

UDC 004.65:004.89:519.852

## MODELS AND ALGORITHMIC FRAMEWORK FOR INFORMATION EXCHANGE IN VIRTUAL PLATFORMS FOR LOCAL PRODUCT TRADING

*Jumaboev B.F.<sup>1</sup>*

<sup>1</sup> Tashkent University of Information Technologies named after Muhammad al-Khwarizmi, Tashkent, Uzbekistan

<sup>+</sup> jumaboevbehzod@gmail.com

**Abstract.** This study is devoted to modeling and optimizing information exchange processes in a virtual platform for local product trade. The research object is the information flow within the digital platform, while the subject is the database model and its algorithmic support. The aim is to develop an optimization model under multi-constraint conditions. ER modeling, relational database design, indexing techniques, algorithmic analysis, and mixed-integer linear programming (MILP) were applied. The Time-Driven ABC approach was used to define cost drivers. The proposed solution improves information retrieval efficiency and reduces operational costs in digital logistics systems.

**Keywords:** virtual platform, information exchange, database model, ER modeling, relational database, MILP, digital logistics, optimization algorithm.

### 1 INTRODUCTION

In the context of the digital economy, virtual trading platforms have become an important infrastructure for managing commercial and logistics processes. In particular, platforms supporting local product trade integrate producers, warehouses, distributors, and consumers into a unified digital environment. As transaction volumes increase and supply chains become more dynamic, operational efficiency increasingly depends on the quality, reliability, and speed of information exchange. Local product trade is characterized by seasonal production, fluctuating demand, distributed suppliers, and heterogeneous logistics conditions. These factors significantly complicate information flows within virtual platforms, where orders, inventory updates, delivery schedules, transportation costs, and warehouse capacities are interconnected through complex transactional processes. Any delay or inconsistency in information exchange can negatively affect operational efficiency, increase costs, and reduce service quality. Modern virtual platforms operate as multi-user transactional systems in which numerous operations are executed simultaneously. Ensuring data consistency, integrity, and real-time synchronization in such environments represents a major technical challenge. Relational database models remain the primary approach for organizing structured information in digital systems. The theoretical foundations of relational databases were introduced by Codd [1], while Chen developed the Entity–Relationship (ER) modeling approach for conceptual database design [2]. These models provide the structural basis for scalable transactional systems capable of supporting complex operational processes. Database infrastructures in digital trade platforms support key processes such as order management, inventory control, warehouse operations, and delivery coordination. Efficient management of these processes often requires mathematical optimization techniques capable of handling complex operational decisions. Optimization approaches such as vehicle routing and integer programming are widely applied in logistics planning and cost minimization problems [5]. The objective of this study is to develop a database model and algorithmic support that enable efficient information exchange processes within a virtual platform for local product trade.

Information retrieval systems research focuses on mechanisms for structured data collection, storage, indexing, and high-speed processing. With the rapid growth of digital trade ecosystems, virtual platforms generate large volumes of transactional data, making database architecture and query optimization essential for ensuring system scalability and performance [4]. Recent studies by Uzbek scholars address digital logistics, e-commerce platforms, and supply chain optimization. Yakubov M.S. analyzed distribution process optimization in digital logistics systems using mathematical modeling [8]. Xolmatov B.T. and Raxmonov D.S. examined the role of digital platforms in agricultural product distribution and demonstrated their efficiency in supporting local product trade [9]. Abdullayev S.A. and To‘xtasinov A.B. investigated transportation logistics and last-mile delivery challenges and proposed optimization approaches for improving delivery efficiency [10].

International research provides strong theoretical foundations for database systems and optimization models. The relational database model introduced by Codd established the basis for organizing structured data [1], while Chen’s Entity–Relationship (ER) model enabled conceptual database design [2]. Transactional reliability in multi-user systems is ensured through ACID properties described by Gray and Reuter [3]. Ramakrishnan and Gehrke demonstrated that indexing structures such as B-tree and composite indexes significantly improve query performance and system scalability [4]. In logistics optimization research, Toth and Vigo as well as Nemhauser and Wolsey developed theoretical frameworks for Mixed Integer Linear Programming (MILP), widely used for supply chain planning and operational decision-making [5, 6]. Supply chain planning processes operate at multiple decision levels, including strategic, tactical, and operational planning. These levels integrate procurement, production, distribution, and sales activities within a coordinated planning framework.

## 2 METHODOLOGY

The general structure of supply chain planning is illustrated in Figure 1.

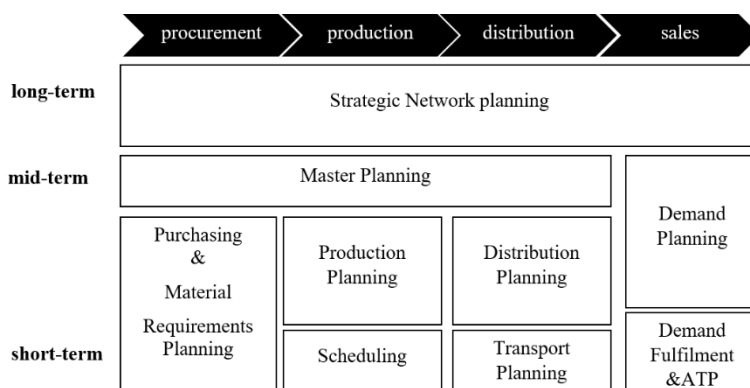


Fig. 1. Multi-level supply chain planning framework

The virtual trading platform is modeled as a multi-component information system consisting of a user interface layer, transaction processing module, database management system (DBMS), and analytical optimization module. The logistics structure of the virtual trading platform connects suppliers, warehouse facilities, and customers through inbound, warehousing, and outbound distribution processes. The general operational structure of this logistics network is presented in Figure 2. Operational planning is formulated as a Mixed Integer Linear Programming (MILP) optimization problem where binary variables represent activation decisions and integer variables represent product flows [6]. To parameterize the optimization model, the Time-Driven Activity-Based Costing (TD-ABC) approach is applied, where time-based operational parameters derived from transactional data serve as cost drivers [7]. The proposed methodology therefore enables an integrated framework for structured information exchange, efficient data retrieval, and cost-optimized operational planning in virtual local product trading platforms. To support operational decision-making in the virtual local-product trading platform, the information exchange and logistics processes were formulated as a Mixed Integer Linear Programming (MILP) optimization model.

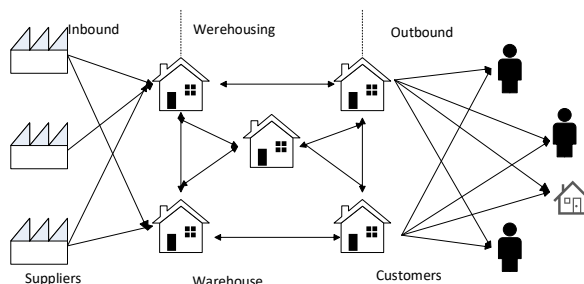


Fig. 2. Logistics network structure of the virtual local-product trading platform

The model determines optimal product allocation, warehouse operations, and shipment decisions over a multi-day planning horizon while minimizing total operational cost. The decision variables used in the optimization model are presented in Table 1. Binary variables represent activation of logistics operations, while integer variables represent product quantities or resource allocations.

The objective of the model is to minimize the total operational cost of the supply chain, including transportation costs, additional labor capacity, storage costs, and shortage penalties.

$$\text{minimize } z - \sum_{j=0}^J \sum_{z=0}^Z \sum_{k=0}^K \sum_{t=0}^T \sum_{d=0}^J Y_{jdk}^z \text{Transport}_{jdk}^z + \sum_{j=0}^J \sum_{z=0}^Z H_j^z \text{Work}_j^z + \sum_{j=0}^J \sum_{z=0}^Z \text{Inv}_j^z \text{Storage}_j + \sum_{i=0}^I \sum_{j=0}^J \sum_{z=0}^Z M \cdot N_{ij}^z. \quad (1)$$

The objective of the model is to minimize the total operational cost of the supply chain, including transportation costs, additional labor capacity, storage costs, and shortage penalties.

**Table 1.** Decision variables of the optimization model

Variables	Description
$Flow_{ij}^z$	Flow of product $i$ on warehouse $j$ on day $z$
$Y_{jdk}^z$	(=1) allow transfer from warehouse $j$ to $d$ for drop $k$ on day $z$ via $t$
$X_{djkt}^z$	(=1) receive drop $k$ on warehouse $j$ from $d$ , on day $z$ via $t$
$I_{ij}^z$	Pick to Stock of product $i$ on warehouse $j$ on day $z$
$Split_{ijdk}^z$	Split Stream of product $i$ of drop $k$
$Ship_{ijdk}^z$	Cumulative Split Stream of product $i$ of $k$
$O_{ij}^z$	Pick from Stock of product $i$ on warehouse $j$ on day $z$
$S_{ij}^z$	(=1) allow Pick to Stock of product $i$ on warehouse $j$ on day $z$
$N_{ij}^z$	Need of inventory of product $i$ on warehouse $j$ on day $z$
$H_j^z$	Additional working capacity at warehouse $j$ on day $z$
$R_{ija}^z$	Reception of product $i$ on warehouse $j$ on day $z$ from arrival $a$
$Inv_j^z$	Total inventory of warehouse $j$ on day $z$

The first component represents transportation costs, the second additional workforce costs, the third warehouse storage costs, and the fourth a penalty associated with potential inventory shortages:

$$Flow_{ij}^z = \sum_{a=0}^A R_{ijs}^z + \sum_{K=0}^K \sum_{d=0}^J \left( Ship_{ijdk}^z - \sum_{t=0}^T Y_{ijdk}^z * Q_{lk} \right), \quad \forall i, j, z. \quad (2)$$

A positive flow indicates that products remain available and must be allocated to inbound operations, while a negative value indicates that additional products must be retrieved from stock. Inbound operations allocate products either to warehouse stock or to the split stream:

$$\sum_{d=0}^J \sum_{k=0}^K Split_{ijdk}^z + I_{ij}^z \leq Flow_{ij}^z - M(1 - S_{ij}^z), \quad \forall i, j, z, \quad (3)$$

$$\sum_{d=0}^J \sum_{k=0}^K Split_{ijdk}^z + I_{ij}^z \geq Flow_{ij}^z + M(1 - S_{ij}^z), \quad \forall i, j, z, \quad (4)$$

$$\sum_{d=0}^J \sum_{k=0}^K Split_{ijdk}^z + I_{ij}^z \leq M \cdot S_{ij}^z, \quad \forall i, j, z. \quad (5)$$

Inbound operations allocate products either to warehouse stock or to the split stream:

$$O_{ij}^z \leq -Flow_{ij}^z + M \cdot S_{ij}^z, \quad \forall i, j, z, \quad (6)$$

$$O_{ij}^z \geq -Flow_{ij}^z - M \cdot S_{ij}^z, \quad \forall i, j, z, \quad (7)$$

$$O_{ij}^z \leq M(1 - S_{ij}^z), \quad \forall i, j, z. \quad (8)$$

If the material flow becomes negative, the required products must be retrieved from stock:

$$\sum_{l=0}^z (I_{ij}^l - O_{ij}^l) + N_{ij}^z + Inv_{ij}^z \geq 0, \quad \forall i, j, z, \quad (9)$$

$$\begin{aligned} \sum_{i=0}^I \left( \sum_{l=0}^z \left( \sum_{d=0}^J \sum_{k=0}^K \left( Split_{ijdk}^l - \sum_{t=0}^T Y_{jdk}^l * Q_{ik} \right) + \sum_{k=0}^K \sum_{t=0}^T \sum_{d:d \neq j}^J X_{djkt}^l * Q_{ik} + I_{ij}^l \right) + Inv_{ij}^z \right) = \\ = Inv_j^z, Inv_j^z \leq Cap_j, \quad \forall j, z. \end{aligned} \quad (10)$$

Warehouse inventory must remain non-negative and cannot exceed storage capacity:

$$\sum_{j=0}^J \sum_{z=0}^Z \sum_{t=0}^T Y_{jjkt}^z = 1, \quad \forall k, \quad (11)$$

$$\sum_{z=0}^Z \sum_{d=0}^J \sum_{t=0}^T Y_{jdkt}^z \leq 1, \quad \forall j, k, \quad (12)$$

each drop can only be assigned to a single warehouse and shipment operation:

$$\sum_{l=0}^z R_{ija}^l \leq \sum_{l=0}^z A_{ija}^l, \quad \forall i, j, a, z, \quad (13)$$

$$\sum_{z=0}^z R_{ija}^z = \sum_{z=0}^z A_{ija}^z, \quad \forall i, j, a, \quad (14)$$

split stream allocation is only allowed when shipment or transfer operations are scheduled:

$$\sum_{z=0}^Z Split_{ijdk}^z \leq \sum_{z=0}^Z \sum_{t=0}^T \left( Y_{jdkt}^z - \sum_{d:d \neq j} X_{djkt}^z \right) \cdot Q_{ik}, \quad \forall i, j, d, k, \quad (15)$$

$$Split_{ijdk}^z \leq \left( 1 - \sum_{l=0}^z \sum_{t=0}^T Y_{jdkt}^l \right) \cdot M, \quad \forall i, j, d, k, z, \quad (16)$$

$$Split_{ijdk}^z \leq 0, \quad \forall i, d, k, z, \forall j \neq h, \quad (17)$$

shipment aggregation constraints

$$\sum_{i=0}^l Ship_{ijdk}^z \leq M \cdot \sum_{t=0}^T Y_{ijkt}^z, \quad \forall j, d, k, z, \quad (18)$$

$$Ship_{ijdk}^z \geq \sum_{l=0}^z Split_{ijdk}^l + M \left( 1 - \sum_{t=0}^t Y_{idkt}^z \right) + \sum_{l=0}^z \sum_{t=0}^T \sum_{d:d \neq j} X_{djkt}^l * Q_{ik}, \quad \forall i, j, k, z, \quad (19)$$

$$Ship_{ijdk}^z \geq \sum_{l=0}^z Split_{ijdk}^l - M \left( 1 - \sum_{t=0}^t Y_{idkt}^z \right) + \sum_{l=0}^z \sum_{t=0}^T \sum_{d:d \neq j} X_{djkt}^l * Q_{ik}, \quad \forall i, j, k, z, \quad (20)$$

time constraints:

$$\Delta_{ijk}^z * Y_{jjkt}^z \leq D_k, \quad \forall j, z, k, t, \quad (21)$$

$$Y_{jdkt}^z = X_{djkt}^{z+\delta_{jd}}, \quad \forall j, z, k, t, d : d \neq j, \quad (22)$$

resource capacity constraints:

$$\sum_{l=0}^i \left( \sum_{a=0}^A (TR_{l0a} + TA_{l0a}^z) + TI_{l0}^z + \sum_{k=0}^K \sum_{d=0}^J \left( TSplit_{l0dk}^z + \sum_{t=0}^T (TY_{0dkt}^z + TX_{d0kt}^z) \right) \right) \leq W_0^z + H_0^z, \quad \forall z, \quad (23)$$

$$\sum_{l=0}^i \left( \sum_{a=0}^A CR_{ija}^z + CI_{ij}^z + CO_{ij}^z + \sum_{k=0}^K \sum_{d=0}^J \sum_{t=0}^T (CY_{jdkt}^z + CX_{djkt}^z) \right) \leq W_j^z + H_j^z, \quad \forall z, \forall j \neq h, \quad (24)$$

variable domain:

$$Var \geq 0, \quad \forall i, j, d, k, z, t. \quad (25)$$

### 3 RESULTS AND DISCUSSION

The proposed solution models information exchange in a virtual local-product trading platform as a structured pipeline where all interactions are processed through API-connected modules and a centralized transactional database. The process follows a general flow:

User → Request → API → Database → Processing → Response

Warehouse operations within the platform include product reception, stock allocation, order picking, packaging, and shipment processes. The operational workflow of warehouse stock management and order fulfillment is illustrated in Figure 3. To enhance reliability and scalability, two additional mechanisms are implemented. First, trigger mechanisms automatically validate required fields, log transactions, and activate

dependent processes such as stock reservation or status updates when critical events occur. Second, Data Warehouse integration separates analytical workloads from operational data. While the transactional database handles real-time operations, historical analysis and benchmarking tasks are processed in the Data Warehouse, reducing the load on operational tables. The data processing architecture integrates transactional databases, a data warehouse layer, and API-based modules for handling logistics operations. The mechanism of data insertion and data exchange between these components is illustrated in Figure 4.

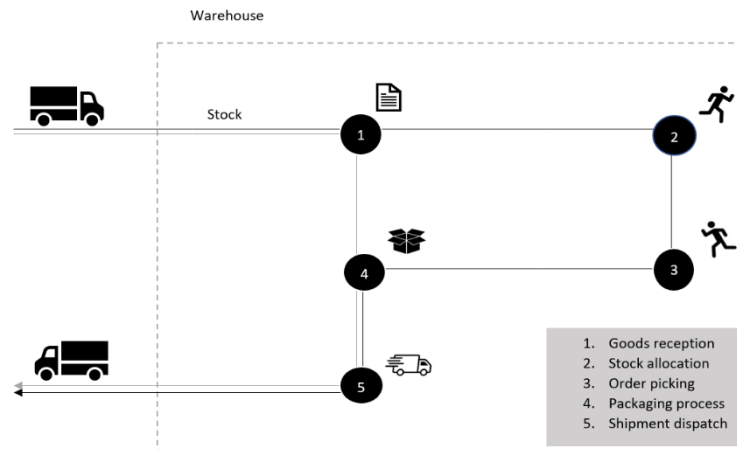


Fig. 3. Warehouse stock allocation and order fulfillment operations

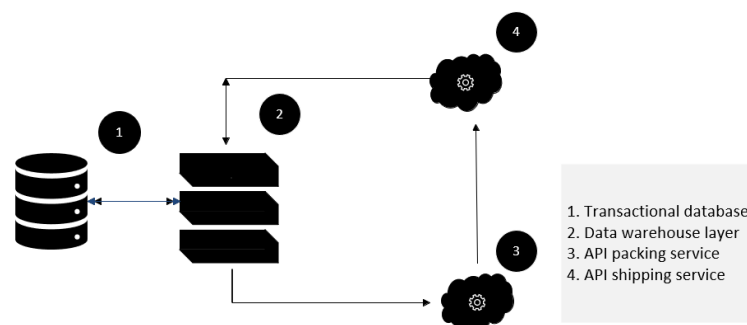


Fig. 4. Warehouse stock allocation and order fulfillment operations

Based on this database architecture, an operational algorithm was designed to process requests efficiently while supporting optimization-based planning when required. The algorithm combines indexed SQL queries with rule-based filtering and MILP-based optimization. Algorithm workflow: (1) receive request parameters (category, price range, deadline, location, stock constraints). (2) execute indexed SQL queries to retrieve candidate records. (3) apply filtering rules (stock availability, price range, deadline feasibility). (4) sort results according to price and logistics criteria. (5) if operational planning is required, solve the MILP optimization model. (6) return results in JSON format. The optimization module was tested under three planning scenarios. For the largest scenario (248 drops and 36 receptions), the total execution time was 14,566.8 seconds, corresponding to 33.72% of the available 12-hour planning window, demonstrating practical feasibility for operational use. Cost estimation accuracy was also evaluated by comparing predicted costs with historical data. The difference between predictive and historical cost values was 11.89%, indicating acceptable estimation accuracy. Cost decomposition analysis showed that the Inbound stage accounts for 67.28% of total operational costs, identifying inbound handling as the primary cost driver and a key target for operational improvement.

The results demonstrate that the proposed integrated model significantly outperforms baseline approaches by combining efficient data retrieval with optimization capabilities. While basic SQL and rule-based methods lack planning support, the proposed model ensures both operational feasibility and cost-efficient decision-making.

A key contribution of this research is the integration of information flow modeling, relational transactional database design, and algorithmic decision support within a unified operational environment. Unlike traditional systems where data storage, information retrieval, and planning functions operate independently, the proposed framework connects them through API-based architecture and consistent data structures. Experimental results show that indexing and structured query design significantly improve

response time. In particular, composite indexes (e.g., ProductID + WarehouseID) and database-side filtering reduce the need for full-table scans, ensuring more stable performance under increasing transaction volumes. This directly supports the primary objective of information retrieval systems—fast and reliable access to relevant data. The Time-Driven cost framework was applied both as an input parameter for optimization planning and as a predictive mechanism for estimating cost per unit. The difference between predicted and historical cost values was 11.89%, indicating acceptable accuracy for operational use. Cost decomposition also revealed that Inbound activities account for 67.28% of total operational cost, identifying inbound handling as the dominant cost driver and a priority area for process improvement. The integration of MILP-based optimization enables automated decision-making under multiple constraints such as deadlines, stock availability, warehouse capacity, and operational costs. For the largest experimental scenario (248 drops and 36 receptions), the total computation time represented 33.72% of the allowed 12-hour planning window, demonstrating that the proposed framework remains computationally feasible for operational-scale workloads. The architecture is designed as a modular system where functional components communicate through APIs. This allows integration with internal modules such as OMS (Order Management System), WMS (Warehouse Management System), and DMS (Delivery Management System). Since operational data are stored in a centralized transactional database, all modules operate on consistent and validated records. In addition, the use of JSON-based output enables lightweight integration with external services such as logistics APIs. The separation between the transactional database and a Data Warehouse supports analytical tasks—including reporting, benchmarking, and historical analysis—without overloading operational tables. This improves system scalability and maintains responsiveness as the platform grows.

**Table 2.** Performance evaluation and comparison of the proposed model

Criteria	Basic SQL	Indexed SQL	Rule-based Filtering	Optimization-only (MILP)	Proposed Model (SQL + MILP)
Data retrieval speed	Slow	Fast	Medium	Not applicable	Fast
Index usage	No	Yes	Partial	No	Yes (B-tree + composite)
Filtering capability	No	Limited	Yes	No	Advanced (rule-based)
Optimization capability	No	No	No	Yes	Yes (integrated MILP)
Planning support	No	No	Partial	Yes	Full
Execution time (sec)	–	–	–	~18000+	14566.8
Planning window usage	–	–	–	~40–50%	33.72%
Scalability	Low	Medium	Medium	Low	High
Cost estimation accuracy	Low	Low	Medium (~25–30% error)	High	High accuracy (11.89% error)
Real-time applicability	High	High	Medium	Low	High
Integration capability	Low	Medium	Medium	Low	High
System complexity	Low	Low	Medium	High	Medium (balanced)

## 4 CONCLUSION

This study developed an integrated database model and algorithmic framework to support the information exchange process in a virtual platform for local product trade. The main scientific results obtained are as follows: (1) an information exchange model was developed based on the sequence User → Request → Database → Processing → Response, where transactional data are centrally managed through a relational DBMS. (2) a conceptual and logical relational database model was proposed. The ER model defined the key entities and their relationships, and the relational schema was normalized to Third Normal Form (3NF) to ensure referential integrity through primary and foreign keys. (3) an information retrieval and processing algorithm was designed, including indexed filtering, logistics- and price-based ranking, and structured result generation. (4) the effectiveness of indexing mechanisms was experimentally validated. The application of B-tree and composite indexes significantly reduced query execution time and improved system performance under increased workload. (5) An optimization model based on Mixed Integer Linear Programming (MILP) was developed to support operational planning under multiple constraints such as inventory levels, deadlines, capacity, and operational costs. Experimental results demonstrated feasibility for large-scale scenarios. (6) a Time-Driven cost forecasting mechanism was implemented. The deviation between predicted and historical cost values was 11.89%, while cost analysis revealed that 67.28% of operational costs correspond to inbound processes. From a practical perspective, the proposed framework integrates information exchange, cost evaluation, and operational planning into a unified algorithmic

environment. Data are retrieved through SQL queries, processed within a Python-based analytical module, optimized using a solver, and returned to the platform in JSON format.

## REFERENCES

- [1] Codd E.F. A relational model of data for large shared data banks. *Communications of the ACM*, 1970, Vol. 13, No. 6, pp. 377–387.
- [2] Chen P.P. The Entity–Relationship model - Toward a unified view of data. *ACM Transactions on Database Systems*, 1976, Vol. 1, No. 1, pp. 9–36.
- [3] Gray J., Reuter A. *Transaction Processing: Concepts and Techniques*. Morgan Kaufmann, 1993.
- [4] Ramakrishnan R., Gehrke J. *Database Management Systems*. 3rd ed., McGraw-Hill, 2003.
- [5] Toth P., Vigo D. *Vehicle Routing: Problems, Methods, and Applications*. SIAM, 2014.
- [6] Nemhauser G.L., Wolsey L.A. *Integer and Combinatorial Optimization*. Wiley, 1999.
- [7] Kaplan R.S., Anderson S.R. Time-Driven Activity-Based Costing. *Harvard Business Review*, 2004, Vol. 82, No. 11, pp. 131–138.
- [8] Yakubov M.S. Raqamli logistika tizimlarida taqsimot jarayonlarini optimallashtirishning nazariy asoslari. *TATU Ilmiy jurnali*, 2022, №3, B. 44–52.
- [9] Xolmatov B.T., Raxmonov D.S. Qishloq xo‘jaligi mahsulotlarini taqsimlashda raqamli platformalarning o‘rni va afzalliklari. *O‘zbekiston Qishloq xo‘jaligi jurnali*, 2021, №6, B. 25–33.
- [10] Abdullayev S.A., To‘xtasinov A.B. Transport logistikasi va “oxirgi kilometr” yetkazib berish muammolari: tahlil va yechimlar. *Logistika va Transport*, 2023, №2, B. 17–29.
- [11] Sulstonov I.J. Sun‘iy intellekt asosida taqsimot tarmoqlarini boshqarish: nazariya va amaliyot. *TATU Axborotnomasi*, 2022, №4, B. 58–67.
- [12] Rahmatov O.A. Raqamli iqtisodiyot sharoitida elektron tijorat va logistika integratsiyasi. *Iqtisodiyot va Innovatsion Texnologiyalar*, 2021, №5, B. 33–40.
- [13] Jumaboyev B.F., Mansurova M.Y. An overview of transport logistics in Kazakhstan: Focus on the case of Astana. *Journal of Multidisciplinary Science and Innovation*, 2025, Vol. 4, Issue 4, pp. 1129–1132.
- [14] Jumaboyev B.F., Mansurova M.Y. Integratsiyalashgan axborot tizimlarida elektron savdoni amalga oshirish usullari. *Development of Science*, 2025, T. 3, №7, B. 51–62.

*Received: January 22, 2026*

**Citation:** Jumaboev B.F. 2026. Models and algorithmic framework for information exchange in virtual platforms for local product trading. *International journal of theoretical and applied issues of digital technologies*. Volume 9, Issue 2, pp. 92-98. <https://doi.org/10.62132/ijdt.v9i2.380>.

## МОДЕЛИ И АЛГОРИТМИЧЕСКОЕ ОБЕСПЕЧЕНИЕ ИНФОРМАЦИОННОГО ОБМЕНА В ВИРТУАЛЬНЫХ ПЛАТФОРМАХ ТОРГОВЛИ ЛОКАЛЬНОЙ ПРОДУКЦИЕЙ

*Жумабоев Б.Ф.<sup>1</sup>*

<sup>1</sup> Ташкентский университет информационных технологий имени  
Мухаммада ал-Хоразмий, Ташкент, Узбекистан

**Аннотация.** Исследование посвящено моделированию и оптимизации процессов информационного обмена на виртуальной платформе торговли местной продукцией. Объектом исследования являются информационные потоки цифровой платформы, предметом - модель базы данных и алгоритмическое обеспечение. Цель работы - разработка оптимизационной модели в условиях многокритериальных ограничений. Применены ER-моделирование, реляционная модель, методы индексирования, алгоритмический анализ и MILP. На основе Time-Driven ABC определены драйверы затрат. Предложенное решение повышает эффективность информационного обмена и снижает операционные издержки.

**Ключевые слова:** виртуальная платформа, информационный обмен, модель базы данных, ER-модель, реляционная база данных, MILP, цифровая логистика, алгоритм оптимизации.