The socio-economic efficiency of computer-integrated transport modelling

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Abstract. In the article has been analysed the possibilities of using modern digital technologies to optimize the transport system of a big city. The Urbanization’s processes lead to high rates of urban development, which provides for the creation of assorted transport supplying. However, there are situations when the geographic, landscape, natural and climatic area features, architectural solutions (characteristics) or blunders in the design of the city do not allow to create the road infrastructure of the necessary level. This leads to congestion of the main transport networks and generate traffic jams, increasing the degree of environmental pollution. The authors consider the horizons of creating a transport model of the Odessa city as an effective method of traffic management. It has been made out a case that the digitalization of the urban highways management reduces the trip time, alleviates the level of the road network congestion, increases the reliability and safety of transport, minimizes the number of non-standard traffic situations, and increases the economic efficiency of the city's transport system. The using of powerful content solution allows you to build a mental (virtual) model, taking into account the actual traffic situation at this time and predict its changing when you have to make a certain management decision. This article is dedicated to the economic issue of the building a city transport model, the contemplation for its use to improve the efficiency of the city economy operation.

1. Introduction
The transport system of the city is a significant part of supporting its life-activity, it combines varied districts of the city, allows you to get a work, shops and holiday destination. The city's transport system includes a street and road network, transportation items, cases of transferring (public transport, private motor transport, trucks, special vehicles, etc.), likewise the relevant infrastructure - bicycle and foot walks, parking places, gas stations, public transport stops. The structure and length of the road network, its branching and severity level, the quality of road surface directly affect the safety and reliability of transport networks, passenger and freight traffic scope, the situation of the environment, therefore it is one of the important life quality indicators in the city living. The growing number of residents increases the load on the city's transport system. The discrepancy of the city's transport system and modern requirements, deficiency of proper infrastructure significantly affects to socio-economic situation: it leads to appreciable wastes of working time, increases traffic accidents, interferes efficiency, reduces social mood, increases conflicts in various areas. The optimization of traffic streams brings appreciable, social and commercial effects, which may not always be obvious, but at the same time can be identified and calculated by using modern methods of analysis. An important part of this optimization is the development of the city's transport model.

2. Methodology
The transport model of the city is an implement that is used to reason some management decisions in strategic planning of city development. It allows to estimate the distribution of passenger traffic on the existing or projected transport network on the basis of functional and spatial characteristics of the city, items of demand for transport, supply of transport. This will determine the transport time costs and
wastes in the way of comparing different options of the city development and carry out their economic evaluation.

The growth of computer power counting, software development, availability of information of the transport system condition, its load and population movements, geographic information systems allow to develop and use detailed transport models of cities and take into account many different factors influencing road user behaviour.

It is used the PTV VISUM software package [1], data on the city's transport system (OpenStreetMap [2], 2GIS map data [3], and Google Earth Pro with the historical and photographic information [4].

PTV VISUM is a modern information and analytical decision support system, which allows to do a strategic and operational transport planning of cities and regions, forecasting traffic intensity, optimization of passenger transport and furthermore justification of the volume and economic feasibility of investment in transport infrastructure modernization. Many researchers use this system to optimize traffic streams [5, 6].

The PTV VISUM software complex integrates all road users (car and freight transport, passenger transport, cyclists, gangers etc.) into a single mathematical transport model. PTV VISUM combines data from geographic information systems, data on the population, ideas and directions of its movements in space, data on transport support into a single database with several levels.

Strategic macroscopic modelling and construction of the demand model provides: Strategic planning, Operational analysis, Real time traffic management. To build a model of transport demand, the source data is used: behaviour data; network model; land use data.

Output data: data of the passenger traffic distribution in different ways, identification of "bottlenecks", forecasting changes in passenger traffic during the commissioning of new facilities, meaning losses of time during the trip. The new transport infrastructure facilities typically reduce the load on the transport system by redistributing flows. And new facilities that are the source of trips or the destination of travel can both increase and decrease the load on the transport system. To determine the demand for transport services, a 4-step demand determination program is used (Figure 1).

Figure 1. Classic 4-step transport model.

At every step, the model provides for its verification and calibration, which involves returning to the previous steps if necessary. The model can be used both to analyse the current situation and to forecast the development of demand for future periods.

- In the first stage, the potential value of the flow is estimated. On the socio-economic and demographic basis factors the purposes of trips and places of passenger flows attraction are defined.
- In the second stage, the distribution of traffic flows in different directions is analysed and a matrix of inter-district correspondence constructs.
- In the third stage, the correspondence is distributed by different modes of transport. In the estimation way, it takes into a usefulness of a particular kind of transport for different groups of people and the purpose of trips.
- In the fourth stage, the intensity of traffic flows on different alternative routes is calculated.
The amount of transport demand in the area depends on socio-economic and demographic characteristics. Residents of the district can be segmented by the availability of transport, comings, age, etc.

The choice of a certain district depends on a goal of the trip is influenced on the one hand by its attractiveness, on the other - the resistance by the moving from the start place to destination, which consists of travel time, fare, travel comfort, etc.

The volume of traffic flow \( Q \) from district \( i \) is calculated by the formula [1]:

\[
Q_i = \sum agSGg(i)
\]

where \( SGg \) is summed up by all structural properties;

\( SGg(i) \) designates the value of \( SGg \) in zone \( i \), (the number of people);

The coefficient \( ag \) is an efficiency which describes how many trips per structural property unit accomplished.

For a similar purpose, the volume of traffic flow to the target \( Z_j \) is calculated.

The total volume of traffic flows from start place for this layer of demand to all districts is usually equal to the total volume of traffic to the target:

\[
\sum_j Q_i = \sum_j Z_j
\]

where

\( Q_i \) – efficiency of zone \( i \) (the number of people moving out zone \( i \));

\( Z_j \) – attraction of zone \( j i \) (the number of people moving in zone \( i \)).

To appraise the feasibility of measures to unload road traffic, it is necessary to determine the effectiveness of investment.

The potential efficiency of road infrastructure investments is reflected in transport accessibility improving. The consequence is a reduction in trip time from one point to another, i.e. the individual social effect. The total result will be the time savings for all transport correspondence. And although the social effect is obvious here, it is quite challenging to determine the commercial effect, which is based on benefits and costs. One of the using approaches is to estimate the cost of working hours in the work market in this city on the basis of statistics on the average salary. This allows you to recalculate in monetary terms the total amount of time saved and compare it with the amount of invested finance [7]. Evaluation of the investments effectiveness in transport projects should be based on the general principles of project analysis, i.e. taking into account the time factor and the use of discounted estimates. The World Bank’s recommendations in this area are also based on this point [8].

These notes contain recommendations on the use of a number of summary economic indicators giving an overall measure of the project's performance in cost-benefit terms. These include the Internal Rate of Return (IRR) and the Net Present Value (NPV). NPV is calculated by the formula [9]:

\[
NPV = \sum_{k=1}^{n} \frac{C_k}{(1+r)^k} - \sum_{j=1}^{m} \frac{IC_j}{(1+r)^j}
\]

Where

\( C_k \) is the currency flow in year number \( k \) (pecuniary units);

\( IC_j \) is the investment in year number \( j \) (pecuniary units);

\( n \) is the number of years during which the currency flow takes place;

\( m \) is the number of years during which the investment takes place;

\( r \) is the discount rate (decimal).

Internal Rate of Return is a discount rate at which the NPV of the project is 0, i.e. the condition is fulfilled:

\[
\sum_{k=1}^{n} \frac{C_k}{(1+r)^k} = \sum_{j=1}^{m} \frac{IC_j}{(1+r)^j}
\]

In practice, the formula of linear interpolation is used to determine this indicator:
\[ IRR \approx r_+ + \frac{NPV(r_+)}{NPV(r_+) + [NPV(r_-)]} (r_- - r_+) \] (5)

Where
\( r_+ \) is discount rate at which NPV is positive (decimal);
\( r_- \) is discount rate at which NPV is negative (decimal);
\( NPV(r_+) \) is NPV value at \( r_+ \) (pecuniary units);
\( NPV(r_-) \) is NPV value at \( r_- \) (pecuniary units).

In our opinion, you should also use the PI indicator, which can be used in choosing between project alternatives.

\[ PI = \frac{\sum_{k=1}^{n} C_k}{\sum_{j=1}^{m} IC_j (1+r)^j} \] (6)

Also, it is possible to offer the formula for definition of the project break-even point level. For example, to find the break-even point of a project to optimize the transport system, you need to use the equation:

\[ PI = \frac{\sum_{k=0}^{n} Ts \cdot AS (1+r)^j}{\sum_{j=1}^{m} IC_j (1+r)^j} \] (7)

Where
\( Ts \) is amount of time saved (man-hours);
\( AS \) is the average salary per hour (pecuniary units).

3. Case study
The city of Odessa is a prominent, historical, cultural and resort-recreational center of Ukraine. The formation of the architectural and planning structure of the city can be divided into the following stages:

- 1st stage (1794 - 1819) - the period of the city's foundation and construction according to the plan drawn up by engineer-colonel F. Devolan. The plan is based on a planning module - rectangular blocks. The pace of development of the city in the XIX century had no analogues in Europe due to the port complex, through which passed more than 70% of all grain exports of Russia and imported goods from Europe, the Middle East and America.

- 2nd stage (1819 - 1858) - The central part of the city is being built and the main architectural ensembles are being formed. A significant role in the development of the city was played by the implementation in 1819 of the "Porto Franco" regime. As a result of accelerated economic growth, the city's population increased rapidly and the settlement area expanded. Around the historic center, behind the line of defense of the barracks, built in the early XIX century, there were belts of suburbs: Moldavanka, Peresyp, Slobodka, Near and Far Mills. After De Volan's plan, in the planning development of Odessa for a long time there were inconsistencies. The city was considered as a sum of state, municipal and private lands, and not as a whole organism.

- 3d stage (1859 - 1917) - After the liquidation of "Porto Franco" in 1859, a period of unplanned territorial growth of the city began. Urban growth is characterized by an increase in industrial and transport production, which as a result led to the formation of a kind of ring around the central part of the city and to some extent blocked its further territorial development. There were arrays of spontaneous residential and industrial development in the area of "Odessa-Malaya", there were areas of residential development in the Soldier's settlement near Zhevahova mountain.
- 4th stage (1918 - 1941) - Restoration of the city after the Civil War of 1917-1922. From 1920, plans for the development of the city began to be developed, the old districts were reconstructed, new construction was carried out according to the general plan of 1930, the settlement of the city was expanded, and large industrial enterprises were built by forming new industrial districts.

- 5th stage (1945 -1965) - Restoration of the city after the Second World War. A significant part of the buildings was destroyed, the unity of the architectural style was not observed during the restoration of the city, and monumental houses of the "Stalinist" style and panel buildings without architectural refinements (so-called "Khrushchevs") were built next to the most beautiful buildings of the 19th century.

- 6th stage (1965- 1990). The construction was carried out according to the general plan of 1966 with the development of agricultural lands adjacent to the city both in the north and in the south. (residential blocks of the village named Kotovsky, Yuzhny and Yugo-Zapadny). The number of the population of the place increased significantly, the place-supporters grew up - Illichivsk and Pivdenne. Multi-apartment high-rise buildings were carried out, which were mainly of a focal nature. Public service establishments were located, as a rule, in places of public transport stops. The low level of car mobilization of the population in the Soviet Union determined the adoption of planning decisions without the allocation of parking and garage areas. In the 1989 general plan, the city of Odessa, according to the directives, was assigned to the category of resort cities of all-Union significance.

- 7th stage (1991 - present) After Ukraine's secession from the Soviet Union and the transition to a market economy, the processes of housing construction in the city of Odessa are focused primarily on obtaining a commercial effect and are predominantly elemental way. The existence and area of lots that can be used by building influencing on the city development. The mass development of coastal areas and beaches with high-rise residential buildings begins. In the general plan, adopted in 2015, in the development of a functional planning model for the development of the city, one of the ways of the rational use of intracity territories is the reorganization of industrial territories. Lack of free areas for living forget in the central part of the city due to the creation of new wake-up calls according to the point principle.

Chaotic development revealed imbalances in the planning structure of the city of Odessa, significantly increased the load on the city's transport infrastructure. These problems were exacerbated by natural geographic factors. Historically, Odessa was formed as a large seaport and resort town, therefore, geographically, it is strongly stretched along the coast. Features of the terrain, the proximity of groundwater, the threat of landslides and the presence of catacombs are the reasons for the refusal to build the metro. The street and road network of Odessa turned out to be unable to perceive the increase in population density and the sharply increased level of motorization. At the same time, there is a reserve of extensive growth through the expansion of the road to the maximum extent.

The construction of the "Arcadia" district of the Odessa city, which has been a favourite vacation part of Odessa for guests in the town. Proximity sea with a comfortable beach, lots of greenery, coziness and comfort of living formed an increased demand for housing in this neighbourhood. Now there is a significant amount high-rise building, landscaping has decreased significantly, and the available transport, engineering, communal and social infrastructure does not meet the needs that are caused significant increase in population density (Figures 2, 3).
One of the microdistricts of Arcadia, the Gagarin table land, has undergone active development since the beginning of the 90s. The number of the population increased during this period from 0.5 thousand to 18.85 thousand people. At the present time, residential buildings are still under construction, which are planned to be commissioned within 5 years. Thus, by 2025, it is expected that the population of the Gagarin table land will be more than 33 thousand people, what is shown in figure 4.

The population density on the Gagarin table land is 16830 people / km², and when the houses under construction are commissioned and populated it will reach 30,000 people / km².

Currently, you can get to the Gagarin table land either along the 4-lane Genezeskaya street, 1240 m long, or along the 2-lane Posmitnogo street, 1180 m long. Trolleybus, fixed-route taxis in the general flow of cars and the tram travel along the dedicated lane along Genezeskaya street. Private cars and fixed-route taxis drive along Posmitnogo Street. In addition, you can get to the area by car along Kurortny Lane with a partly one-way traffic.

Traffic intensity during peak hours along Genezeskaya Street is up to 1300 vehicles / hour in one direction, along Posmitnogo Street up to 500 cars, along Kurortny Lane up to 200 cars. The roads adjacent to the microdistrict were not designed for such traffic intensity, and now there are congestions on them most of the time. what is shown in figure 5.
According to research [10] there are 300 cars per 1000 residents of Odessa. Thus, the actual presence of cars among residents of the Gagarin table land is about 5700 cars. Assuming that about 70% of cars leave the Gagarin table land every day, the total traffic flow from private cars is 3990 in the morning and evening, which, taking into account the capacity of the roads, corresponds to the picture of traffic jams in the area. The average speed in this section is 7 kilometres per hour.

The graphs below show the average congestion level, for several main purposes of travel for residents of the Gagarin table land. Congestion level shows the percentage of travel lengthening in congestion conditions relative to travel on an empty transport network.

At the trip to and from the Pryvoz market area (figure 6), morning traffic jams are practically combined with evening ones and the congestion level is 40-92%, what is shown in figure 7.

A similar point is observed by trip to the city center, what is shown in figures 8 and 9. This is connected with the trips of the residents to and from work and with the trips of tourists.
For trips to the area of the Polytechnic University (figure 10) the peak of morning and evening traffic jams are more pronounced and the congestion level reaches 130%, what is shown in figure 11.

For trips from the district to the shopping center in the Gagarin table land area (figure 12), there is also a high load throughout the day, what is shown in figure 13. The morning peak may be due to the general high congestion of alternative roads towards the city center.
PTV Visum was used to simulate the traffic load on this transport network section (figure 14).

The Demand matrix in figure 15 shows the movement of the population between the zones, in this case it shows isolating movements from and to Arcadia.
Figure 15. Demand matrix for the existing population of the Gagarin table land (the number of trips per day)

Can calculate skims such as travel times between the individual zones, what is shown in figure 16.

Figure 16. Skim matrix for the existing population of the Gagarin table land (average duration of the trip in minutes)

With the commissioning and occupancy of houses under construction, the number of cars in the area will increase to 10,080, the number of leaving cars, while maintaining proportions, to 7056 (figure 17), which, taking into account the capacity of roads, will increase the duration and intensity of morning and evening traffic jams.

Figure 17. Demand matrix for the projected population of the Gagarin table land (the number of trips per day)

The results of congestion modelling with an increase in the population to 33 thousand people, that is, 1.8 times are shown in the matrix, what is shown in figure 18.

Figure 18. Skim matrix for the projected population of the Gagarin table land (average duration of the trip in minutes)
To calculate the difference between matrix indices, we find the increase in time spent on one trip for each direction. By multiplying the number of trips, you can get the overall increase in time spent and calculate the economic loss.

The following matrix (figure 19) shows the loss of time if, with an increase in the number of residents, measures are taken to increase the capacity of roads.

| Name      | 1   | 2     | 3     | 4     | 5     |
|-----------|-----|-------|-------|-------|-------|
| Arkadia  | 140.10 | 0.00 | 28.70 | 39.20 | 42.10 | 30.10 |
| University| 27.90 | 27.90 | 0.00  | 0.00  | 0.00  | 0.00  |
| Privoz   | 36.12 | 36.12 | 0.00  | 0.00  | 0.00  | 0.00  |
| City Center| 40.07 | 40.07 | 0.00  | 0.00  | 0.00  | 0.00  |
| Shopping Center| 28.15 | 28.15 | 0.00  | 0.00  | 0.00  | 0.00  |

Figure 19 Skim matrix with the projected population of the Gagarin table land and an increase in road throughput (average duration of the trip in minutes)

Time savings will amount to 96360 hours per year.

We will calculate the efficiency of investments in increasing road capacity.

Average salary in Odessa 11646 UAH. Hourly salary for a 168 working hours per month - 69 UAH/hour [11].

According to the Odessa City Administration, the average rate on loans attracted in 2020 was 18% per year. This rate determines the minimum level of return on investment and therefore was taken in the calculations as the discount rate for cash flows.

We can calculate at what savings hours per million investments, the PI efficiency index will be greater than or equal to 1, that is, the investment will pay off.

Based on the intervals between major road infrastructure repairs, we will take a planning horizon of 10 years. By formula (7):

\[
PI = \frac{\sum_{k=1}^{n} x \cdot AS}{IC} \geq 1
\]

\[
PI = \frac{\sum_{k=1}^{10} x \cdot 69 UAH}{1000000 UAH} \geq 1
\]

We have solved the equation, to determine that \( x \geq 3210 \) man-hours.

Now, at the exit from the Gagarin table land, up to 199,500 hours a year are spent.

The city authorities are planning some investments in the reconstruction and extension of the cycle path, regulation of traffic lights, and repair of the road surface in the amount of UAH 20 million. If the time of each train is reduced by at least 5 minutes, then the total time savings per year for residents of the Gagarin land table will amount to 83,125 hours. In this case, the condition \( PI \geq 1 \) will be fulfilled.

It should be borne in mind that the transport infrastructure of a city is a complex system with many different interconnections, and changes in its efficiency are best evaluated in a comprehensive manner. Therefore, for more accurate forecasts, it is necessary to develop a transport model of the city as a whole, simulate the complete road situation and evaluate the efficiency of investments in its optimization.
4. Conclusions
The modern traffic situation in overcrowded microdistrict is complicated by many subjective and objective actualities. Modelling the traffic situation in the city by the PTV Visum software package makes it possible to predict the traffic intensity, traffic jams, therefor it is possible to estimate the economic wastes or benefits from the new transport infrastructure constructions. The consumption of transport modelling at the period of urban development planning will ensure a balance between transport infrastructure and the load on it and reduce economic wastes. It is simulating the transport situation in the article for the one of an extensively developing Odessa city microdistricts, predicts the load on the transport system at the end of its development, proved the correlation between the economically justified level of transport infrastructure investing and reducing the waste of time in traffic jams. In the course of depletion of the unloading transport system extensive possibilities (expansion of roads, creation of detour opportunities, additional cycle paths, installation of “smart” traffic lights, etc.), it is necessary to consider the alternative possibilities for optimizing road traffic. The promoting of online services, spacing of social infrastructure items within walking distance, the popularization of a healthy lifestyle and an increase in the share of cycling will contribute to reducing the level of traffic congestion.

It is future-oriented but cost-intensive the further development of public transport, the start-up of a high-speed tram, the organization of a ferry crossing the Black Sea.

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