ПРОБЛЕМИ ЕКОЛОГО-ЗБАЛАНСОВАНОГО РОЗВИТКУ

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ANALYSIS OF ENVIRONMENTAL AND ECONOMIC EFFICIENCY OF "CAR-FREE CITY" PROJECTS – CASE STUDY OF OPOLE, POLAND

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The role of cars and transportation in modern urban systems was considered in the paper. The benefits and drawbacks of urban transport were analyzed in terms of the possibility of efficient management and limitation of the traffic in favor of environment and social-economic situation improvement. Private transport is currently considered the necessary element of living standards and provides better access to services and other conveniences of cities. Being so efficient in personal needs provision it is still the major degrading factor for environment quality, as well as the source of health risks due to accidents and hypokinesia. The methods of environmental and economic efficiency assessment suitable for the analysis of the projects of the given type were offered as a combination of SWOT-analysis and monetary expression of benefits, obtained from implementation of their projects. The list of factors to be considered in efficiency assessment was developed and substantiated. The major environmental, social and economic issues of private transport use in urban settlements were characterized and the most suitable of them were chosen for further analysis. The intensity of traffic was shown to be the starting point for calculations of environmental benefits of the project. The proposed model of assessment was applied to the city of Opole, Poland. The geographical, economic and environmental characteristics of the city were given with specific interest to the transport infrastructure status. Having excessive traffic pressure, Opole was shown to be in need for limitation of transport flow within the central part. For this purpose it was offered to introduce ban on private cars at 6 streets of city center with allocation of additional parking areas at other territories and use of released land in the center for green spaces and recreation facilities. The economic values of the possible environmental benefits as well as indirect incomes from the project were calculated, and the possible expenses on project implementation were described. *Key words:* environmental and economic efficiency, environment pollution, private cars, traffic intensity, transport flow management.

Аналіз еколого-економічної ефективності проєктів типу «місто-без-автомобілів» на прикладі м. Ополе, Польща. Радомська М.М., Колотило А.О.

У статті розглянуто роль автомобілів і громадського транспорту в сучасних міських системах. Переваги та недоліки міського транспорту було проаналізовано з погляду можливості ефективного управління та обмеження руху на користь покращення екологічної та соціально-економічної ситуації. Приватний транспорт нині вважається необхідним елементом рівня життя і забезпечує кращий доступ до послуг та інших зручностей міст. Будучи настільки ефективним у забезпеченні особистих потреб, він є головним фактором зниження якості довкілля, а також джерелом ризиків для здоров'я внаслідок нещасних випадків та гіпокінезії. Методи оцінки еколого-економічної ефективності, придатні для аналізу проєктів цього типу, були запропоновані як поєднання SWOT-аналізу та грошового вираження вигод, отриманих від їх реалізації. Перелік факторів, які слід враховувати під час оцінки ефективності, був розроблений та обгрунтований. Охарактеризовано основні екологічні, соціальні та економічні проблеми використання приватного транспорту у міських поселеннях та обрано найбільш придатні для подальшого аналізу. Інтенсивність руху визначено вихідною величиною для розрахунків екологічних переваг проєкту. Запропонована модель оцінки була застосована до міста Ополе, Польща. Представлено географічні, економічні та екологічні характеристики міста з особливим акцентом на стані транспортної інфраструктури. Маючи надмірний транспортний тиск, Ополе потребує обмеження транспортного потоку в центральній частині. З цією метою було запропоновано запровадити заборону на рух приватних автомобілів на 6 вулицях центру міста з виділенням додаткових ділянок для паркування на інших територіях і використанням звільнених земельних ділянок у центрі для створення зелених насаджень та об'єктів відпочинку. Було розраховано фінансові параметри можливих екологічних вигод, а також непрямі доходи від проєкту, та описано можливі витрати на реалізацію проєкту. *Ключові слова:* еколого-економічна ефективність, забруднення довкілля, приватні автомобілі, інтенсивність руху, управління транспортними потоками.

Problem statement. Over the past years, researchers have revealed that one of the most powerful air pollutants in cities is transport, in particular private cars. The impact of road transport on the environment is formed while driving cars; during maintenance and the general functioning of the cars operation infrastructure.

The greatest impact from the car is at the stage of its operation, while impacts of maintenance are less distributed, but more intensive. The stage of the operation is determined by the rate at which its resource has already been used, that is, the total mileage from the beginning of operation to its decommissioning and disposal. Researchers have also found that up to 35– of total vehicle emissions are caused by the condition of the road surface and the organization of traffic [1].

Everyday operation of cars consumes running materials, such as petroleum products, natural gas, atmospheric air, water for cooling systems of the internal combustion engine and car washing, land resources expropriated for the construction of roads and other objects of transport infrastructure. It is accompanied by a wide range of negative consequences for the environment, including:

– pollution of the atmosphere and release of unpleasant odors;
– pollution of the water bodies;
– consumption of natural resources;
– change in the chemical composition of soils and damage to pedobiota;
– loss of agricultural lands and green spaces for the road infrastructure construction and due to its functioning;
– degradation of plants;
– waste generation, including production and service waste and vehicles themselves;
– noise, electromagnetic and vibration effects;
– direct thermal pollution and contribution to climate change;
– negative impact on building materials, historical architectural and sculptural monuments and other works of art;
– corrosion of metals, deterioration of leather and textile products;
– activation of adverse geodynamic processes such as water erosion, wetlands, mudflows, landslides and landslides.

Another important negative factor to emphasize is the injuries and deaths of humans and animals, and material damage caused by accidents and catastrophes. The less dramatic, but still serious health risks from private transport originate from hypokinesia and hypodynamia, typical for urban residents, as they mostly move by means of transport instead of walking. Moreover, switching to personal transport increases social separation among people, which is also associated with health risks and makes communities more vulnerable.

To improve the situation many countries are working on introduction of programs for control and mitigation of car-related environment degradation. Among the possible solution of this problem is limitation of traffic in cities. The **purpose** of the given paper is to analyze the perspective – benefits and drawbacks of car-free cities creation.

The environmental issues of transport are widely covered in research works; however, the use of cars is still among the top elements of living standards and is perceived as a necessary element of comfort, providing easier access to any destination and independence from regulated transportation services. Thus, the assessment of transport limitations in any form will need to cover a complex set of factors, often having opposite values.

Methods and materials. The methods, which could be applied to evaluate the advantages and disadvantages, range from mostly descriptive SWOT or PESTLE analysis to numerical methods of environmental and economic efficiency assessment. The latter one is representative and comparative, but demands clear formulation and description of factors involved in efficiency formation. Thus, it is necessary to define the list of parameters important for consistent characteristics of projects involving limitation of traffic in any urban settlement. In this term SWOT analysis is a goof theoretical background, able to reveal options for consideration.

SWOT analysis is a process of establishing connections between the most characteristic of the enterprise opportunities, threats, strengths (advantages), weaknesses, its implications can be used later to formulate and select enterprise strategies. It is conducted to investigate the environment, which a specific project implemented in.

The concept of “car-free city” incorporates a wide spectrum of project solutions from a total ban on cars to only limitation [2]. If to consider the most general case, the positive/negative outcomes of the project can be attributed to environmental, social and economic components (Table 1).

The central element for efficiency assessment is, of course, the environmental impacts to be reduced by implementation of such project.

According to statistics, cars of the world are already emitting more than 400 million tons of carbon oxides, 100 million tons of hydrocarbons, hundreds of thousands of tons of lead and many other harmful compounds every year. It should not be forgotten that they consume a lot of oxygen, from 100 to 200 times more than that consumed by one person.

There are few important factors, which increase the magnitude of transport impacts on the environmental and human health in the end:

a) the activity of the bulk of road transport is concentrated in places with high population – cities, industrial centers;

b) harmful emissions from cars are delivered in the lowest, ground level of the atmosphere, which is the level of the basic living activity;

Table 1

SWOT-analysis of "car-free city" project

Strengths	Weaknesses
– improving the environmental situation; – increased incomes to local budget;	– long process; – inconvenience during project implementation; – additional load of the nearness roads; – additional costs;
Opportunities	**Threats**
– stimulating the urban population to more active lifestyle; – encouraging use of environmentally friendly vehicles or urban vehicles; – expansion of green spaces or recreation facilities at the released land;	– congestion of adjacent roads; – opposition from population.

c) exhaust gases from car engines contain highly concentrated toxic components, which are major pollutants of the atmosphere.

Also transport is one of the largest sources of greenhouse gas emissions due to burning fossil fuels, which are mostly primarily based and produce noticeable amounts of carbon dioxide and relatively small amounts of methane and nitrous oxides and hydrofluorocarbon (they result from the use of mobile air conditioners and refrigerated transport), which makes road transport responsible for almost 11– of greenhouse emissions [3]. In line with climate issues, traffic-related emissions contribute to the formation of urban smog and acid rains.

Another problem with cars that only happens in cities is thermal pollution, as heat generated by transport falls into the "trap" due to poor ventilation (ventilated urban canyons) and forms so called urban heat island [4].

Motor vehicles emit heavy metals such as nickel, mercury, chromium, cadmium, zinc, iron, arsenic, manganese, and beryllium. Among them arsenic, mercury, cadmium and lead are highly toxic in very low concentrations. The accumulation of heavy metals in soils changes their chemical and biological properties. Metals accumulate in living organisms and enter the food chains. Although heavy metals can remain in atmospheric air for up to 10 days and can be transported up to 2000 km the, most of the traffic related pollution resides along the roads [5]. This impedes the economic use of roadside lands, but also complicates the cultivation of protective green spaces in cities.

Some components of pollution are dissolved and penetrate to groundwater and then enter rivers and with drinking water can enter the human body. Thus, the Environmental Protection Agency estimates that up to 1/2 of suspended solids and 1/6 of hydrocarbons reaching streams originate from freeways. Vehicle-related particulates in highway runoff mostly come from tire and pavement wear (1/3 each), engine and brake wear (20–), and emissions (8–) [6].

In addition, operating motor vehicle disc brakes contribute heavy metals to non-point source pollution. Disc brakes are open to the environment, so each time semi-metallic brake pads squeeze against the wheels' rotors, tiny amounts of metal dust, often copper, but sometimes also zinc and lead, are deposited along the roadway and washed to water bodies by rain or snow. While used oil and used coolant/antifreeze pollution mostly affect surface waters, gasoline spills from leaking underground storage tanks are a major source of groundwater pollution [7].

The most common environmental problem of transport widely assessed by scholars and authorities is of course noise pollution. Large volume of collected data state, that road noise is still the dominant source affecting human exposure above the 55 dB action levels with around 100 million people exposed in EU [8].

Thus, the environmental efficiency of the projects involving any form of traffic limitation inside the urban territory is provided by the direct changes: reduction of emissions and noise pollution, as well as land use improvement through making land previously occupied by transport infrastructure available for any green spaces expansion or social activity and recreation facilities. The economic benefits are indirect and reflect the monetary equivalent of the environmental gains, as well as increased incomes due to usage of public transport and improved health of the residents.

The major physical parameter necessary for the assessment of air and noise pollution mitigation before and after the project implementation is traffic intensity. Traffic intensity is the number of vehicles that passed the cross-section of the street or roads per unit of time. It can be expressed in actual units (auto/hour), as well as in consolidated units (one hour) when traffic flow is reduced to a conditional car on the basis of comparison of the dynamic dimensions of the vehicles. Next the value of traffic intensity is used to define potential reduction of emissions by major components and noise levels. The corresponding parameters are expressed in monetary values using state regulations of the cost of emissions and health effects from noise exposure.

The area released due to traffic reorganization could be evaluated based on the direct cost of land typical for the area under consideration.

The incomes to the local budget might come from increased use of public transport and payment

for interception parking, as well as development of recreational and tourist activity at these territories.

The drawbacks of such projects are of organizational and economic nature as well. Thus, there will be a need for investments into expansion of parking areas and reorganization of traffic at the adjoining roads. The administrative steps are also time-consuming, as the submitted project must be evaluated by authorities. For this, the managing authority should set up a commission consisting of, in particular, a representative of the Police and a representative of the road management and consult an expert, auditor or expert on the impact of planned traffic organization on its safety, and also consult an expert on the impact of the planned traffic organization on the environment. After considering the submitted traffic organization project, the traffic management authority may approve the traffic organization in whole or in part. The final element in the "negative" group of factors is the need to invest efforts and costs into building public consent on the reduced traffic permeability of the territory, which inevitably leads to limitation of residents comfort and time management.

The bottom line of these factors is not completely represented in monetary units, but the evaluation will be in favor of the project implementation. To approbate the offered model of environmental and economic efficiency assessment the city of Opole was chosen.

Results and discussions. Opole is the capital of the Opolskie Voivodship situated in the south of Poland, near the border with the Czech Republic (Trzebinia-Bartulovice – 54 km) and Germany (Olszyna – 240 km). It occupies the area of 96 km^2 and has 126 000 residents (approx. 12 – of the population of the voivodship), together with adjacent communes, it comprises an urban agglomeration inhabited by over 262 000 people. The population density is approximately 1 350 people/km^2.

The city of Opole is a developed industrial center: it has one of the highest entrepreneurship indexes among Polish cities – 162 enterprises per 1 thousand inhabitants. As a result, Opole is characterized by a large percentage of professionally active people (over 49 thousand) and young people, making 36 percent of the total Opole population. Such an intensive activity has its unavoidable pressure on the environment, being significantly transformed by now.

Opole is located in the Silesian Lowland which is joined to the Odra valley and Pradolina Wrocławska, occupying most of the city's area, and extends to the east the Opole Plain and to the west the Niemodlin Plain. Opole is one of the warmest cities in Poland with mild climate, suitable for rest and recreation.

The natural system of Opole includes the areas of the city's ecological corridors stretching along the Odra River, areas of urban arranged and unorganized green spaces and water reservoirs. There are valuable natural areas in the city of Opole, including monuments of nature and grasslands.

Opole has convenient railway, international highway and airport connections. Urban transport is also developing on a stable basis. An example of this is the installation of vending machines for public transport tickets near each bus stop in this year and the purchasing of electric buses. The quality of roads is improving as well. In recent years, the bicycle rental facilities have also appeared.

One of the problems in the city is the large number of cars. This is due to the poorly developed urban transport infrastructure on the outskirts of Opole, consequently residents are forced to use the car to get to work in the city of Opole (every day, a large proportion of visitors come from neighboring settlements).

The second problem is low number of quality bike paths. In general, there are 43 paths in Opole with a total length of 35 km, which is not enough for a city with the area near 96 km². In addition, most of these tracks are mixed with pedestrian paths, making it difficult to travel.

Another issue is parking. In Opole city has two parking zone with over 3000 places for parking and 123 parking meters. Despite the fact that the parking is paid in the central part of the city, the location of the parking spaces is complicated by narrow roads, leading to blocking of the pedestrian sidewalk and roadway, which worsen pedestrian passage and traffic in many areas of the city.

The environment degradation under the influence of traffic is quite considerable: over the last 5 years the particulate matter PM10 and benz-a-pyrene concentrations exceeded standards [9]. Noise pollution in Opole is also a serious problem: the area with noise levels over the standards is 1 194 km^2 and it is inhabited by 11 608 people.

Having considered the major transportation issues and environmental problems of the city of Opole, it is proposed to limit the entry of transport into the city center by blocking several sections of the highway. These are the streets of Rynek (Ratusza), plac Świetego Sebastiana, ul. Edmunda Osmańczyka, Mały Rynek – Staromiejska, Mały Rynek – Muzealna (Fig.1).

Selected streets provide entering and leaving the center. By blocking streets for private transport it is possible to make this area free of cars – except for special services. It is important to emphasize that this area is historic, which is why it is a very popular destination for both tourists and residents of the city. Also it is located within residential buildings, which are very close to the selected highways. There are no green areas in the area. The proposed restrictions, in the first place, will help to reduce the impact of road transport (in the form of air and noise pollution) on residents and users (pedestrians) of the territory.

The released roads are planned to be converted into bike lanes, bicycle parking, and areas for landscaping and recreation. At the same time, parking spaces outside the city center should be made 1.5 times more

Fig. 1. The cars-free area proposed for Opole

expensive – so that it is not profitable to use the car. To improve the car parking situation it is offered to build underground and aboveground parking spaces. It is important to improve urban transport on the outskirts of the city and its neighboring settlements, including development of new ways, introduction of new stops and bus routes for easy transportation of residents of the surrounding areas to the city.

To express the benefits of the project in monetary equivalent, the following parameters were defined: volume and cost of emissions reduction due to decreased traffic; level of noise reduction due to decreased traffic; cost of the newly released land areas in the city center; incomes to local budget from increased use of public transport.

For the purpose of economic calculation, accounting the diversity of car flow during a day, the intensity of traffic at these sections was defined in the morning, afternoon, and evening and recalculated to annual values. The traffic-related emissions of the following pollutants were calculated CO, NO_2, CH, soot, SO_2, formaldehyde and benz(a)pyrene. The economic efficiency was determined, multiplying the values obtained by the cost per ton of emissions [10].

Separate calculations were used for CO_2 with the assumption that a typical passenger vehicle emits about 4.6 metric tons of carbon dioxide per year. Thus, emissions of CO_2 make up 107566.86 ton/km per year.

Noise pollution was also measured on selected road sections and recalculated accounting the reduction of traffic flow. It should be noted, that noise pollution in the city center exceeds the acceptable level in all cases, especially on the Świetego Sebastiana plac. The economic costs of traffic noise were calculated on the basis of human's health recovery, using the methodology presented in [11].

Also, it is offered to introduce a minimum parking fee of 0.50 zł, which is equivalent to 15 minutes of parking. Funds from parking places will go to the state budget, just like money from additional use of public transport. The latter was calculated from the assumption that the residents, normally using cars in the center, switch to public transport.

The cost of released land was defined by summing up the area revealed and taking prices for 1 ha of land in Opole Voivodeship for 2019.

So, the total environmental and economic efficiency of the project (Table 2) is considerable. However, it will be flattened due to necessary expenses on public transport development, organization of bicycle route, project analysis and legal substantiation, as well as propaganda and information campaign.

Conclusions.

1. A car has become an integral part of our lives by this time. On the one side automobiles improve living conditions, but on the other hand it has led to severe environmental pollution affecting human health, contributing to climate change and degrading living conditions in cities. Thus, big cities suffer from smog, urban heat island and health deterioration.

2. There is a wide range of methods to be applied for the assessment of cars impacts on the environment. For the purposes of the given research the methods of traffic intensity and related emissions and noise pollution levels and approaches to the assessment of environmental and economic efficiency were considered. The parameters important for evaluation of environmental and economic efficiency of the "car-free city" projects were defined and methods of their assessment were offered.

3. Based on the considered examples of cities with limitations of traffic, the project of the car-free city for Opole was proposed. It involves blocking 6 main city center roads for private car entry, removing car parking spaces in the center, development of cycling network and creation of underground parking instead of old buildings. The released roads are to be converted into bike lanes, bicycle parking, and areas for landscaping and recreation.

4. To characterize the intensity of environmental pressure the traffic on the environment of Opole the annual emissions of pollutants and noise levels were established. The results of economic costs of the given impacts, that were calculated in terms of Ukrainian and Polish regularities show, that banning traffic on the selected streets will give economic benefits of over 26988734 UAH/year or 4374279 PLN/year.

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