. Congestion modelling in transit system

In order to include comfort in traffic assignment models for travel, two methods were selected:
- Method A: Modelling comfort using stated preferences results in trip distribution and modal choice steps
  This method consists of conducting a stated preference survey to estimate by econometric methods of discrete choices the disutility value linked to congestion (multiplicative penalty coefficients or a quantification of the additional perceived travel time associated with the congestion) distinguishing crowd levels and whether the user is standing or sitting. In this method, congestion is taken into account in users’ modal and trip distribution.
- Method B: Modelling comfort in route choice step
  This approach uses the penalty values associated with crowd level in an iterative process that allows capacity constraints to influence users’ perception of travel time. A modeling software is needed and comfort is taken into account in the route choice step (the 4th stage of the traditional four-step approach: trip generation, trip distribution, mode choice and route choice).

4.1. Method A: modelling comfort using stated preferences results in trip distribution and modal choice steps

The four step model is a tool for forecasting performance and future demand of a transportation system, based on the econometric theory maximizing one’s utility. An individual (as a unit of statistical observation) is supposed to behave rationally and choose the alternative maximizing its usefulness.

Utility is expressed in the trip distribution and mode choice steps. It’s formulation for a mode m in a combined modal and destination choice, including, for an origin and destination i to j, the mode characteristics and the socioeconomic parameters of the destination zone j:

$$ U_{mij} = \sum a_m NS_{mij} + \mu \ln \left( \sum \exp \left( p_j \right) \times T_j \right) $$

(1)
where $\alpha_m$: the level of service coefficient for the mode $m$; $\text{NS}_{mij}$: the linear combination of the levels of service for the mode $m$ and the flow $ij$; $\mu$: the weighting factor of the attractiveness of the area; $p_j$: the size parameter of attractiveness; $T_j$: the attractiveness of the area $j$.

For each transport mode (private car, Tram, Bus, Train), we estimate these parameters as well as a formulation of generalized time/cost taking into account the different components of a transit trip. The user chooses afterward the most interesting mode (i.e. the one who maximizes his utility).

Hence, to take into account comfort in the utility formulation, we add the additional crowd additional time to the in vehicle time spent in the said mode of transport. The crowd additional time is a penalty expressed in minutes that varies according to trip purpose, which comes from the Stated Preferences Survey we did in St Etienne). Comfort is thus considered in distribution and modal choice.

This method allows comfort modelling in the early stages of transport modelling by adapting the demand to comfort constraints before assigning it to the different networks.

4.2. Method B: modelling comfort in route choice step

Many modelling software offer the possibility to model congestion through an iterative process allowing the “Public Transport” components (transport assignment module) to influence the travel time on board according to congestion levels. In our tests, CUBE software was used to model congestion in route choice step (the last step of the traditional four-step method). The possible routes as well as the likelihood of their use are therefore calculated iteratively following the congestion constraints. This method adapts time spent in vehicle and waiting time on the platforms before boarding according to congestion levels using what we call in CUBE software “link travel time adjustment” and “wait time adjustment”.

Depending on the purpose of the study to conduct, these two adjustments may be applied separately or combined.

4.2.1. Link travel time adjustment

In congested conditions, the perceived time becomes more onerous and the conditions in which users travel more limiting. To reflect the inconvenience associated with travelling in congested conditions, we define levels for which the in_vehicle_time of each section and mode is multiplied by a congestion factor:

\[
\text{in}_\text{vehicle}_\text{time} = \alpha \times \text{in}_\text{vehicle}_\text{time} \tag{2}
\]

where $\alpha$, the “crowd factor”, is defined in terms of mode of transport, type of vehicle, Seating/standing capacity. Crowd levels are defined with occupancy ratio (0%, as long as a seated place remains and 100% when no more standing space exists). In this type of model, a level 100% corresponds to a value of five persons standing per m². What is permissible per m² varies greatly according to cultures and countries.

4.2.2. Wait time adjustment

In this type of model, the additional waiting time that affects a particular line will make the line less attractive and thus redirect passengers to other possible routes or mission for the same origin destination. In this way, we will cover the panel of users who wait for the next service and thus incur additional waiting time.

Increasing waiting time when initial charges at each stop every time the line has exceed the available capacity to allocate and assign the excess demand. This demand is henceforth assigned to the next service or to other lines that have more capacity. With this adjustment, it would be possible to limit boarding according to the demand and available capacity.

4.2.3. Input data for modelling comfort in route choice step

- Transit lines capacity: Line capacity is needed to be encoded for each modes for which the crowd model is applied. Seated and standing capacities are to be informed in a way to represent the distribution of the rolling stock capacity throughout the year.
- Representative curves defining crowd levels: These curves are implemented as multiplicative curves in the public transport assignment process (under Cube software). For each level of congestion, the in-vehicle travel time is multiplied by the appropriate adjustment factor to represent travelling conditions. We assume here that all users perceive congestion in the same way on a given section of the route, regardless of the stop where they boarded. Crowd levels are expressed in percentage of standing passengers (proportion of the standing ability).
- Number of iterations: Crowd modeling is an iterative process. After a first assignment, the model compares the resulting charges to the available capacity (indicated by the modeler) and subsequently calculates the excess demand before reassigning a second time, and so on. The model convergence is achieved when the load (and therefore
generalized costs or utility) does not change significantly between iterations. Typically, five iterations of the public transport loop are generally sufficient for a model of this nature. Model users should consider reviewing the number of iterations based on tests.

Congestion modelling can be used to analyze the relationship between the demand and capacity for each mode and period. The benefits of each measure aiming at improving condition under which transit users travel will be valued and lines or modes for which demand exceeds capacity will be sensed. However, modelers should be aware that crowd component would extend the computation time.

5. Example of congestion modelling application

We applied the methods set above to three case studies conducted by SYSTRA: The assignment model of Saint-Etienne’s (France) public transit, the feasibility study of the Guayaquil (Ecuador) cable line and the restructuring study of Baku bus network (Azerbaijan). For Guayaquil and Baku case studies, crowd penalties were derived from the literature review and adjusted according to the context (size of the network, means of transport, demand volume…).

5.1. Assignment model of Saint-Etienne’s (France)

In Saint Etienne case, we applied the two methods separately for regional train users (TER).

5.1.1. Method A: modelling comfort using stated preferences results in trip distribution and modal choice steps

A stated preference (SP) survey was conducted in Saint Etienne in October 2014 for car and train users who own a car. The penalty of comfort (in minutes) was determined for 4 trip purposes (Work, Studies, Personal and Professional). The results of this SP survey have shown that not having a guaranteed seating place makes the transit user feels a certain penalty linked to congestion.

By calculating the excess demand, we could visualize areas under which congestion exists. For example in 2010, reducing the rolling stock capacity under the current average train occupancy rate impacts 13% of the studied area (figure 1). To these areas we applied a time penalty function of the trip purpose (on average ten minutes): 8.6 minutes per trip for workers, 6 minutes for students, 15.8 minutes for personal trips and 13.9 minutes for professional trips.

In morning peak hour, congestion is witnessed in axis Montbrison, Roanne and Firminny for commuters traveling to Saint-Etienne City and in the evening peak hour, congestion is especially shown in employments areas (Lyon and Saint-Etienne). Based on this findings we rephrased the utility function to include congestion penalty (function of trip purpose) and integrating it into trip distribution and modal choice loop process.

![Fig. 1. (a) Saint-Etienne city and its main axis; (b) Origin zones under congestion in morning peak hour; (c) Origin zones under congestion in evening peak hour.](image)
The tested scenarios were:

Table 2. Tested scenarios in 2010 (Method A).

<table>
<thead>
<tr>
<th>Scenario name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>With infinite capacity</td>
<td>Very large capacities and no congestion penalty has been applied</td>
</tr>
<tr>
<td>With actual capacity</td>
<td>Capacities of 2010 and SP congestion time penalties</td>
</tr>
<tr>
<td>With reduced capacity</td>
<td>Capacities reduced under the average of TER occupancy rates in 2010 and SP congestion time penalties</td>
</tr>
</tbody>
</table>

For all these scenarios, we considered that when 90% of seated capacity is occupied, the user experiences a certain penalty to find an available seat. Thus, above 90% we apply congestion penalties.

The values of exceed demand per scenario were as follows:

Fig. 2. Exceed demand values using Method A for morning peak hour for 2010 TO Saint-Etienne model.

The assigned demand here represents the TER users who have managed to reach their destination. The excess demand represents users who couldn’t reach their destination using the TER (no attractive alternative was found).

Figure 2 highlights the impact that congestion has on demand in trip distribution step better drawing the user’s modal choices. The excess demand is higher each time we lower the rolling stock capacity. Reducing the rolling stock capacity under the current average train occupancy rate leads to the loss of up to 12% of TER users. In 2010, users were ready to afford on average ten minutes extra travel time to ensure their displacements. This fact is mainly due to two reason: the limited number of relationships impacted by congestion in TER and the lack of alternatives particularly for non-motorized commuters who travel between Saint-Etienne City and Lyon City.

5.1.2. Method B: modelling comfort in route choice step

For Saint-Etienne case, we defined crowd levels in the model according to occupancy rates. Each crowd level was linked to a comfort penalty to reflect the inconvenience associated with moving in congested conditions. For each scenario we used a crowd curve where x represents the occupancy rate of the standing capacity and y the associated penalty.

The tested scenarios were:

Table 3. Tested scenarios in 2010 (Method B).

<table>
<thead>
<tr>
<th>Scenario name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>With infinite capacity</td>
<td>Very large capacities and no congestion penalty has been applied</td>
</tr>
<tr>
<td>With actual capacity</td>
<td>Capacities of 2010</td>
</tr>
<tr>
<td>With reduced capacity-Test 1</td>
<td>Capacities reduced under the average of TER occupancy rates in 2010 and standing is not allowed</td>
</tr>
<tr>
<td>With reduced capacity-Test 2</td>
<td>Capacities reduced under the average of TER occupancy rates in 2010 and 50% standing – 50% sitting</td>
</tr>
<tr>
<td>With reduced capacity-Test 3</td>
<td>Capacities reduced under the average of TER occupancy rates in 2010, 50% standing – 50% sitting and very high penalties for standing travelers</td>
</tr>
</tbody>
</table>

We used for Saint-Etienne both link travel time adjustment and wait time adjustment. The results for morning peak hour were as follows:
From these scenarios, it was shown that modelling congestion increased the perceived in vehicle time as well as the perceived waiting time at platforms before boarding. The value of excess demand is also higher each time we lower the rolling stock capacity as well as the congestion generalized cost. In Saint Etienne case study and by drawing the results of assignment from some origins to a certain destinations, we found that the assigned demand equals the initial demand because the majority of the TER users don’t have other alternatives and are non-motorized commuters. Users were constrained to use this mean of transport to ensure their displacements but their perceived travel time increased by almost 8% as well as their waiting time which increased considerably (up to +250%).

5.2. Cable line of the Guayaquil (Ecuador)

Guayaquil model allows decision makers to study different alternatives of the implementation of the cable line. The model assesses the technical definition of the selected alternatives, economic and financial impacts, and functional and operational requirements (demand and supply constraints). This study had as purpose identifying a cable transport project that can meet the most urgent needs in transportation of Guayaquil’s population.

Guayaquil transport network is a developed bus system but with a poor level of comfort and security. According to the latest road inventory of the study conducted by the Municipal Transit Authority, conventional bus fleet is compound of 2732 units, divided into 2059 bus (with a capacity of 80 passengers) and 673 vans of 35 passengers (capacity), carrying about 650 passengers per day on average (bus) and 500 passengers (vans) in normal day. In the purposes of providing a better quality transportation services (Bus + Cable) and encouraging the middle and upper classes to use public transport, vehicles capacity was an important component to take into account.

In this case study, we applied method B modelling congestion in public transport at route choice step. As illustration, these figures highlight the impact that has congestion modelling on network loading.

Fig. 3. Results of applying Method B in the assignment model of Saint-Etienne (results of morning peak hour for 2010).

Fig. 4. (a) Initial demand for Guayaquil bus; (b) Loaded demand for Guayaquil Bus taking into accounted limited capacities.
In fact, reducing or limiting the public transport capacity has a great impact on user’s distribution. In this case, the demand is better distributed toward less-charged areas. Henceforth, users take other alternatives less crowded to reach their destination or wait for the next mission in other to avoid crowds. However, it is important to note that this redistribution of the demand implies an increase in the number of transfers that remains less costly than the perceived cost due to congestion.

5.3. Metro bus network in Baku (Azerbaijan)

Baku model is a decision-making tool. It allows decision makers to assess the impact of the proposed transport projects on Baku bus and metro network (215 existing bus lines and 2 metro lines) given current and expected future demand for transport, according to the evolution of socio-economic factors. The model has been built on a four-stage model approach. It comprises a generation stage, a distribution stage, a modal choice stage and an assignment stage. All modelling have been done for a typical morning peak hour working day between 8.00 AM and 9.00 AM.

To model congestion, we applied method B with only Link travel time adjustment in the assignments step. Using congestion modelling on Baku network, we were able to perform the assignment process to estimate the ridership on each line providing a relevant representation of mobility. We tested the congestion model on Baku Metropolitan Master Plan by 2025 since productions and attractions for each zone were expected to grow significantly (from 1.7 in 2011 to 2.5 in 2030) and thus mobility. The results were as follows:

Table 4. The maximum load by segment with and without considering congestion in the model of Baku 2025.

<table>
<thead>
<tr>
<th>Line Name</th>
<th>No crowding model</th>
<th>Crowding model – Method B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max load</td>
<td>Passenger at morning peak Hour</td>
</tr>
<tr>
<td>Red</td>
<td>45 636</td>
<td>114 209</td>
</tr>
<tr>
<td>Purple</td>
<td>19 424</td>
<td>52 518</td>
</tr>
<tr>
<td>Green</td>
<td>24 361</td>
<td>114 493</td>
</tr>
<tr>
<td>Blue</td>
<td>9 499</td>
<td>31 425</td>
</tr>
<tr>
<td>Yellow</td>
<td>8 400</td>
<td>27 465</td>
</tr>
<tr>
<td>Total</td>
<td>107 320</td>
<td>340 110</td>
</tr>
</tbody>
</table>

![Fig. 5. (a) Initial distribution without congestion modelling; (b) Distribution with congestion modelling.](image)

These graphics highlight the effect of the method B by using the link travel time adjustment which penalise the exceed demand taking the overloaded lines. As a results, the demand is better dispatched and some of the red line (the overloaded line in Baku’s case) users are now taking the other available alternatives to reach their destination. In total we have more passengers in comparison to the scenario without congestion because users in order to avoid crowds take other alternatives with a higher number of transfers.

6. Concluding remarks

Until recently, most of case studies, even for new transportation projects, did not take into account comfort in transport modeling. To model the phenomenon of congestion, transport supply is subject to several constraints, namely: the limited capacity of vehicles (seating and standing room), the vehicle arrival profile, boarding and alighting movements…

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2 Colours match line names.
An inventory of existing studies dealing with the enhancement of comfort in transport was used to analyze the possibilities for modelling comfort and congestion in traffic assignment models. Two methods were selected. Method A was based primarily on the results of stated preference surveys. Method B modeled congestion (under a modelling software) through an iterative process that adapted trip times on board according to congestion levels. The different studied models can treat now the issue of crowding, a key element to value public transport at the expense of the private car.

Conducting a SP survey is essential to calibrate the specific user behaviors of the study area, to evaluate time penalties of crowding or for example the users’ willingness of changing habits to avoid congestion. The results of the survey can be used in the mode choice model (congestion affect the total public transport demand) or only in the route choice. But if no survey is available, it is recommended to use values or penalties from literature surveys.

Therefore, it should be noted that the crowd model must be used according to the goal of the study. If the aim is the estimate the maximum future demand, a model without capacity constraint is sufficient, but if the objective of the study is to analyze the impact of limited rolling stock capacity on users’ choices, it is recommended to use the model with the crowd component.

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References

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