SOLVING DATA INTERACTION PROBLEMS IN INFORMATION SYSTEMS OF FREIGHT TRANSPORT LOGISTICS IN UZBEKISTAN

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Abstract.
The article examines the problems of integrating heterogeneous data in information systems of international road freight transportation in Uzbekistan. A comparative analysis of evolutionary route optimization algorithms is carried out, including genetic algorithms, differential evolution, ant colony optimization, and local search methods. A conceptual model for applying hybrid evolutionary algorithms to optimize logistics processes in the agro-industrial complex of the Samarkand region is proposed, taking into account the seasonality of perishable goods transportation.

Keywords: genetic algorithms, differential evolution, heterogeneous data, transport logistics, Uzbekistan.

Freight transportation in Uzbekistan faces critical challenges, including the heterogeneity of information systems and the lack of unified mechanisms for data integration among participants in logistics chains [1, 9]. Incompatibility of message formats, differences in data semantics, and heterogeneous communication protocols significantly hinder effective interaction between carriers, customs authorities, and trade partners.

To exchange structured logistics information, standards such as EDI and UN/EDIFACT are widely used, along with modern digital solutions including e-TIR and e-CMR, which provide electronic support for transport operations [3, 11]. However, these standards do not address the problem of intelligent route optimization and therefore require integration with analytical and computational modules.

Evolutionary algorithms, in particular genetic algorithms (GA) and differential evolution (DE), have proven to be effective methods for solving complex combinatorial optimization problems, including vehicle routing problems [2, 7, 8]. Recent studies indicate that the application of evolutionary approaches makes it possible to accelerate convergence and improve solution quality by 5–6% compared to traditional heuristics [2, 6].

The aim of this study is to develop a comprehensive approach to solving data interaction problems in transport information systems based on evolutionary optimization algorithms, taking into account the specific features of the agro-industrial complex of the Samarkand region.

Modern transport and logistics systems operate under conditions of diverse data formats and heterogeneous data sources, which necessitates a formalized description of transportation planning processes [5]. As a basic mathematical model, the Vehicle Routing Problem (VRP) is used, which is aimed at minimizing total transportation costs [6].

The objective function of the VRP can be expressed as follows:

$$min\ D = \Sigma\, d_{ij} \times x_{ij}, \quad (1)$$

where d_{ij} - denotes the distance or transportation cost between nodes i and j;

$x_{ij} \in \{0,1\}$ - a binary decision variable that equals 1 if nodes i and j are connected by a route, and 0 otherwise.

The VRP belongs to the class of NP-hard problems [6]; therefore, the application of exact solution methods becomes computationally inefficient as the number of nodes increases. In practical information systems, metaheuristic optimization methods are widely used to solve medium- and large-scale problems [7].

Genetic algorithms are based on the principles of natural selection and evolution and are widely applied to solve routing problems [2, 7]. A solution is encoded as an integer chromosome, where:

0 denotes the depot;

values from 1 to n correspond to delivery nodes;

additional separators are used to form individual routes.

The most commonly used crossover operators are Order Crossover (OX) and Edge Recombination Crossover (ERX), which preserve route structure and ensure solution feasibility [7].

Differential evolution was originally developed for continuous optimization problems. Mutation is performed according to the following formula:

$$v_i = x_{r1} + F \times (x_{r2} - x_{r3}), \quad (2)$$

where F ∈ [0, 2] is the scaling factor.

Local search methods are applied either as standalone heuristics or as components of hybrid algorithms. They are based on local route transformations (such as 2-opt, 3-

opt, and their modifications) and are characterized by high computational efficiency; however, they are sensitive to the initial solution and prone to being trapped in local optima [6].

Table 1 presents the comparative characteristics of the studied route optimization algorithms.

Table1.

Comparative Characteristics of Route Optimization Algorithms

Algorithm	Computational Complexity	Gap from Optimum	GPU Acceleration	Dynamic Problems	Recommended Application
GA	O(g·p·n)	0.5–5%	Up to 561×	Yes	VRP, VRPTW
DE	O(g·p·n)	0.5–5%	Up to 400×	Yes	CVRP, heterogeneous data
ACO	$O(n^2 \cdot m \cdot t)$	0.5–5%	Up to 300×	High	Dynamic VRP
LS	$O(n^2 \cdot t)$	0–5%	Up to 200×	Partial	Local optimization

where ***g*** denotes the number of generations, ***p*** *is the population size,* ***n*** *is the number of nodes,* ***m*** *is the number of ants,* ***t*** *is the number of iterations.*

Table 2 presents the results of an experimental comparison of algorithm execution times depending on the problem size [6, 7].

Table 2

Algorithm execution time (seconds)

Number of nodes	GA	DE	ACO	LS
2	0,80	0,90	1,20	0,50
10	5,20	5,80	8,10	4,20
50	35,80	42,10	58,40	28,70
100	82,30	95,40	145,20	68,90

As can be seen from Table 2, when the number of nodes exceeds 100, genetic algorithms outperform the above-mentioned algorithms in terms of execution time due to their heuristic search strategy.

Table 3

Deviation from the optimal solution (%)

Number of nodes	GA	DE	ACO	LS
2	0,2	0,3	0,5	0,4
10	1,5	1,8	2,5	2,1
50	4,2	4,8	5,8	5,2
100	5,5	6,2	7,5	6,8

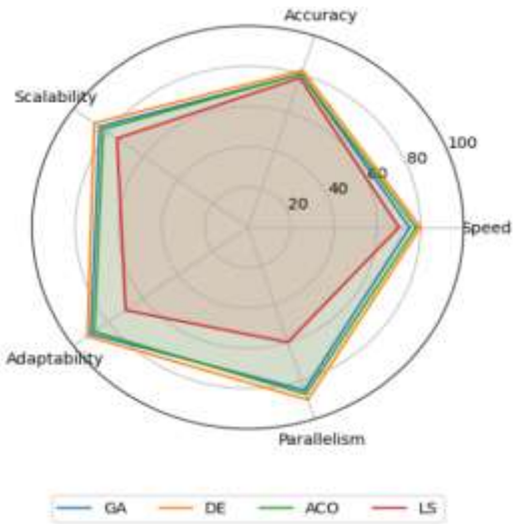

Figure 1. Multi-criteria comparison of optimization algorithms.

Table 4.

Comparative characteristics of the algorithms

Algorithm	Computational complexity	Gap	GPU acceleration	Dynamic capability
GA	O(g·p·n)	0.5–5%	561×	✓
DE	O(g·p·n)	0.5–5%	400×	✓
ACO	$O(n^2 \cdot m \cdot t)$	0.5–5%	300×	✓✓
LS	$O(n^2 \cdot t)$	0–5%	200×	△

In 2024, Uzbekistan transported 1.52 billion tons of cargo, of which 1.4 billion tons were carried by road transport [1, 9]. The international road freight market includes 483 carriers operating a fleet of approximately 11,000 trucks.

The Samarkand region is a leading agricultural producer in Uzbekistan, with vegetable production reaching 1.64 million tons in 2023 and potato production amounting to 632 thousand tons during the first nine months of 2025 [12, 13]. The region comprises 1.3

million hectares of agricultural land, with 7,188 farms organized into 44 agro-clusters. The population of the region is 4.137 million people, of whom 63% reside in rural areas.

Table 5

Geographical structure of Uzbekistan's fruit and vegetable exports (2024).

Country	Share of exports, %	Growth vs. 2024, %
Russia	42.1	+56
Kazakhstan	12.7	+67
Pakistan	12.6	+23
China	8.9	+45
Kyrgyzstan	5.2	+38
Other countries	18.5	+31

The proposed data integration system is based on a multi-level architecture [4, 5], which comprises three layers, as shown in Figure 2.

LEVEL 1: DATA SOURCES UN/EDIFACT (Europe) | e-TIR / e-CMR (Customs) | REST API (E-logistika) | E-Permit (KZ, TM, TR)
↓
LEVEL 2: INTEGRATION LAYER (ESB) Format transformation | Message routing | Schema validation | SCOR vocabulary
↓
LEVEL 3: GA+DE OPTIMIZATION MODULE VRPTW | Multi-depot | Heterogeneous vehicle fleet | Green VRP (CO_2) | Real-time adjustment (ACO)
↓
SYSTEM OUTPUTS Optimized routes (7,188 farms) | Delivery schedules (44 clusters) | KPI monitoring

Figure 2. Three-level architecture for heterogeneous data integration.

Table 6 presents an analysis of the compliance of the algorithms with the requirements of the agro-industrial complex.

Table 6

Compliance of algorithms with the requirements of the Samarkand region agro-industrial complex

Requirement	GA	DE	ACO	LS
VRPTW (time windows)	++	++	+	+
Perishable goods	++	+	±	±
Heterogeneous fleet	++	++	+	±
Multi-depot (agro-clusters)	++	+	++	±
Integration of heterogeneous data	+	++	±	–

where ++ high effectiveness; + good; ± satisfactory; − low

CONCLUSION

Addressing data interaction problems in the transport systems of Uzbekistan requires a comprehensive approach that integrates semantic interoperability, modern data exchange standards, and evolutionary optimization methods.

The specific characteristics of the agro-industrial complex of the Samarkand region—such as seasonality, perishable products, and limited cold-chain infrastructure—impose unique constraints on routing algorithms. Evolutionary algorithms outperform classical methods in medium- and large-scale problem instances: for cases with more than 100 delivery points, the deviation from the optimal solution reaches 20–30% for basic genetic algorithms, whereas it is reduced to 0.5–5% when hybrid approaches incorporating local search are applied.

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