Mathematical modeling of transportation problems related to freight movements

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Abstract. This paper, prepared for conference presentation, examines mathematical models used to optimize transportation processes within logistics systems. Planning the movement of goods from production points to consumption points plays a crucial role in ensuring economic efficiency. The study analyzes the mathematical structure of the transportation problem, its solution methods, and major fields of application. It is demonstrated that mathematical modeling enables the minimization of transport costs and the optimal allocation of available resources in logistics systems.

Keywords: Freight transportation, logistics, transportation problem, mathematical modeling, optimization methods

Introduction

Logistics plays a significant role in the development of modern economic systems. It encompasses the planning, management, and control of product flows from production facilities to end consumers. One of the principal challenges in this process is ensuring that goods are delivered through optimal routes at minimum cost. Mathematical modeling methods are widely applied to solve such problems in logistics systems. These approaches facilitate the optimization of transportation and distribution processes and contribute to higher economic efficiency.

1. Transportation Problems in Logistics Systems

The movement of goods within logistics systems requires properly structured connections between various locations. Supply points, demand points, transportation routes, and shipping costs constitute the main components of such systems. Effective planning of transportation operations reduces logistics expenditures and improves the efficient use of resources.

2. Mathematical Model of the Transportation Problem

One of the most widely used models for solving transportation problems in logistics is the classical transportation model. It determines the optimal allocation of goods from several supply points to several demand points.

Parameters:

- (a_i) – quantity of goods available at the *i-th* supply point
- (b_j) – demand of the *j-th* consumption point
- (c_ij) – transportation cost from point *i* to point *j*

3. Decision Variable:

- (x_{ij}) – quantity transported from point *i* to point *j*

The objective function seeks to minimize total transportation costs. Through this model, the optimal distribution of products within the logistics network can be determined.

4. Methods for Solving the Transportation Problem

Several techniques are used to solve transportation problems. These methods help construct an initial feasible solution and identify the optimal plan.

- Northwest Corner Method – used to generate an initial feasible allocation.
- Least Cost Method – begins with routes having the lowest transportation cost.
- Vogel's Approximation Method – provides an initial solution closer to optimality.
- Potential (MODI) Method – used to test whether the current solution is optimal.

5. Applications of Logistics Models

Mathematical modeling is widely applied in logistics and transportation systems. These models are used in industrial logistics, warehouse and distribution systems, international trade, and the planning of transportation networks.

6. *Conclusion*

Mathematical modeling of logistics transportation problems plays an essential role in the management of modern logistics systems. Mathematical models make it possible to determine optimal freight distribution plans and minimize transportation costs. Therefore, the application of optimization techniques is of great importance for the future development of logistics systems.

7. *Example: A Sustainable Urban Transport Model*

Principle 1: Transit-Oriented Urban Development

An examination of Baku's population density and urban structure indicates that the central districts are not suitable for extensive private car use. At the same time, low-density suburban expansion encourages dependence on private automobiles and creates substantial transport difficulties.

From the perspective of sustainable mobility, urban development should follow the paradigm of Transit-Oriented Development (TOD). TOD is one of the fundamental principles of sustainable transportation. It promotes multifunctional and mixed land use by integrating residential, commercial, educational, cultural, and other urban functions. It also ensures convenient access to public transport while creating favorable conditions for walking and cycling.

Transport hubs such as railway or metro stations are central to TOD. These nodes should be pedestrian-accessible, and public transport should generally be located within 400–800 meters of residential areas.

During the early Soviet period, Baku developed in ways broadly consistent with modern TOD principles. However, from the 1960s onward, mixed-use planning gradually declined, and monofunctional residential microdistricts were constructed. Although these areas remained relatively public transport-oriented because car ownership was low, more recent suburban growth has produced low-density settlements highly dependent on private cars or low-quality bus services.

Future development in Baku should incorporate TOD principles more systematically.

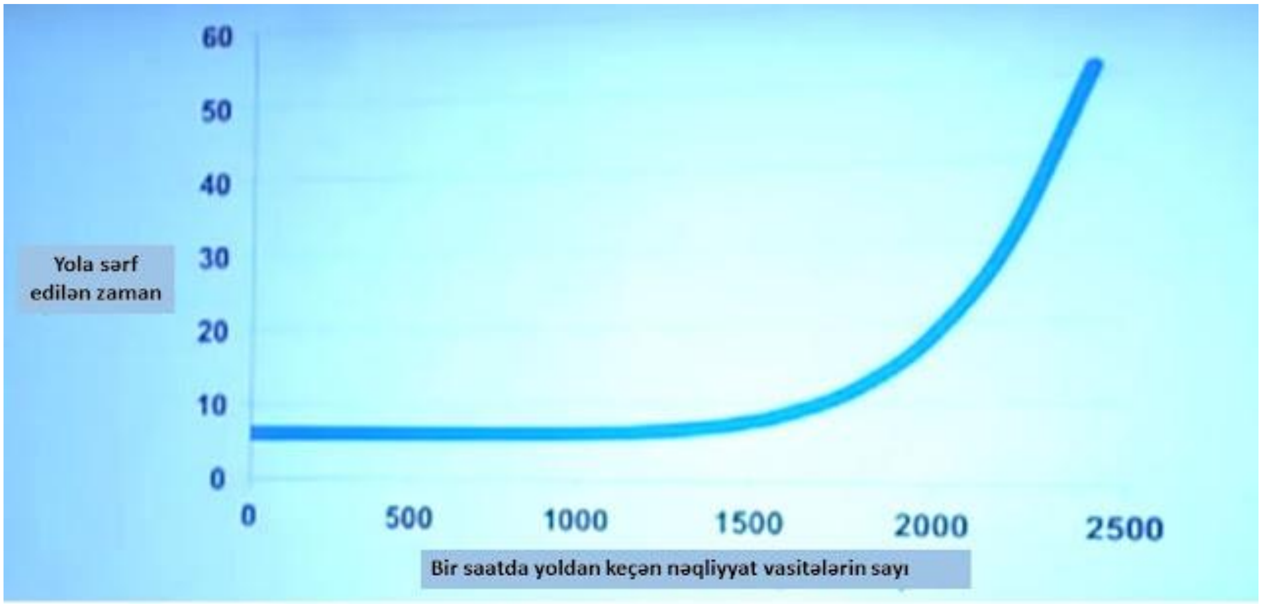
Principle 2: Optimization of the Urban Road Network and Its Use

Most cities around the world experience traffic congestion. A common intuitive response is to build more roads; however, road expansion does not always produce positive long-term outcomes.

Modern transport research, including the Lewis–Mogridge position, suggests that newly built roads often generate only short-term relief. Rising traffic volumes soon absorb additional capacity. In many cases, new road infrastructure merely shifts congestion from one location to another.

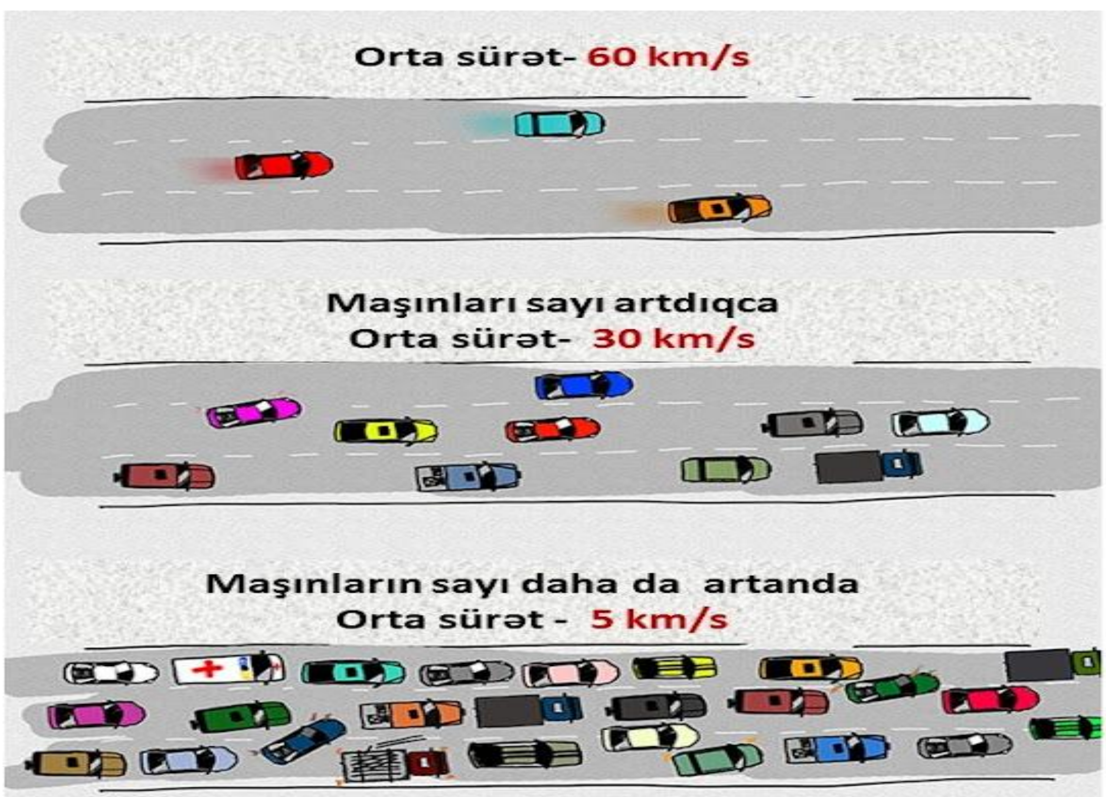
Economics describes this phenomenon as induced demand**.** British researchers identified this effect in the 1960s: new or expanded roads encourage greater traffic volumes and increase dependence on private automobiles.

When driving becomes easier, urban sprawl expands, making distant suburban housing more attractive. Yet uncontrolled urban expansion is generally undesirable.



Interestingly, reducing road capacity can also lower traffic demand. Consequently, narrowing certain roads and allocating dedicated lanes for public transport may significantly reduce congestion.

Another important characteristic of road systems is that when too many vehicles enter the network, traffic speed decreases disproportionately. As the number of users rises, road efficiency falls sharply.



Thus, attempting to solve congestion solely through road construction resembles trying to extinguish fire with gasoline. Sustainable transport modes must therefore be strengthened.

Principle 3: Promotion of Walking and Cycling

The third principle of sustainable urban mobility is the promotion of pedestrian movement and bicycle use.

The concept of a livable city rejects automobile-dominated urban design and instead creates environments that prioritize pedestrians, cyclists, and public transport users. Streets should first function as public spaces and only secondarily as transport corridors.

In a livable city, accessible infrastructure should be created for all pedestrians, especially persons with reduced mobility. This includes:

- wide and comfortable sidewalks;
- barrier-free environments;
- cycling lanes;
- safe crossings.

When streets become more active and people-oriented, local businesses such as shops, food services, and other enterprises also benefit, thereby stimulating urban economic growth.

At present, Baku still lacks adequate conditions for pedestrians and cyclists:

- sidewalks are often unsuitable for walking;
- barriers are excessive;
- cars are parked on sidewalks;
- pedestrians are forced to use underpasses or overpasses;
- some crossings are unsafe or poorly located;
- elderly people, persons with disabilities, and parents with strollers face particular difficulties;
- bicycle lanes are largely absent, making cycling unsafe.

Baku’s approach to pedestrian and cycling infrastructure should therefore change substantially:

- create wide sidewalks, barrier-free environments, and safe crossings;
- prevent vehicles from entering sidewalks through physical barriers;
- apply high-quality street design standards;
- introduce traffic calming measures on selected streets;
- establish a complete cycling network.

On Underground and Overground Crossings

Urban streets are public spaces where pedestrian movement should be natural and convenient. Requiring people to descend and climb multiple levels simply to cross a street creates unnecessary barriers.

Older adults, persons with disabilities, and caregivers with strollers often cannot use such facilities effectively. Furthermore, crossings are commonly spaced at intervals of approximately 500 meters, which may be excessive for vulnerable users.

Human behavior naturally favors the shortest and easiest route. As a result, grade-separated crossings may paradoxically create more dangerous at-grade crossing behavior nearby.

Principle 4: Regulation of Private Car Use

The fourth principle of sustainable urban transport is the regulation of private automobile use.

Since the 1980s, transport research has increasingly concluded that private car travel is one of the least efficient forms of mobility from an economic perspective. In addition to direct user expenses, automobile use imposes substantial external costs on society.

Direct Costs for Car Owners

- fuel expenses;
- parking fees (often below true market cost);
- maintenance and depreciation;
- taxes and insurance.

Publicly Financed Costs

- road construction, repair, and maintenance;
- traffic management systems;
- traffic police and enforcement services.

External Social Costs

- congestion;
- noise pollution;
- air pollution;
- deterioration of the urban environment due to roads and parking areas;
- reduced pedestrian accessibility.

These impacts have real economic value. Roads are financed through taxation, congestion wastes citizens' time, and law enforcement requires public expenditure. Some costs, such as reduced urban quality and obstacles to walking, are more difficult to quantify but remain socially significant.

Parking infrastructure requires large amounts of land, which is among the most limited resources in cities. It is expensive to provide and often damages the urban environment.

Although in Baku private automobiles account for only a minority of daily trips, a disproportionately large share of street space is allocated to them. For this reason, many cities regulate car use through three principal approaches:

1.Administrative Measures

Some cities, such as Singapore, regulate vehicle ownership directly or limit new registrations. Others restrict daily use through license-plate rotation systems.

2. Infrastructure Measures

Cities may reduce road space, remove parking spaces, and create pedestrian zones, thereby physically limiting room for cars.

3. Economic Measures

These include paid parking systems and congestion charging for entry into city centers. Economic instruments are widely regarded as among the most effective regulatory mechanisms.

REFERENCES

1. Hillier, F., & Lieberman, G. *Introduction to Operations Research.*
2. Taha, H. *Operations Research: An Introduction.*
3. Winston, W. *Operations Research: Applications and Algorithms.*
4. Chopra, S., & Meindl, P. *Supply Chain Management.*
5. Sharifov, R. *Logistics and Transportation Systems.*