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O. Liashenko,

Doctor of Economic Sciences, Professor, Professor of the Department of Economic Cybernetics, Taras Shevchenko National University of Kyiv

ORCID ID: https://orcid.org/0000-0002-0197-4179

B. Yakymchuk,

Postgraduate student, Taras Shevchenko National University of Kyiv

ORCID ID: https://orcid.org/0000-0003-2574-3815

STRATEGIC DECISION SUPPORT SYSTEM FOR OPTIMIZED LAST-MILE GROCERY DELIVERY POLYGON DISTRIBUTION

О. І. Ляшенко,

д. е. н, професор, професор кафедри економічної кібернетики, Київський національний університет імені Тараса Шевченка

Б. Б. Якимчук,

аспірант, Київський національний університет імені Тараса Шевченка

СИСТЕМА ПІДТРИМКИ ПРИЙНЯТТЯ СТРАТЕГІЧНИХ РІШЕНЬ ДЛЯ ОПТИМІЗАЦІЇ РОЗПОДІЛУ ПОЛІГОНІВ ДОСТАВКИ «ОСТАННЬОЇ МИЛІ»

The grocery retail sector has undergone transformative shifts driven by the confluence of the COVID-19 pandemic and the subsequent Russian invasion of Ukraine. These events have led to a surge in online shopping as consumers

increasingly prioritize safety and convenience, triggering a significant transition from traditional shopping habits to e-commerce. Grocery retailers have responded by embracing an omnichannel approach, integrating physical stores and online platforms to provide a seamless shopping experience. To meet the growing demand for swift and efficient delivery, retailers focus on enhancing last-mile delivery solutions. However, e-commerce grocery retailers encounter narrow profit margins owing to the elevated expenses associated with delivery and order collection.

This study explores a strategic decision support system aimed at optimizing last-mile grocery delivery within the dynamic and intricate Ukrainian retail market. The model is designed to bolster operational efficiency and drive business profitability in this complex urban setting. The System incorporates three primary layers: a Data & Business Inputs Layer, an Optimization Layer, and a Business Intelligence Layer. This configuration integrates diverse data sources, and leverages advanced algorithms to simulate delivery routes, optimize micro-polygon allocation, and empower user-driven decision-making for strategic planning. The Decision Support System empowers users to interact with the system, select scenarios, and understand the impact of chosen metrics on the delivery network. This system offers a dynamic, data-driven platform for strategic decision-making, aiming to improve operational efficiency and profitability in the grocery retail last-mile delivery landscape. By concentrating on key metrics like gross margin, collection and delivery costs, and EBITDA per order, this research aims to create a tool that significantly improves grocery retailers' operational efficiency, cost-effectiveness, and customer satisfaction, providing a sustainable advantage amid challenging market conditions.

Сектор продуктового ритейлу зазнав трансформаційних змін, спричинених поєднанням пандемії COVID-19 і подальшого російського вторгнення в Україну. Ці події призвели до сплеску онлайн-покупок, оскільки споживачі все більше віддають перевагу безпеці та зручності, що спричинило значний перехід від традиційних купівельних звичок до електронної комерції. Продуктові ритейлери у відповідь застосували омніканальний підхід, об'єднавши фізичні магазини та онлайн-платформи, щоб забезпечити

безперебійний досвід покупок. Щоб задовольнити зростаючий попит на швидку та ефективну доставку, продуктові ритейлери зосереджуються на покращенні рішень доставки «останньої милі». Однак через високі витрати, пов'язані з доставкою та збором замовлень, ритейлери, що розвивають електронну комерцію стикаються з низьким рівнем маржинальності прибутків.

У цьому дослідженні розглядається система підтримки стратегічних рішень, спрямована на оптимізацію доставки продуктів «останньої милі» на динамічному та складному українському ринку роздрібної торгівлі. Модель розроблена для підвищення операційної ефективності та прибутковості бізнесу в комплексному міському середовищі. Система містить три основні рівні: Data & Business Inputs Layer, Optimization Layer та Business Intelligence Layer. Ця конфігурація об'єднує різні джерела даних і використовує розширені алгоритми для імітації маршрутів доставки, оптимізації розподілу мікро-полігонів і розширення можливостей прийняття керованих користувачами рішень для стратегічного планування. Система підтримки прийняття рішень дає користувачам можливість взаємодіяти з системою, вибирати сценарії та розуміти вплив вибраних показників на мережу доставки. Ця система пропонує динамічну, керовану даними платформу для прийняття стратегічних рішень, спрямовану на підвищення операційної ефективності та рентабельності в роздрібній торгівлі продовольчими магазинами. Зосереджуючись на таких ключових показниках, як валовий прибуток, витрати на збирання та доставку і EBITDA на замовлення, це дослідження спрямоване на створення інструменту, який значно покращує операційну та фінансову ефективність, і задоволеність клієнтів продуктового ритейлера, забезпечуючи стійку перевагу в умовах складних ринкових умов.

Keywords: *strategic decision support systems, optimization, grocery retail, decision-making, last-mile delivery, e-commerce.*

Ключові слова: *системи підтримки прийняття стратегічних рішень, оптимізація, продуктовий ритейл, прийняття рішень, доставка останньої милі, електронна комерція.*

Statement of the problem in general and its connection with important scientific or practical tasks. The grocery retail sector has experienced significant upheavals due to the intersection of the COVID-19 pandemic and the subsequent Russian invasion of Ukraine. These occurrences have reshaped traditional sales channels, compelling consumers to shop online. The dual priorities of safety and convenience have fueled this paradigm shift, prompting more shoppers to opt for the virtual aisle over physical stores. This surge in e-commerce was further propelled by streamlined logistics and the availability of user-friendly online platforms, setting the stage for a fundamental shift in consumer buying behavior within the grocery retail market.

Grocery retailers have responded proactively by adopting an omnichannel approach to cater to consumers' changing preferences. This strategic shift aims to create a seamless shopping experience, integrating various platforms such as physical stores, online portals, and mobile applications. This approach allows customers to effortlessly navigate between in-store and online shopping, benefitting from consistent pricing, promotions, and a tailored shopping journey. Notably, major retailers have expanded their Click & Collect services and fortified their e-commerce infrastructure, aligning with the mounting demand for online orders complemented by in-store pickup services.

Recognizing the growing consumer demand for swift and efficient delivery services, retailers are diverting attention and resources toward refining their "last-mile" delivery solutions. This endeavor involves meticulous optimization of delivery routes, utilization of advanced delivery applications, and exploration of cutting-edge technologies like drones and autonomous delivery vehicles. The primary goal is to ensure the timely and efficient delivery of products, meeting the heightened expectations of today's consumers for convenience and rapid order fulfillment.

The trends mentioned above have collectively driven the swift evolution of the emerging market for online delivery services. As per McKinsey's estimations [4], the European market has exhibited an annual growth rate of approximately 15% since 2019 (Fig. 1). This growth trajectory has led to a penetration level of around 6% in relation to the total sales within the industrial retail sector. The digital market is in a state of continuous evolution, characterized by multiple services that exhibit partial

overlap. However, the future of this market is likely to reflect the existing offline services while also superseding or enhancing them [10]:

- Comprehensive online offerings from traditional supermarkets usually offer a vast array of products, same-day delivery within hours or for predefined specific delivery timeframes, and competitive pricing on essential items. In Ukraine, such services are provided by Silpo, Novus, Varus, and Zakaz.ua as platforms.

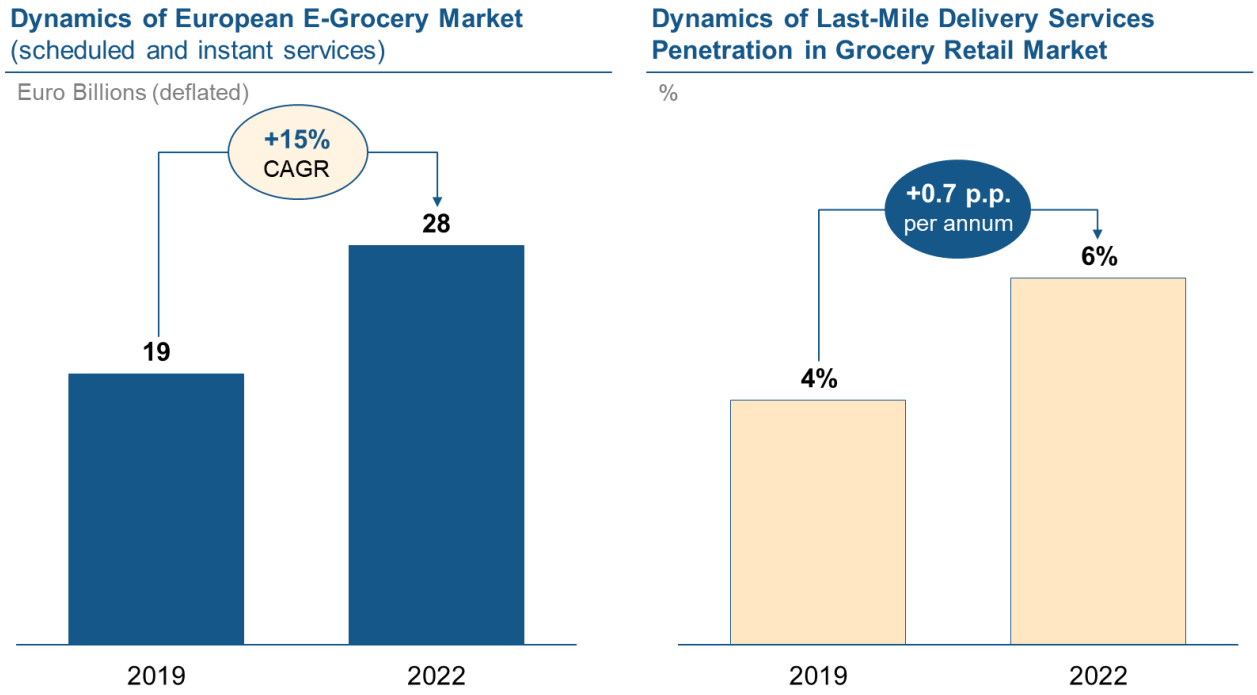


Fig. 1. Dynamics of European last-mile delivery services and its penetration to the grocery retail market

Source: formed by the authors based on [4, 6, 7, 11].

- Instant delivery services are akin to online convenience stores and smaller supermarkets. Prominent European players such as Flink, Getir, and Gorillas cater to customers ordering smaller baskets from a more focused range of products. The competition here revolves around speed and user experience, primarily for immediate and unplanned needs. These instant delivery services are increasingly adding different categories, including ready-to-eat meals, aiming to capture a larger market share and provide meal options from restaurants or meal delivery services. In Ukraine, such a market is at the starting point and is being developed by companies such as Loko and Glovo.

- No-frills services are the discounters in the online sphere. Companies like Picnic from the Netherlands offer low minimum order values and no delivery fees while highlighting value for money in product pricing. However, customers often need to accept trade-offs in terms of the depth of product selection, delivery

options, and additional services.

With the rise of last-mile delivery services, grocers face a crucial challenge in managing unit economics while transitioning to online services alongside their physical stores. According to McKinsey [2], a North American grocer generates a positive net profit margin of approximately 4% in traditional in-store shopping. Even employing more conservative estimates by Damodaran [3], retailers are suggested to attain a net profit margin of 1.96%. However, fulfilling online grocery orders results in a net loss of around -13%, without any additional customer fees. Some grocers currently rely on higher pricing or fees for online orders to maintain positive unit economics. However, customers' willingness to pay these extra charges may diminish as online services become more common.

The key issue lies in managing fulfillment costs, notably driven by manual picking labor and last-mile delivery expenses. Labor and overhead costs for picking may be close to 8% of revenue, with an additional 8% for last-mile delivery service. These extra costs heavily outweigh the slim margins from traditional in-store purchases, posing a challenge for grocers striving to balance unit economics. This challenge is further compounded when customers demand rapid order fulfillment, as it becomes challenging for grocers to optimize labor and delivery resources for swift service.

The prevailing circumstances in Ukraine have created a unique economic landscape, particularly impacting Ukrainian players involved in various industries. While the pressure on margins might not be as overt for these individuals in terms of high wages, the component of expenditure does exert significant strain, particularly amidst times of conflict. This pressure necessitates the achievement of improved profitability indicators. The ongoing war has led to a considerable decrease in the labor market due to mass migrations and mobilization. Consequently, the labor market conditions have become less favorable, resulting in increased order collection and delivery expenses.

In light of these challenges, this study is dedicated to identifying a tool that can effectively optimize operating costs and augment business profitability. The focus is on developing a strategic decision-making support system that aims to streamline the distribution of delivery polygons. This optimization seeks to attain the best metrics

for order margin, considering various factors such as the gross margin concerning the network's primary store range, the pace of collection based on the store's location format (be it the shopping area of the store or a distinct dark store), the distance to consumers, and the expenses associated with rental locations.

This comprehensive research is driven by the need to address the current economic constraints and complexities arising from the conflict situation in Ukraine. By leveraging a strategic decision-making support system, the study aims to develop an efficient model that considers multiple variables to enhance the efficiency and profitability of business operations. The emphasis lies in fine-tuning the delivery polygons to achieve optimal outcomes in order margin metrics, thus contributing to the sustainability and success of businesses amidst these challenging circumstances.

Analysis of recent research and publications, which initiated the solution of this problem and on which the author relies, the selection of previously unsolved parts of the general problem, which is the subject of his article. The scientific perspective of authors concerning strategic network design in omnichannel grocery retailing has evolved significantly over the years, especially with the advent and evolution of new delivery services and innovative e-commerce concepts. Authors in this field have observed a shift in consumer preferences towards a more integrated shopping experience, where individuals expect a seamless connection between online and offline retail channels. This change has compelled retailers to reevaluate their network designs to effectively cater to this omnichannel demand.

The development of new delivery services, including rapid or on-demand delivery, subscription models, and innovative last-mile solutions, has significantly influenced strategic network design. Authors have recognized the importance of optimizing last-mile logistics and reconfiguring distribution centers to meet evolving consumer expectations of faster and more convenient delivery options. Moreover, the evolution of e-commerce concepts such as click-and-collect, virtual inventory management, and the utilization of data analytics for personalized customer experiences has led to a broader and more intricate understanding of strategic network design. Authors have emphasized the need for flexible and adaptive networks to accommodate these novel concepts while maintaining efficiency and cost-effectiveness.

The research of D. Aksen and K. Altinkemer [1] investigates the shift from traditional brick-and-mortar retailing to a hybrid click-and-mortar business model, focusing on distribution logistics. The study addresses the challenge by formulating a static location-routing problem for companies adopting the “clicks-and-bricks” strategy. It considers walk-in customer proximity to the nearest open store as an indicator while emphasizing timely delivery as the quality of service guarantee for online customers. The paper proposes a solution methodology: an augmented Lagrangian relaxation technique within a subgradient optimization process to generate lower bounds, coupled with a heuristic approach to attain feasible solutions. The methodology exhibits promising potential in efficiently resolving the static location-routing problem for retail companies transitioning to a click-and-mortar business model.

The paper of R. Ishfaq, R., and U. Raja examined various online order fulfillment options available to retailers, including store-facing distribution centers (DCs), dedicated order fulfillment facilities (DTC), retail stores, and direct-fill by vendors. The findings revealed that distribution facilities (DC and DTC) outperformed fulfillment from stores and vendors due to their superior order fulfillment efficiency. However, the study suggested that retailers could utilize their network of stores to offset the higher costs associated with store-based fulfillment by optimizing the order delivery process.

The study of M. Janjevic, D. Merchán, and M. Winkenbach conducted numerical experiments to demonstrate the impact of diversified customer demand and innovative distribution network features on overall network performance. The integrated approach proposed in the paper showed economic benefits, optimizing the configuration of distribution networks.

The research of C. Dethlefs, M. Ostermeier, and A. Hübner [5] explores the evolving challenge for brick-and-mortar retailers to establish efficient fulfillment solutions for online orders, emphasizing the increasing competition posed by online-based retailers. The omnichannel approach is gaining traction in response to this challenge, which involves integrating existing structures such as distribution centers (DCs) and local stores into a unified fulfillment concept. This integration is particularly significant for rapid delivery services like same-hour delivery. The

approach mirrors a multi-depot vehicle routing problem, where all facilities, including stores and DCs, function as depots, and orders are assigned based on processing and transportation costs alongside available delivery capacity. The paper empirically identifies key costs linked to order processing in stores and devises a method to evaluate the comprehensive fulfillment expenses. The study considers assigning orders to various depots and vehicle routing for each depot, considering depot-specific fulfillment costs. This involves the development of a tailored cluster-first-route-second heuristic.

Formulation of the goals of the article (task statement). The research paper primarily concentrates on devising a strategic decision-making system designed to craft an efficient network of delivery sites for a food retailer. This System aims to optimize various metrics while ensuring operational and financial efficacy. The retailer possesses a network consisting of dark stores and traditional retail outlets, and the objective is to maximize targeted metrics within this complex operational framework.

Presentation of the main material of the study with a full justification of the obtained scientific results. The Strategic Decision Support System (DSS) designed for optimizing last-mile grocery delivery polygon distribution is grounded in scientific methodologies that harness data analysis and algorithmic modeling to enhance operational and financial aspects within the grocery retail sector.

This system employs complex algorithmic models and geospatial analysis techniques to strategically determine the most efficient delivery routes for grocery items. By evaluating various factors such as geographical data, customer demands, and historical delivery patterns, the System optimizes the allocation of delivery polygons and routes.

Optimization algorithms utilized within the system help minimize overall transportation costs and time, reduce fuel consumption, and effectively utilize resources like delivery vehicles and personnel. Furthermore, the DSS allows for dynamic adaptability by swiftly adjusting delivery routes in response to real-time changes, like traffic congestion or alterations in delivery demand.

Moreover, the System aims to enhance customer satisfaction by ensuring prompt and accurate deliveries, contributing to customer loyalty and retention. By

meeting delivery expectations, the System positively influences customer perceptions, potentially leading to increased sales and a better reputation for the grocery retailer.

Ultimately, this Data-Driven Strategic Decision Support System for optimizing last-mile grocery delivery polygon distribution contributes to a comprehensive improvement in operational efficiency, reduced costs, enhanced customer satisfaction, and, consequently, potential financial gains in the form of optimized EBITDA within the grocery retail sector.

The proposed model's architecture (Fig. 2) represents a sophisticated system designed to revolutionize the operational efficiency and decision-making processes in the grocery retail sector's last-mile delivery. The System was deployed for a retail company in Ukraine managing a network comprising over 80 stores and dark stores situated in Kyiv.

1. Data & Business Inputs Layer. The data integration layer serves as the foundation, consolidating diverse data sources critical to the delivery network.

- SAP Financial System acts as the foundation for crucial financial data. Metrics such as gross margin, collection costs, and lease terms provide essential insights into the profitability of various locations and guide decisions regarding operational expenses and revenue generation. This financial data helps in evaluating the cost-effectiveness of delivery operations and aids in strategic decision-making to maximize profitability.

- Transactional System captures transactional data related to order frequency, average check value, and other influencing factors. These details are fundamental in assessing customer behaviors, delivery patterns, and the profitability of specific delivery sites. Analyzing order frequency and average check values assists in redistributing order density, optimizing routes, and determining the most suitable delivery methods, thereby enhancing the profitability of the delivery network.

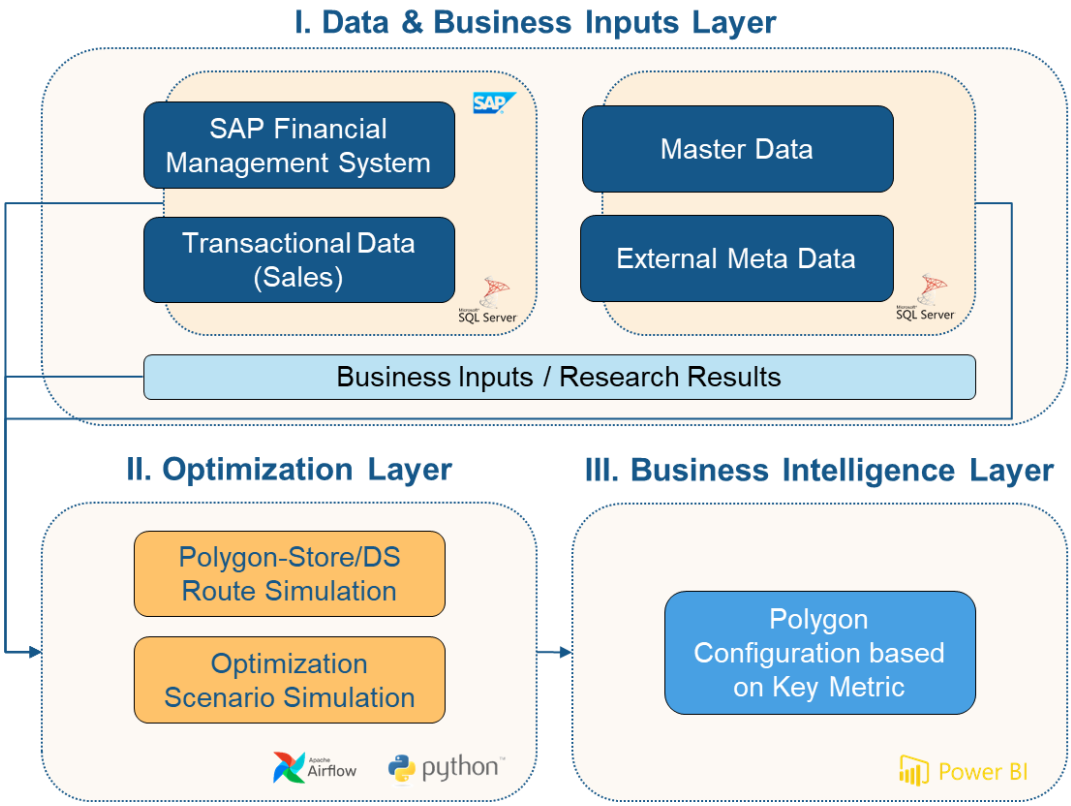


Fig. 2. Architecture of Strategic Decision Support System for Optimized Last-Mile Grocery Delivery Polygon Distribution

Source: formed by the authors.

- Master Data Component provides comprehensive details about various locations, their formats, geographical positions, and specific processing limits. This information acts as a cornerstone for efficient order allocation and aids in determining the optimal distribution of orders among different delivery sites. Understanding geographical positions and specific limits ensures strategic and optimal order processing, contributing to operational efficiency and customer satisfaction.

- External Data Component includes detailed city maps, significantly enriching the System's understanding of the city layout. It enables the segmentation of city areas into smaller polygons, fostering a more granular view of the urban landscape. This segmentation aids in optimizing the allocation of delivery sites, determining the most efficient routes, and enhancing the accuracy of the delivery process.

- Defined business rules set critical guidelines and cost factors, including courier payment rates, maximum route distances for distinct transport types, and fuel costs. These rules serve as benchmarks for decision-making, guiding the System in optimizing delivery routes, selecting appropriate transportation modes, and

effectively managing operational costs, ultimately contributing to cost efficiency and improved delivery performance.

These interrelated components synergistically combine to form a robust decision-making framework, leveraging varied data sources, analytical insights, and predefined guidelines to optimize the last-mile delivery process in the grocery retail sector. Their integration and utilization empower the System to make informed, strategic decisions that drive operational efficiency, cost optimization, and enhanced customer service within the delivery network.

2. Optimization Layer.

Polygon-Store/DS Route Simulation. Employing advanced route optimization algorithms, the System intricately models the most efficient delivery routes from distribution points to consumers. This process involves precise calculations of distances, which serve as critical factors in estimating delivery costs. Furthermore, these calculated distances significantly influence the subsequent polygon optimization algorithm, impacting the strategic distribution of delivery polygons.

The initial phase involves the generation of the smallest polygonal maps utilizing metadata (Fig. 3). Leveraging road data, these maps aid in segmenting routes, effectively facilitating the navigation of couriers along specific paths. The algorithm performs a geospatial transformation on street data for a particular city, aiming to generate smaller polygons derived from the streets' LineString features. This transformation is essential in urban mapping and transportation analysis, providing insights into the city's street layout and enabling the creation of simplified polygons to represent street sections.

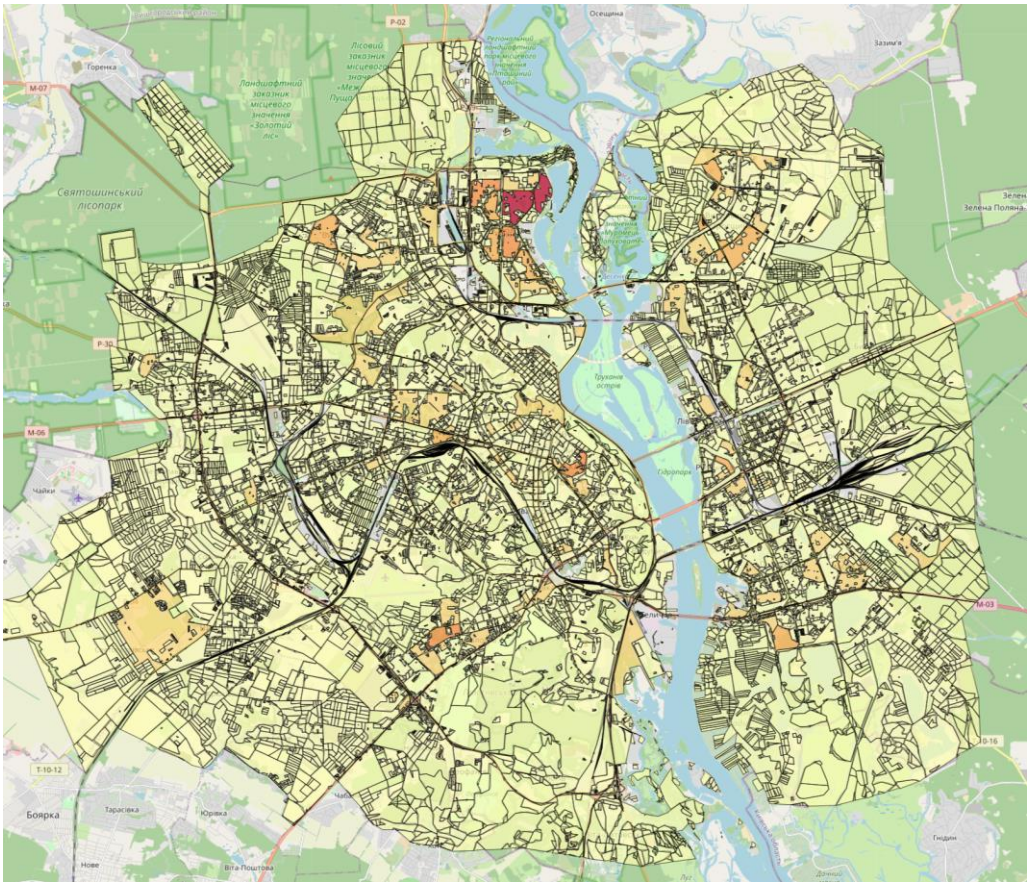


Fig. 3. Polygon representation of the city's street layout

Source: formed by the authors.

The algorithm initially filters street data from the Metadata, retaining specific road types such as primary, secondary, tertiary, residential, and others while excluding footpaths, bridleways, steps, and other non-essential features. It then processes this street data to create smaller LineString segments representing individual sections of the streets. These LineString segments are later converted into smaller polygons using a method called 'polygonize' from the Shapely library, a common approach used in geographic information systems (GIS).

Transaction data establishes the density of each micro-polygon within the city. In instances where certain micro-polygons lack historical transaction records, a single virtual order is generated at the geometric center to represent them. Subsequently, the System calculates optimal routes from each designated location to the actual transaction points and to these virtual points (Fig. 4). These routes are meticulously crafted to ensure efficiency in delivery logistics and strategic coverage of the entire city.

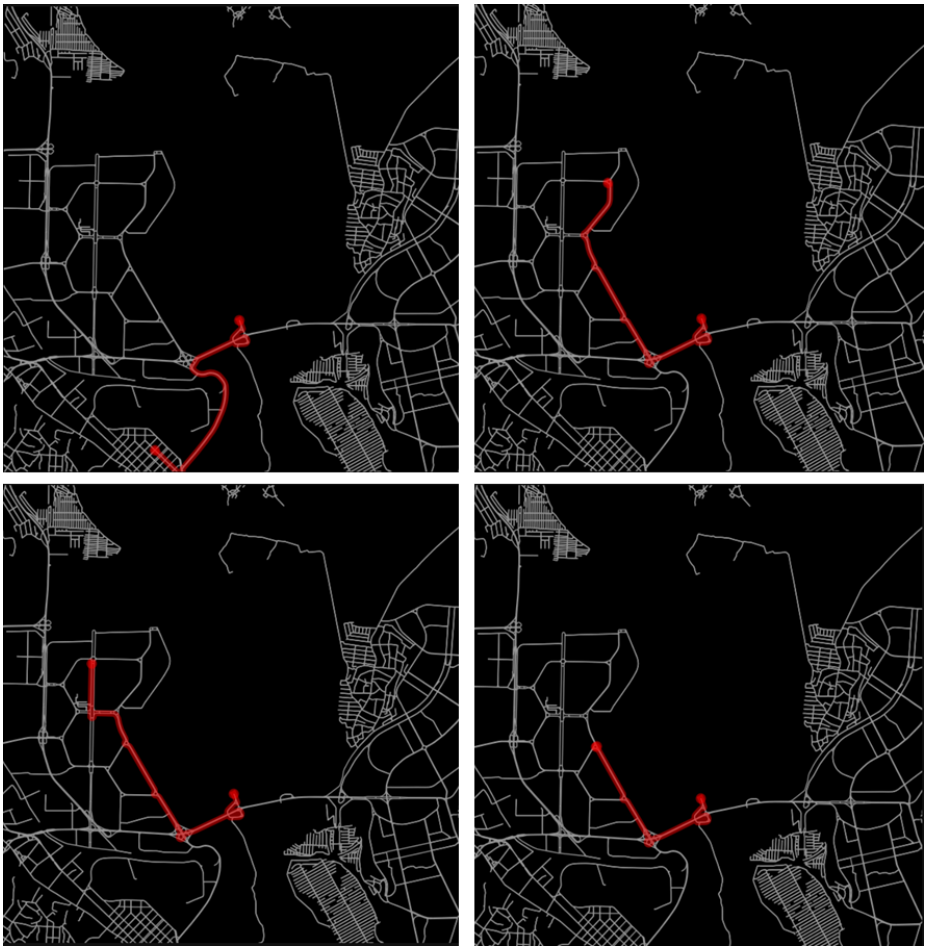


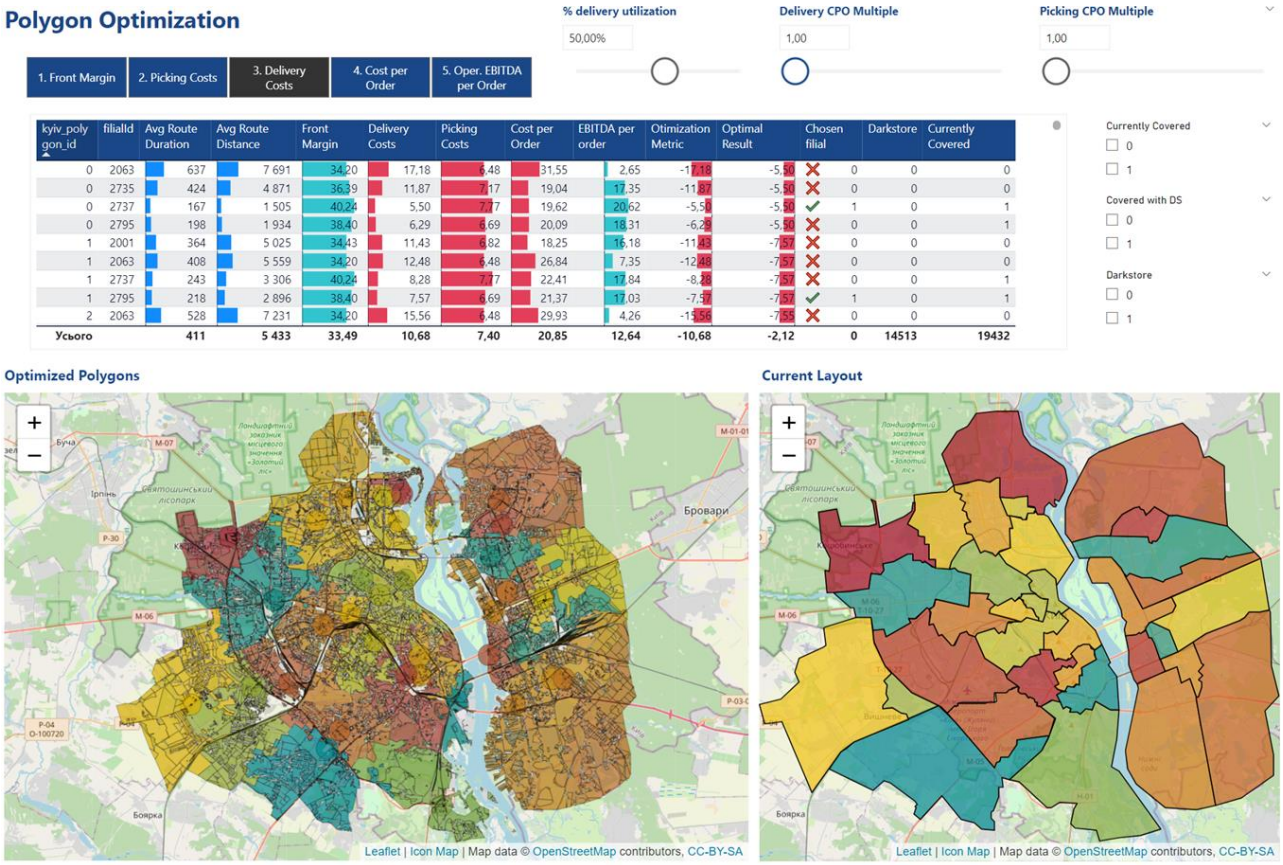
Fig. 4. Polygon-Store/DS Simulation

Source: formed by the authors.

Matrix Scenario Optimization. In this phase, the process concentrates on refining scenarios within a matrix, emphasizing the manipulation of diverse target metrics to achieve specific objectives. These metrics include maximizing the gross margin, minimizing both collection and delivery costs, and optimizing EBITDA per order. The overarching goal is strategically and efficiently allocating micro-polygons to suitable locations within the delivery network, such as stores or distribution centers. This optimization process involves intricate analysis and decision-making strategies aimed at enhancing operational efficiency and financial performance by aligning micro-polygon distribution with the most suitable locations, thereby impacting the overall profitability and effectiveness of the delivery system.

3. The Business Intelligence layer acts as a bridge between the System and end-users, empowering them to make informed decisions (Fig. 5). It allows users to interact with the System, select and analyze scenarios, and view the changing map based on selected metrics. Through this interactive reporting, users can comprehend how alterations in selected metrics impact the city map and evaluate scenarios based on specific business goals. The System's simulation capabilities enable a short-term

evaluation of potential business effects, offering a dynamic platform for understanding and predicting the impact of chosen strategies and metrics on the delivery network.



kyiv_polygon_id	filialId	Avg Route Duration	Avg Route Distance	Front Margin	Delivery Costs	Picking Costs	Cost per Order	EBITDA per order	Otimization Metric	Optimal Result	Chosen filial	Darkstore	Currently Covered
0	2063	637	7 691	34,20	17,18	6,48	31,55	2,65	-1	-5,50	✗	0	0
0	2735	424	4 871	36,39	11,87	7,17	19,04	17,35	-11	-5,50	✗	0	0
0	2737	167	1 505	40,24	5,50	7,77	19,62	20,62	-5,50	-5,50	✓	1	1
0	2795	198	1 934	38,40	6,29	6,69	20,09	18,31	-6,29	-5,50	✗	0	1
1	2001	364	5 025	34,43	11,43	6,82	18,25	16,18	-11,43	-7,57	✗	0	0
1	2063	408	5 559	34,20	12,48	6,48	26,84	7,35	-12,48	-7,57	✗	0	0
1	2737	243	3 306	40,24	8,28	7,77	22,41	17,84	-8,28	-7,57	✗	0	1
1	2795	218	2 896	38,40	7,57	6,69	21,37	17,03	-7,57	-7,57	✓	1	1
2	2063	528	7 231	34,20	15,56	6,48	29,93	4,26	-15,56	-7,55	✗	0	0
Усього		411	5 433	33,49	10,68	7,40	20,85	12,64	-10,68	-2,12	0	14513	19432

Fig. 5. Business Intelligence Layer of Strategic DSS

Source: formed by the authors.

This meticulously designed model combines complex data integration and optimization algorithms and empowers users with interactive decision-making tools. The aim is to facilitate informed, data-driven decision-making, optimize delivery processes, and ultimately enhance profitability and operational efficiency in the dynamic landscape of grocery retail last-mile delivery.

Conclusions from this study and prospects for further exploration in this direction. The dynamic shifts in the grocery retail sector, particularly influenced by the COVID-19 pandemic and the Ukrainian conflict, have substantially altered the landscape, prompting a significant transition towards online shopping. This paradigm shift underscores the pivotal role of safety and convenience in driving consumers toward online purchasing, triggering an evolution in retail strategies. Grocery retailers are proactively adopting omnichannel approaches, integrating physical stores, online platforms, and mobile applications to provide a seamless shopping experience.

The increasing demand for swift and efficient delivery services has encouraged retailers to focus on last-mile delivery solutions. To meet these expectations, the study aimed to optimize delivery processes, leverage strategic decision-making, and enhance the network's profitability within this context.

The architectural design of the proposed Strategic Decision Support System (DSS) showcases an integrated model encompassing multiple layers of data inputs, optimization techniques, and a business intelligence layer. This model is constructed to efficiently manage the complex last-mile delivery network of a Ukrainian retailer with over 80 stores and dark stores in Kyiv.

The System employs sophisticated algorithms to simulate optimal delivery routes and optimize scenarios within matrices, targeting metrics such as gross margin, collection and delivery costs, and EBITDA per order. By leveraging key data sources like SAP Financial Systems, transactional systems, and external data, the System fine-tunes the allocation of delivery polygons, ensuring effective route optimization and cost-efficiency.

The proposed model serves as a bridge between the complex network of delivery polygons and the end-user. It offers an interactive platform for users to select and evaluate various scenarios based on specific business goals. This empowers decision-makers to understand the impact of selected metrics on the delivery network and assess potential business effects in the short-term.

Drawing insights from recent research and publications, the study highlights the evolutionary trajectory of the grocery retail sector and the challenges it faces in adapting to online services. It also identifies the economic constraints faced by Ukrainian players due to the ongoing conflict, emphasizing the significance of optimizing operating costs to ensure business sustainability.

In conclusion, the designed Strategic Decision Support System offers a comprehensive approach to optimize last-mile grocery delivery, utilizing cutting-edge algorithms, integrated data sources, and an interactive decision-making interface. The System's potential lies in its ability to drive operational efficiency, enhance customer satisfaction, and improve financial performance within the evolving landscape of grocery retail last-mile delivery.

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