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A MODEL FOR DETERMINING THE ENVIRONMENTAL INDICATORS OF BUS ROUTES AND OPTIMIZING THEM

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Abstract. This article looks at figuring out the environmental impact of city bus routes, checking how current transport affects the environment, and making them more eco-friendly. The study goes over things like route length, bus speed, number of stops, passenger flow, fuel usage, traffic jams, and the condition of the buses to see how they influence the release of harmful substances into the air. It suggests creating a combined indicator that considers fuel use and emissions to gauge environmental performance.

Keywords: bus route, environmental indicator, emission, fuel consumption, route optimization, passenger flow, environmental performance, city transport.

The assessment of the environmental efficiency of bus routes is important for the sustainable development of the urban transport system. In cities, as the daily mobility needs of the population increase, the intensity of vehicle use is also increasing. Although buses, as a means of mass passenger transport, allow reducing emissions per passenger compared to individual cars, their technical condition, fuel type, driving mode and route organization have a significant impact on environmental results.

It is not enough to assess the environmental performance of a bus route solely by the amount of gases emitted into the atmosphere. A comprehensive assessment should also take into account indicators such as fuel consumption, fuel consumption per passenger, route length, duration of stops, the share of traffic in traffic jams, average bus load and technical condition of the vehicle.

Therefore, the environmental efficiency of a bus route can be expressed by the following general index:

$$E = w_1E_1 + w_2E_2 + w_3E_3 + w_4E_4 + w_5E_5$$

where:

E is the comprehensive environmental efficiency index of the route;

E_1 is the fuel consumption indicator;

E_2 is the harmful emissions indicator;

E_3 is the emissions per passenger;

E_4 is the waiting time at stops;

E_5 is the traffic flow congestion level;

w_1–w_5 are the weight coefficients of the relevant indicators.

Weight coefficients can be determined by expert assessment, statistical data, or multi-criteria decision-making methods. This approach allows routes to be evaluated not only on the basis of one criterion, but on the basis of several factors that determine environmental efficiency[5].

To determine the environmental status of a bus route, the real operating mode of the vehicle along the route is first studied. In this case, the route length, number of daily trips, average speed, number of stops, passenger flow and fuel consumption are determined.

For example, let's assume that there is a 20 km long bus route. On this route, one bus makes a full trip 10 times a day. Therefore, the daily distance traveled by the bus:

$L = 20 \times 10 = 200$ km.

If the average fuel consumption of the bus is 28 liters per 100 km, the daily fuel consumption:

$F = 200 \times 28 / 100 = 56$ liters.

If 8 buses operate on this route, the total daily fuel consumption:

$F_u = 56 \times 8 = 448$ liters.

This indicator can be used as a basis for a preliminary assessment of the environmental impact of a route[3].

However, buses do not always consume the same amount of fuel. For example, frequent stops and starts during traffic jams increase fuel consumption. On the contrary, uniform movement during relatively free traffic flow can reduce fuel consumption.

Therefore, in the environmental analysis, it is advisable to determine the consumption in the “stop-to-stop” section, along with the average fuel consumption. This method allows you to determine which parts of the route have the highest environmental impact.

When determining the environmental impact of buses, the amount of the main pollutants emitted into the atmosphere is important - carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NOx) and particulate matter (PM).

The following formula can be used for a simplified calculation of emissions:

$M = F \times EF$,

where:

M is the mass of the emitted substance;

F is the amount of fuel consumed;

EF is the emission coefficient of the fuel.

For example, when calculating CO_2 emissions for a route with a conditional consumption of 448 liters of fuel, a coefficient of 2.6 kg of CO_2 equivalent per liter of fuel is assumed. Then:

$MCO_2 = 448 \times 2.6 = 1164.8$ kg.

Thus, approximately 1164.8 kg of CO_2 equivalent can be generated per day along this conditional route.

This calculation is considered only as a methodological example. In practical research, calculations based on the actual fuel type, engine technology, manufacturer's specifications or relevant emission coefficients are required.

One of the most important indicators in determining the environmental efficiency of a route is the emission per passenger.

For example, if an average of 4,000 passengers use the above route per day and the daily CO_2 emission is 1,164.8 kg, the emission per passenger is:

$E_i = 1,164.8 / 4,000 = 0.2912$ kg.

That is, one passenger conditionally emits 0.291 kg of CO_2 equivalent.

If the number of passengers on the route increases by 6,000, the environmental load per passenger, assuming that fuel consumption remains unchanged, is:

E_i = 1,164.8 / 6,000 = 0.194 kg.

This example shows that the level of bus loading directly affects environmental efficiency. Therefore, environmental optimization of transport is not only about reducing the number of buses. On the contrary, it is also important to correctly distribute the flow of passengers and ensure optimal loading of buses[5].

One of the main factors that reduces the environmental efficiency of bus routes is excessive waiting at stops. Long waiting times at stops can increase fuel consumption and emissions when the engine is running.

For example, if there are 25 stops on the route and the average waiting time at each stop is 40 seconds, the waiting time at stops during one full trip is:

T = 25 × 40 = 1000 seconds, which is approximately 16.7 minutes.

If, by analyzing passenger flow based on data from the electronic ticket system, it is possible to reduce the average waiting time at stops from 40 seconds to 30 seconds, the total time will be:

T_2 = 25 × 30 = 750 seconds, i.e. 12.5 minutes.

As a result, approximately 4.2 minutes of time will be saved per trip. Considering several buses and many daily trips, even such a small change can affect the overall fuel consumption.

Traffic jams have a similar effect. In traffic jams, the bus is forced to accelerate and decelerate frequently. This reduces the energy efficiency of the movement. Therefore, when optimizing routes, it is important to choose not only the shortest geographical route, but also the one with the most stable traffic flow.

A multi-criteria mathematical model can be used to optimize routes in an ecological way. The main objective of the model is to minimize fuel consumption and environmental emissions while maintaining the quality of passenger service.

The objective function can be expressed as follows:

$\text{Min } Z = \alpha F + \beta M + \gamma T + \delta D$

where:

Z is the general objective function of optimization;

F is the total fuel consumption;

M is the emission of harmful substances;

T is the time lost at stops and in traffic jams;

D is the excess distance traveled along the route;

α, β, γ, δ are the weight coefficients of the criteria.

The following constraints are introduced into the model:

passenger demand for transport is satisfied;

the capacity of the buses is not exceeded;

the interval between trips is within the specified limit;

the number of buses does not exceed the available parking space;

the maximum length of the route does not exceed the specified norm;

the time taken for passengers to reach the stop and wait is acceptable.

The advantage of this model is that the economic and environmental aspects of the transport system are taken into account at the same time.

Suppose that in a city there are three alternative routes from A to B:

Route 1: 18 km, average speed 24 km/h, 20 stops;

Route 2: 21 km, average speed 29 km/h, 17 stops;

Route 3: 24 km, average speed 34 km/h, 14 stops.

At first glance, the most optimal option seems to be route 1, because it is the shortest. However, the environmental assessment should take into account not only the distance, but also the speed, number of stops and the level of traffic congestion.

For example, if route 1 passes through a congested area and the bus is forced to stop and start frequently, its fuel consumption may be 30 liters per 100 km. Although route 2 is longer, its consumption may be 26 liters/100 km due to better traffic conditions. On route 3, although the consumption is 25 liters/100 km due to the greater length of the road, the total fuel consumption may increase.

Thus, when choosing the optimal route, it is advisable to use the principle of “the route with the least environmental and energy costs” instead of the principle of “the shortest route”[3].

An excessive number of buses can also lead to environmental problems. Because the operation of underloaded buses during periods of low demand increases emissions per passenger.

For example, during peak hours, 600 passengers use the route per hour. If the effective capacity of each bus is 75 passengers, theoretically:

$N = 600 / 75 = 8$ buses/hour

is required.

If 12 buses operate during this period, some buses may not be fully loaded. This will result in overcrowding. Conversely, during off-peak periods, 4–5 buses may be sufficient.

Therefore, instead of keeping the number of buses constant throughout the day, it is more environmentally efficient to dynamically control the number of buses in accordance with changes in passenger flow.

The use of GPS, electronic ticketing, video surveillance, passenger flow calculation systems and intelligent transport systems in modern transport systems creates great opportunities for environmental optimization of routes.

For example, using GPS data, the real-time speed of each bus, stops and time spent in traffic jams are determined. An electronic payment system can show how many passengers got on or off at which stop.

By combining this data into a single information system, it is possible to create an environmental “map” of the route. In this case, red zones represent sections with high fuel consumption and emissions, and green zones represent relatively environmentally friendly sections.

For example, if buses constantly travel at a speed of 10–15 km/h for 5–8 km of a certain route, this section is designated as an ecologically problematic zone. Later, special measures can be proposed for this section - the creation of a dedicated lane for buses, coordination of traffic lights or changing the route scheme.

Optimizing bus routes based on ecological criteria can achieve several positive effects. Firstly, reducing fuel consumption will reduce the operating costs of transport enterprises.

Secondly, reducing the amount of harmful emissions will have a positive effect on the quality of urban air.

Thirdly, optimizing the bus travel time and frequency will improve the quality of service provided to passengers.

As a conditional example, let's take the above 448 liters of daily fuel consumption. If the fuel consumption is reduced by 10 percent as a result of route optimization:

448 × 0.10 = 44.8 liters

of fuel will be saved.

Then the new daily consumption will be:

448 – 44.8 = 403.2 liters.

If this result is maintained for 300 working days during the year, the conditional annual savings will be:

44.8 × 300 = 13,440 liters

of fuel.

This indicator can be a significant result for a transport company, both economically and environmentally[4].

In general, three main areas of ecological optimization of bus routes should complement each other: optimizing the route network, increasing the efficiency of vehicle use, and introducing digital monitoring systems. Such an integrated approach will create an opportunity to reduce the environmental load while maintaining the existing level of transport service.

Also, in the future, expanding the use of electric buses, vehicles running on gas or other alternative energy sources may be one of the important areas of increasing ecological efficiency. However, when choosing such technologies, it is necessary to comprehensively assess not only the environmental characteristics of the vehicle, but also the infrastructure, energy supply, operating costs, and real operating conditions of the route.

Thus, the model for determining and optimizing the environmental indicators of bus routes allows for scientifically based decisions in managing the transport system. The model analyzes fuel consumption, emissions, passenger flow, route length, number of stops, speed, and traffic congestion in an interdependent manner. As a result, it is possible to achieve a combination of economic efficiency and environmental sustainability of urban transport.

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