Subjective travel time and transport system design

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Abstract. There are many complex tasks to be solved and many different factors to be taken into account during the design process of the optimal transport system. On the one hand, we have computer-aided design which provides an algorithmically optimal solution, but it does not take into consideration the preferences of people who use both public and private transport every day. On the other hand, experience-based designing has a limited sphere of application. So, the best result is given by semi-automatic design with subsequent expert evaluation. This scientific work analyses eight factors which should be laid down in the automated optimization algorithm and in the expert evaluation. These elements include travel time, possible delays, number of transfers/changes in multimodal trips, distance to stops, possibility of changing a route, vehicle comfort, possibility of productive time spending in a trip and travel cost. The factors mentioned above have an impact on the subjective perception of travel time and on making a decision about choosing a route and a vehicle. Taking these factors into account during designing a transport system will help to create an optimal traffic plan, increase passenger loyalty to public transport and reduce the amount of personal transport on the road during peak hours.

1. Introduction
The category of time has both physical and psychological meaning. On the one hand, scientists measure and record time using special devices (chronometers, etc.), evaluating its objective duration. On the other hand, psychologists and neurobiologists study the subjective perception of time, which depends more on the characteristics of the subject who evaluates time intervals. Both types of studies are equally important in the creation of the passenger transport system.

2. Design of transport systems
In order to create an efficient transport system, it is necessary to solve a number of complex tasks. Firstly, the specialists shall set routes, secondly, select types and number of vehicles for each route, further, develop traffic schedules, distribute routes by carriers, etc. Since the passenger transport system is to meet the needs of the population, creation of the networks necessitates taking into account the current moving flows. Other criteria for optimizing networks are finding the shortest way between the starting and ending points, the minimum time taken to move, the ratio between passengers and vehicles, etc. [1] Public satisfaction and performance of transport companies depend on how well the network is designed.

Rational designing of a network can be done in one of three ways:
1) automated creation of passenger transport routes based on formalized mathematical models;
2) partial automation of the creation of passenger transport routes with the following expert estimation;
3) decision making backed by experience and non-formalized expert analysis.

Automated design based on formalized mathematical models produces an optimal solution to the problem. However, it does not make allowance for real traffic conditions and possible changes in the situation as a whole. So, for example, a route in service Yandex.map takes much less time without due regard to traffic jams. The travel time calculated via “taking into account traffic jams” is more reliable. But as for long distances, it also gives a significant margin of error due to the ever-changing traffic situation. Moreover, the automated designing does not consider the developed traditions and habits of passengers, an ecological situation and other conditions not subject to the formal description.

The creation of transport routes supported by experience is the most appropriate measure. An exemplary situation is found in design of pavements and footpaths. Very often in Russia, you can see many paths of the most bizarre shape and direction, along with well-appointed paved paths. This means that the designers have not taken into account the needs of pedestrians, who seek to reduce the distance and travel time. However, using this method in its purest form is not effective in designing traffic routes to newly built areas. It is only possible to populate the area if transport accessibility is ensured. Therefore, roads with adequately proposed public transport routes should appear as early as at the design stage and not after the first cars and buses have driven along them. It is advisable to use this method to adjust existing transport schemes and as an additional step to automated design.

The most effective means is a partial automation of route creation with subsequent expert evaluation. An expert enters various combinations of conditions, receives calculations, analyzes the obtained results and makes the final decision. This method allows specialists to get the route network optimal both for the proper calculation algorithm and in terms of psychological perception of travel time.

Many factors influence the subjective perception of time. For example, emotions felt during the trip [2, 3, 4], focusing on activity or on time itself [5]. It has been experimentally proved that there is a difference in perception of time between young and old [6], sick and healthy people [7, 8]. A connection between time perception and movement has been proved by sundry studies [9, 10]. The time interval when the person sees moving objects is estimated to be longer than in reality. The faster the objects move, the larger distortion is.

Psychological features of time perception are used to predict the behaviour on the roadway [11], the choice of transport mode [12, 13]. Still, most existing studies consider only some individual factors affecting people using transport. This article attempts to summarize different factors influencing the choice of public or private transport as well as the route of travel.

3. Practical experiences
At the initial stage of the study, I analyzed the published empirical results and answers of megalopolis residents about the factors that are important in choosing a trip route. As a result, 8 such factors were identified. They were conditionally divided into 2 blocks. The first block includes 4 factors directly related to the physical characteristics. The second block includes 3 factors that influence the subjective perception of time and 1 factor that is not related to time but is relevant for deciding on the route.

Subsequently, respondents aged 15-75 were asked to rank these factors by importance. The most important was rated 1, the least important was rated 8. When processing the results, the citizens were divided into two groups. Participants in the first group use private transport and taxis for travel. The second group using public transport was then divided into three age subgroups. This division was related to the purpose of the trips and some social characteristics.

Junior passengers use transportation to reach the place of study, additional classes and spots of leisure activities. The more diverse their interests are, the more importance they attach to travel time. Otherwise, they risk not being able to reach the destination. It is also the most mobile group, with minimal physical limitations though lacking funds.
Passengers in the middle age group mainly use transport to reach their place of work, as well as for other personal purposes. Their high responsibility places the highest demands on travel time. For a number of professions, the “time is money” motto is a key one in deciding on the means and route of travel.

The older age group generally uses transport for periodic tasks that have no time limit. Any trip is a separate independent event for them. As a consequence, it is possible to leave home in advance or to postpone the trip without any outcomes. In addition, this group has some material and health restrictions, which also affect the decision to choose a route. The results obtained are shown in Table 1.

| Criterion                      | Personal car / taxi | 15-19 y.o. | 20-60 y.o. | over 60 y.o. |
|--------------------------------|---------------------|------------|------------|-------------|
| travel time                    | 3                   | 1          | 1          | 6           |
| possible delay (waiting, traffic jams, etc.) | 4 | 2 | 7 | |
| number of changes              | -                   | 2          | 3          | 2           |
| “door-to-door” distance        | 5                   | 8          | 6          | 3           |
| possibility to change the route while being on the way | 1 | 3 | 5 | 8 |
| convenience of the vehicle     | 2                   | 4          | 8          | 4           |
| possibility to spend time productively | 7 | 6 | 7 | 5 |
| fare                           | 6                   | 5          | 3          | 1           |

4. Discussion
Let us consider how each criterion can be used for designing of transport system.

4.1. Travel time
Travel time is the period of time required to move from one point to another. Subjectively, it is usually defined as a “door-to-door” way [14]. This criterion can only be used to assess trips that have predetermined starting and ending points and means of available transport.

Travel time factor is often used by drivers and passengers to compare and evaluate possible routes. Those respondents who put this factor first are willing to tolerate physical and emotional inconvenience in order to reduce travel time. Typically, they choose subway, railway and bus routes with fixed schedules. Their route can have multiple transfers/changes and they use scooters, roller skates and other mobile vehicles to increase their speed.

How can transport planners and transport companies take cue from this factor in their work? They shall envisage as many intersections of different routes as possible; create transport hubs [such as 12]; put into operation a single travel card that would save time on payment; prioritise lanes for public transport; create a fixed schedule; synchronize the arrival/departure of different means of transport, reducing waiting time [e.g. 15]; introduce a system of rental points for mobile vehicles (bicycles, scooters, etc.) [such as 13] paid for by a single travel card. And finally, the authorities shall set up a warning system informing about failures in the public transport system, such as [16].

4.2. Possible delays
Long studies of travel time (e.g. [17, 18, 19]) have shown that it is very variable even when walking, and this factor can change many times. Therefore, for the automated designing of transport systems one shall calculate probable values of a delay in relation to the minimum time of the trip. For example, traffic lights can cause technical delays. If a pedestrian or a vehicle approaches a traffic light when the green light is on and continues moving immediately, the delay can be considered minimal. If a pedestrian or vehicle approaches a traffic light that has just turned red, they have to wait.
Consequently, their travel time increases. By multiplying the waiting time by the number of traffic lights on the route, we get an idea of the possible increase in travel time.

In this example, an objective increase in travel time is described. In rare cases, this change in time will remain invisible to subjective perception. However, the same travel time along two routes, with and without possible delays, may be perceived differently. The situation of uncertainty creates an increased stress load and affects decision-making. As a consequence, a large number of traffic lights on a route can be essential for making the decision to opt for a longer route with fewer possible delays.

Other objective delays of public transport are related to the peculiarities of traffic organization. If passengers see a traffic schedule at a bus stop, etc., with a clear indication of the departure time, they have the right to expect the drivers to adhere to this schedule. This reduces the feeling of uncertainty and allows the person to better calculate the time and route of travel. The situation with the interval schedule is different. It states, for example, from 12:00 to 16:00 that bus N crosses this point once every 10-25 minutes. When a passenger arrives at a bus stopping, he/she usually does not know when the previous bus left. He/she starts to count down the time from the moment of his/her arrival. And if the waiting time is longer than the minimum indicated, the subjective waiting time increases. This is partly due to the moving of the passing by vehicles. As noted above, observing moving objects as if increases waiting time. Uncertainty and a distorted sense of time, in turn, increase the tension that results in passengers’ discontent and complaints to transport companies and carriers.

A separate problem with travel delays occurs at final stops. Private carriers, in an effort to make a profit, do not depart if there are only a few passengers. Passengers who come first have to wait. And that time is not regulated. It is especially noticeable in “off-peak” hours with low passenger traffic. Late in the evening, private carriers generally stop working due to low profitability, depriving people of public transport and forcing them to use a private car or taxi.

The use of mobile applications and public transport monitoring services such as Yandex.Transport, Citymapper, Transit, etc. helps to reduce tension. Problems related to the work of private carriers can partly be solved if they start to work under public contract.

4.3. Number of changes
The subjectively perceived time grows in case of multimodal trips. A multimodal trip is characterized by the use of more than one mode of transport. Each stage of such a trip is made with a certain type of transport [14]. There are necessarily the so-called transfers in-between, which entail additional physical effort. These very efforts increase fatigue and subjective travel time. For example, a cross-platform transfer from one underground line to another or from one bus route to another within a single stopover is seen as an undesirable holdback, but not as a barrier preventing travelling. Besides, similar transfers with the need for long walk through tunnels, stairs, bridges, pedestrian crossings, etc. are considered as a separate stage of the route. The more such crossings a traveller has to make on the way, the longer he/she perceives the travel time. This is especially true for the older age groups and passengers with low mobility. In addition, when changing from one means of transport to another, it is often necessary to wait, which boosts the objective and subjective travel time. This has already been mentioned in the previous factor.

Thus, a large number of transfers is a way to reduce travel time for some passengers, but for others it is a serious obstacle forcing them to choose longer routes with fewer stages. So, when planning the transport network, it is necessary to create long direct routes running through several areas.

4.4. Distance from “the door” to destination
The distance from the place of residence/work to the nearest public transport stop in a city does not usually exceed 10-15 minutes. The traveller factors it into determining travel time. However, the nearest stop may not be the one needed by the person. In this case he/she has to choose between a longer walking distance, a multimodal trip or another route. While physically healthy people are more likely to choose between the first or second option, older and less mobile passengers opt for the third
option. As mentioned above, multimodal journeys cause them physical inconvenience, greater stress and subjective travel time.

The location of bus stops is a complex topic. Owing to the reduced distance between stops, additional stopovers, walking time decreases, but the total travel time may increase. Express routes increase the speed of the journey, but lead to longer walking distances. In any case, satisfying the needs of passengers from one category results in ignoring the needs of another. This problem can be solved by automated optimization algorithms such as [20, 21] and passenger trajectory studies such as [15].

4.5. Possibility of changing the route
This factor is partly related to the number of transfers. The difference is that in the first case it describes a forced measure when there is no direct way. In the second case, this factor is an “additional option” for a passenger who decides to change the route after it has started (e.g., an urgent affair or an appointment). The ability to change the way quickly and return to a previously planned route as quickly as possible is certainly appreciated by the mobile group of residents. Such trips are often perceived as “stopping by on the way” rather than as a separate trip, as the time is calculated not “from the door”, but from the point of the route change. It is this factor (combined with the freedom to choose travel time) that is crucial for those who choose to travel by a private car or taxi.

Taking this factor into account when designing transport networks does not require special efforts. The criteria are absolutely similar to the travel time factor, which was discussed in detail.

The indicators considered above are subject to standardization and can be either automated or semi-automated. Two following factors have purely psychological value, but they are also relevant. The emphasis should be neither on the trajectory nor on speed, but on the transport’s internal equipment.

4.6. Convenience of vehicle
This is the second most important factor affecting the decision to use a private car or a taxi. It is not a secret that public transport in Russia is largely outdated and does not meet modern requirements. Noise, dust, a large number of passengers, the lack of seats, unfriendly and sometimes aggressive other passengers offer little comfort to the passengers of public transport. Under such conditions, even a short journey can be perceived as a long one. And vice versa: the opportunity to take a comfortable seat, appropriate temperature, little noise level, friendly attitude of other passengers can make even a long trip psychologically acceptable. The subjective comfort of transport may also include characteristics that have deep personal roots. For example, some people experience fear of small spaces and movement underground [22]. No matter how comfortable and super modern an underground train is, such passengers will always choose to use ground transport. Excessive pounding or the smell of gasoline may force other people to choose electric rail transport, even if the journey by bus is several times faster. The poor quality of roads also contributes to the inconvenience for both drivers and passengers and speeds up the wear and tear of vehicles, lessening their comfort.

Undoubtedly, transport companies will not be able to pay attention to the personal characteristics and phobias of all passengers, though regular renewal of vehicles and road quality could influence the preferences of passengers, as their subjective time on the road will be less objective.

4.7. Possibility to spend time productively
Many people think that if a long trip cannot be avoided, you should make good use of that time. When a person is focused on activities rather than on time spent, travel time is subjectively assessed as shorter. The main activities indicated by passengers are reading, checking mail and sending letters, making phone calls, listening to audio books, learning languages, handicrafts, simple exercises (e.g. for the eyes), sleeping. Car drivers may only use activities that do not involve eye contact or physical movements (listening and speaking only). There are many more activities available to passengers of public transport that can be performed during the journey and that do not interfere with other people. Some of them do not require special facilities. They can be done standing up in crowds. But some
conditions can still be created by transport companies on purpose. For example, proving a free Wi-Fi in public transport.

4.8. Fare
This factor is crucial for a large group of passengers with low income. They would like to travel short distances on foot or on their own bicycle. But for long journeys they have to use public transport. In this case, decisions do not depend on the time or comfort of the trip, but on the means available. If there is not enough money to pay for a certain stage of the trip, there is no way to finish it. Such passengers prefer direct routes and are ready to walk a few hundred extra meters to the distant stop. The only exception for now is the underground, where the change from one line to another takes place at no extra charge.

The cost of the train tickets can be reduced by introduction of preferential (for pensioners, students, schoolchildren, etc.) tickets and flexible payment systems (unlimited ticket for a month, a day, a few hours, etc.) But for such a payment system, all carriers involved in the transport system must work under a government contract. Unfortunately, for many regions this is just an unattainable dream.

5. Conclusions
The most effective way of designing the optimal transport system is a semi-automated way with a subsequent expert evaluation. Apart from taking into account standardized indicators, it also considers social and psychological needs and some passengers’ characteristics, which indicate who will use the routes laid.

The size of passenger flows in different directions from one district to another is the main factor to think about. The more correctly the territory of the city is divided into transport districts, the more accurate the values of passenger flows are. Therefore, the route network of public passenger transport should mainly satisfy passengers’ needs and be approved by consumers.

Travel time and possible delays are factors which concern passengers the most while they are choosing a route. Without a doubt, reliability of travel time plays a big role in estimating transport systems’ quality. It also influences the individual choice of route and means of transport for traffic participants. However, the factor of individual sense of travel time shall not be excluded. All these factors may significantly increase passengers’ loyalty to the public transport system and improve the level of service without significant additional expenses.

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