Platform Architecture and Functionality for Efficient and Intelligent Logistics

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***Abstract*— This paper describes the layered architecture and functionality of an intelligent logistics platform for logistics companies to centrally coordinate their transportation operations. It offers real-time tracking, tracing, and reporting capabilities to logistics stakeholders, as well as dynamic scheduling and routing of deliveries forming shipments and routes with optimized resources allocation and costs. The optimization of shipments scheduling and routing is performed drawing on the backpressure technique, which, to the best of our knowledge, has never been applied to optimize supply chain transport operations. The algorithm combines a variety of factors that affect transportation operations (such as the capacity and current inventory of each node in the transportation network and the fleet characteristics) and proposes dynamically shipments and optimal paths for the company fleet and couriers for last-mile delivery.**

Keywords—logistics, routing, and scheduling, optimization, system architecture

I. Introduction

Transportation/ logistics is a key driver of supply chain, and its cost has a major effect in supply chain efficiency and sustainability. Logistics operations have been disrupted during the pandemic due also to the huge increase of ecommerce buying and, simultaneously, the need for fast last-mile deliveries. Generally, the more demanding behavior of customers, the complex distribution networks, the traffic in urban areas and the new transportation modes call for more "intelligent" logistics operations that provide satisfying service level at affordable costs. Respectively, the advancement in technologies (e.g., IoT, machine learning) and optimization methods pave the way for intelligent transportation systems that may include all the aforementioned factors and generate efficient optimized transportation routes.

In this spirit, this paper describes the layered architecture and functionality of an intelligent logistics platform for logistics stakeholders/courier companies to centrally coordinate the transportation operations for serving their delivery requests (individual items and pallets for businesses). Each logistics company/user can insert its transportation network (e.g., transit hubs) and track and trace its shipments to consumers or other businesses in real-time. The shipments scheduling and routing is optimized employing the backpressure technique [1], which, to the best of our knowledge, has never been applied to optimize supply chain logistics. The algorithm combines a variety of factors that affect transportation operations (such as, capacity and inventory of each node in the transportation network, characteristics of fleet, delivery priority and costs) and proposes dynamically shipments and optimal paths for the company fleet and couriers for last-mile delivery. The user can also assess the performance of its transportation network through reports depicting key performance indicators of transportation. The platform can collaborate with the legacy systems of the user company through an appropriate API that we have developed. The platform offers a web interface for interacting with the users/ logistics stakeholders and a mobile application for employees performing the transportation (e.g., truck drivers, couriers, etc.) to provide them with the routing and scheduling plans.

Next, we provide a summarized view of related work in supply chain transportation and the available systems. In section III, the platform's use cases, and architecture are presented. Then, we discuss the platform's design challenges we came across, conclude the paper and outline plans for future research.

II. Related Work

Logistics scholars and practitioners commonly agree that one of the most important objectives of transportation logistics refers to minimization of the transportation costs. Thus, most research in this field has produced algorithms and methods for optimized routing and scheduling of freight transportation that provide efficient routes of transportation fleets (in other words the Vehicle Routing Problem-VRP). The logistics providers utilize logistics systems, but their routing optimization module is not detailed. Respectively, there are few papers that present logistics solutions and systems that implement routing and scheduling optimization methods [2]. Now that customers are more demanding, transportation networks are more complex, and route traffic is a significant issue, we need logistics systems that perform optimized routing and scheduling of distribution services considering the above aspects.

For example, Gayialis et al. [2] present a cloud-based urban logistics system that utilizes operational research methods to offer optimal scheduling and routing of the deliveries under realistic constraints of urban traffic, resources (such as trucks capacity) and customers' needs to achieve efficient logistics.

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Respectively, there is a more recent research stream in the optimization of logistics operations that focuses on the energy efficiency of deliveries. Bányai [3] proposes a model of real-time scheduling of first- and last-mile logistics for optimized energy efficiency of cooperative supply chain package service providers. The optimization model considers factors, such as loading capacity and time frame. The author developed a black hole optimization-based heuristics model. the scenarios showed that cooperation increases energy efficiency.

As a last example, SOLFI [4] is an integrated city logistics platform that exploits uncommon transport services, i.e., the extant city bus network, and bicycles to perform last-mile deliveries. It performs real-time management and optimization of the logistics process when the main travel distance is covered by buses and then, bikes deliver the parcels to their destination.

Our proposed digital platform performs dynamic scheduling and routing of delivery requests building on an algorithm that optimizes the resources allocation in the transportation network which is digitized. It operates in real-time for urban and non-urban areas and each logistics company/user inserts the relevant info (e.g., capacity and inventory of transit hub) for each logistics partner involved. In essence, the platform can also support the collaboration of logistics partners.

III. Platform Functionality and Architecture

We designed and developed an intelligent transportation platform that offers real-time tracking, tracking, and reporting capabilities to logistics stakeholders for B2B and B2C deliveries, as well as dynamic scheduling and routing of deliveries forming shipments and optimal routes optimizing resources allocation and costs. Next, we briefly outline the use cases and the architecture of the platform.

A. Elicitation of functional requirements and use cases

The design process of the proposed platform was performed under the auspices of a research project, entitled VELOS. The project is co-financed by the European Union and Greek national funds through the Competitiveness, Entrepreneurship and Innovation Operational Program. VELOS acts as an online intermediary for logistics/ courier companies that centrally coordinates scheduling and transportation operations of individual items and/ or commercial pallets within a supply chain.

To elicit the functional requirements of the platform, we performed a series of structured interviews with executives of a small-scale logistics company that participates in the project. The company acted as a domain expert that highlighted the typical modus operandi of logistics companies and the corresponding operational challenges that such companies face. Moreover, the company provided the initial pool of design requirements for the platform. Each design requirement was perceived as a use case showcasing the platform functionality. In sum, the initially identified use cases are:

- Registration of a logistics company/ user.
- Formation of the transportation network for the logistics company comprising of other collaborating logistics companies, transit hubs, and transport companies.
- Input of individual transportation requests; distinction between consumer and corporate requests (e.g., consumer packages and pallets).
- Consolidation of transportation requests into shipments based on scheduling and routing optimization; optimization criteria should include minimization of transportation costs and delivery time, maximization of service quality and security (e.g., for perishable or high value products), stability of the supply chain transportation network, and prioritization of high-priority requests over normal priority requests.
- Full Tracking and tracing capabilities of individual items and shipments in the form of a timeline.
- Searching for individual items/ shipments with multiple search criteria (e.g. shipment tracking number, hub name, and date range to name but a few search criteria).
- Evaluation of transportation network performance through aggregated statistics and metrics measuring key transportation performance indicators.

To further elicit the platform's use cases and provide a visual illustration of the platform services for the intended end users, we developed a high-fidelity prototype using Figma online wireframing tool, which is illustrated in the following figure. The high-fidelity prototype was demonstrated to representative personnel from the logistics company participating to the project. Based on their feedback, we revisited the platform functionality and user interactions.

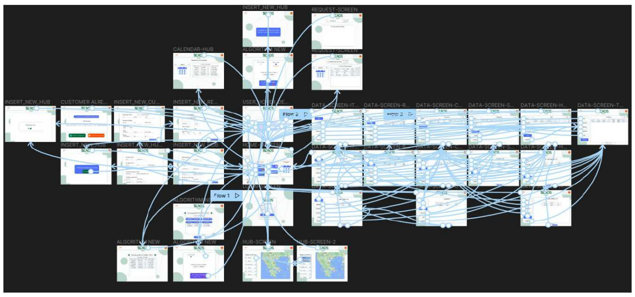


Fig. 1. High-fidelity wireframes in Figma

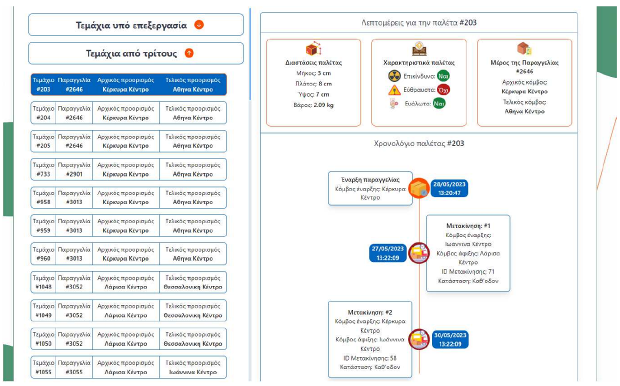


Fig. 2. Example of item tracking in the form of a timeline (in Greek)

B. Platform architecture

In terms of architecture, the platform includes three components/ modules: the Data Collection and Knowledge Representation Engine, The Scheduling Engine, and the Analytics and Visualization Engine.

The *Data Collection and Knowledge Representation Engine* sets the foundations for the platform operation. First, the component allows logistics companies to register and specify their transportation network comprising of other collaborating transit hubs/ logistics companies. In its full potential, the platform may represent the national transportation network of a supply chain in the form of a network graph.

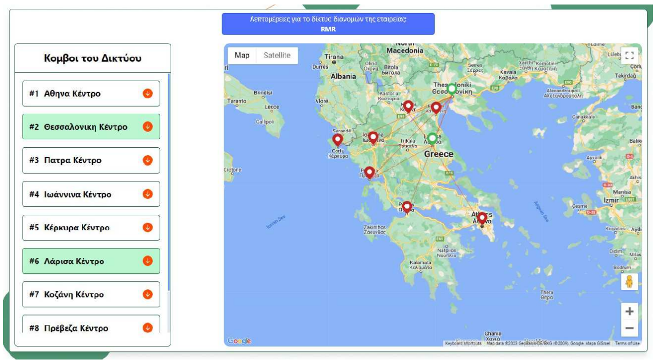


Fig. 3. Representation of the transportation network for a particular logistics company (in Greek)

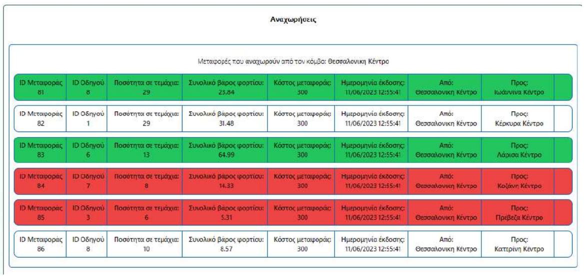
Registered employees from the logistics company may submit new transportation requests either for individual items or for (commercial) pallets/ containers. We also developed an appropriate API that allows the platform to directly accept submitted transportation requests from the legacy information systems of the registered logistics companies.

The *Scheduling Engine* follows the prescriptions of a routing-scheduling algorithm that was designed and implemented particularly for the proposed platform. It is based on the backpressure technique, which has been extensively used in computer networks for the optimization of resources allocation [1]. It should be emphasized that, although the algorithm has been applied to other contexts, such as to optimize urban transportation networks [5], to the best of our knowledge, this is the first time in the supply chain literature that a backpressure technique is proposed for making decisions about cargo transportations by logistics companies.

The algorithm may be automatically executed in predefined fixed time intervals, or it may be manually executed by VELOS administrators. The algorithm uses a multitude of input variables for dynamically scheduling and routing of individual transportation requests, which include: (a) the capacity and current inventory of each transportation node, (b) the number, availability, and capacity of each fleet vehicle (e.g., trucks), and (c) the priority and delivery cost of each shipment. The algorithm uses the aforementioned information to represent shipments (e.g., items and pallets) as a standard queue system in each network node (e.g., warehouses of logistics companies and transit services).

Initially, the algorithm recalculates the available shipments located in each transportation node and sums their volumetric weights to estimate the current inventory of each distribution center. To calculate the optimal path that a shipment should follow from the starting point to its end destination, the algorithm executes a subsystem that applies Dijkstra's algorithm. For each neighboring nodes, the algorithm performs a dynamic programming problem to integrate as many packages as efficiently possible, considering the capacities of the transportation nodes and edges (i.e., routes connecting each neighboring pair of nodes), until the nodes reach their maximum capacity or nodes do not require dispatching any more transportation requests.

Users from the logistics company may accept (highlighted in green) or reject (highlighted in red) the algorithm’s individual suggestions. Upon final agreement/ validation of the algorithm’s recommendations, the sub-system results in a list of packets to be forwarded. The algorithm then groups the packets based on where they will arrive and creates shipments comprising of the necessary movements of the company's fleet that need to be completed to send the packages. On arrival at the final location, parcels are dynamically selected and assigned to the company's couriers for final delivery.


Αναχωρήσεις

Μεταφορές που αναχωρούν από τον κόμβο: Θεσσαλονικη Κέντρο

ID Μεταφοράς	ID Οδηγού	Ποσότητα σε τεμάχια:	Συνολικό βάρος φορτίου:	Κόστος μεταφοράς:	Ημερομηνία έκδοσης:	Από:	Προς:
81	8	29	23.84	300	11/06/2023 12:55:41	Θεσσαλονικη Κέντρο	Ιωάννινα Κέντρο
82	1	29	31.48	300	11/06/2023 12:55:41	Θεσσαλονικη Κέντρο	Κέρκυρα Κέντρο
83	6	13	64.99	300	11/06/2023 12:55:41	Θεσσαλονικη Κέντρο	Λάρισα Κέντρο
84	7	8	14.33	300	11/06/2023 12:55:41	Θεσσαλονικη Κέντρο	Κοζάνη Κέντρο
85	3	6	5.31	300	11/06/2023 12:55:41	Θεσσαλονικη Κέντρο	Πρέβεζα Κέντρο
86	8	10	8.57	300	11/06/2023 12:55:41	Θεσσαλονικη Κέντρο	Κατερίνη Κέντρο

Fig. 4. Scheduling and transportation suggestions following the execution of the backpressure algorithm for a specific logistics company (in Greek)

Last, the *Analytics and Visualization Engine* presents various types of reports with aggregated statistics that support logistics companies in monitoring and assessing the performance of their transportation network and operations and, ultimately, take better decisions that improve their transportation operations. Such reports include statistics results for the following metrics/ KPIs:

- *Operational Efficiency Metrics:* Examples of metrics include average delivery time per route, on-time delivery percentages, total and average distance traveled per route, total and average incoming and outgoing items/ pallets per transportation network node, and total and average transfers/ shipments per day to name but a few of supporting metrics in this category.
- *Cost Analysis Metrics:* These include, among others, calculation of total and average transportation costs per company and per transportation network node, total and average costs per shipment, item, and route, and total and average cost savings per company and shipment following the optimization algorithm recommendations.

Additional metrics and/ or key performance indicators may be developed in the future based on user feedback and inherent requirements.

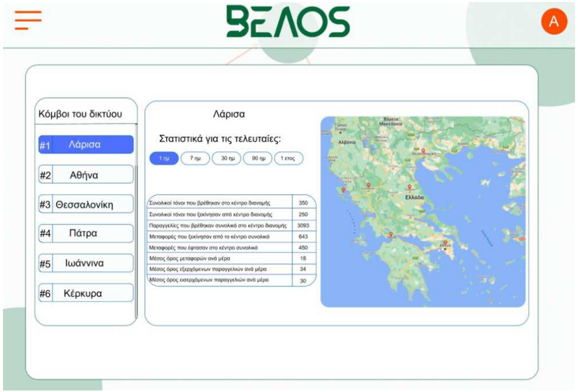


Fig. 5. Reports with aggregated statistics assessing scheduling and transportation of shipments (items) (in Greek)

The platform has adopted a layered architecture consisting of the following layers:

- The *presentation layer* is responsible for rendering the user interfaces to the end-users. A web application was developed for supporting system interactions with employees of logistics companies that use the system for scheduling their transportation requirements, as well as administrative activities. A mobile application was developed for endpoint employees (e.g., truck drivers, couriers, etc) as a means of communicating transportation scheduling and contents.
- The *business logic layer* incorporates the system's functional components, namely the three afore discussed core modules the Data Collection and Knowledge Representation Engine, the Scheduling Engine, and the Analytics and Visualization Engine.
- The *communication layer* acts as a bridge between the system's functional components and the backend of the system. We developed an API engine that supports RESTful communications in a stateless manner (i.e., the server doesn't store client state between requests). Furthermore, we developed an Authentication Engine that supports secure access between clients and API endpoints.
- The *performance/ security layer* handles the internal security of the backend system components through appropriate client certificates as well as distributing all incoming requests across the application server instances to ensure efficient resource utilization and handle potential increased traffic.
- Finally, the *data layer* includes the data components of the system, namely the SQL database (MariaDB) and the API endpoints.

IV. Discussion, Conclusions and Future Steps

This study presents a digital platform for logistics companies that provides dynamic scheduling and routing of transportation requests drawing on the backpressure technique, an established method for optimizing resources allocation in computer networks. The logistics stakeholders see a digital representation of their transportation network serving shipments for individual customers and corporate ones. They can also track, trace and manage their deliveries and with optimized scheduling and routing of their shipments they can improve their logistics operations and decrease costs while mainting satisfying customer service level. The platform also offers to them a variety of reports assessing the key cost and operational metrics of transportation operations.

We adopted user-centered design to select the final use cases of the platform, and we realized several challenges through the design and development of the platform that may support future researcher and designers of such solutions. To name but a few, the complexity of the supply chain networks, and the variety of stakeholders make the digitization of the transportation network more difficult. Moreover, the variety of factors that affect transportation routes and performance is not easy to collect and then, model for optimization methods. Next, the nature of the transportation requests has changed a lot with individual items/ deliveries to increase following the ecommerce breakthrough, especially after the pandemic. Thus, the last-mile deliveries prevail in transportation operations and, simultaneously, affect big costs on the logistics companies. Thus, the routing algorithms should take them under great consideration since they increase and complex even more the transportation routes. Last, such platforms should ensure security since they carry sensitive logistics information and can also be used for fostering collaboration between logistics partners.

To name one of our future research plans, we highlight the two-fold validation of VELOS to ensure that logistics companies will adopt it. First, we will represent the platform and its functionality to several logistics companies during a workshop to collect their perceptions of the platform and the expected impact on established transportation metrics such as the ones that the platform assesses and reports. Secondly, and most importantly, we will perform a pilot application of the

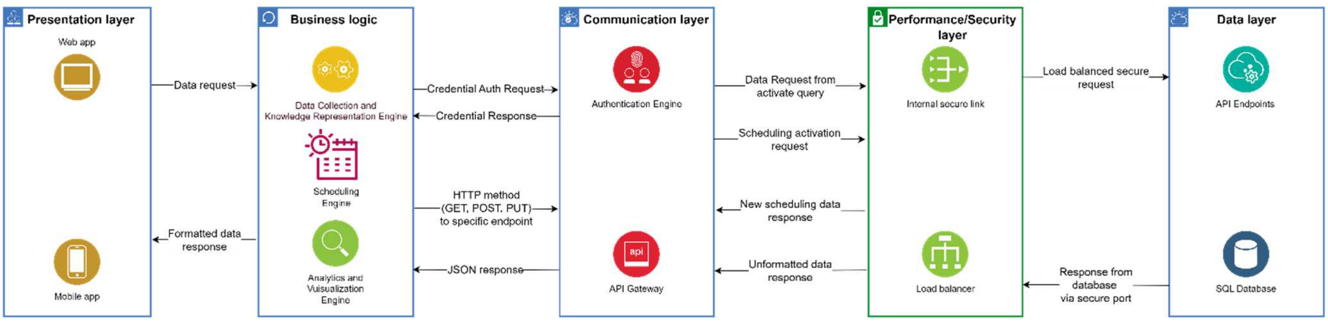


Fig. 6. System architecture

platform to objectively assess its operation and measure the improvement in transportation performance and costs.

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