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Seizing the Potential of Transport Pooling in Urban Logistics- The Case of Thriasio Logistics Centre in Greece

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Abstract

One of the main topics with increasing interest in freight transport and logistics is developing efficient and sustainable supply chain strategies that best cover customer demands and expectations as well as identify considerable cost savings and emission reductions. This study focuses on the evaluation of the potential of a logistics centre for consolidating and delivering goods at urban level, based on economic, social and environmental aspects, by performing both GIS simulation and SWOT analysis, while considering key criteria of transport management, infrastructure and fleet attributes as well as logistics and market features in the Attica region of Greece. The case refers to the largest Logistics Centre of Greece, located at Thriasio, offering door-to door services to the main industrial areas of the region. The approach followed, consists of two core elements: a) a specific model of a last-mile delivery network in GIS environment, towards simulating and solving the Vehicle Routing Problem (VRP) as well as b) a strategic assessment of the foreseen logistics activities through the SWOT business tool. For a transport operator with 5 vehicles, an operational distance-related cost of €1.8-1.9 per pallet was estimated. Results also show the lower environmental impact of larger vehicles due to transport pooling.

Keywords: Transportation, City logistics, Vehicle routing, SWOT analysis, Freight village, Sustainability, GIS.

1 | Introduction

Urban logistics plays a vital role towards economically viable cities, by linking supply and demand in the distribution industry and keeping strong relationships between suppliers and customers [1]. Transportation is key, since it represents the most significant amount of the final cost of logistics, accounting for about 50% [2]. Concurrently, a rising number of freight vehicles in urban areas is observed, resulting in non-sustainable effects on environment, economy and society [3]. Transportation systems should strive to move towards pretty organized and more efficient freight transport planning, management and operation processes in order to reduce transportation costs, improve level of service and enable a more sustainable future in cities, aligned with global climate change targets.

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In this context, the concept of sustainable transport is gaining attention globally by researchers, business owners and government officials not only for economic reasons, but also for the negative transportation externalities such as vehicle-related carbon emissions, air pollution, congestion, noise and accidents [3] and [4].

The topic of urban goods distribution concerns the design of an effective logistics distribution network requiring strategic as well as operational levels of decision-making. At operational level, goods distribution takes place on a daily basis, considering the vehicle routing schedule with the itineraries to be followed, along with the service time interval and the demand of the customers to be served. Focusing on major urban centres, logistics activities have several shortcomings that need to be addressed, based upon the perspectives, insights and considerations of various stakeholders in order to ensure profitable transport of cargo, successive management of available vehicle resources, customer satisfaction and less impact on the urban environment and its users. In fact, the operation and performance of urban logistics is affected by numerous critical factors relying on demographic, market, regulatory, climatic, land use and urban planning issues, as well as on infrastructure/network features, commodity attributes and vehicle properties. In this context, effective policy measures are often required to be implemented towards an improved supply chain from a holistic perspective [3] and [5]. Those measures could be mainly related with a) demand management and last-mile operations, b) logistics infrastructure and land use development, c) vehicles and fleet management, as well as with d) proper cross-cutting Information and Communication Technology (ICT) utilisation.

The term "last-mile" is often used to describe the last critical part of freight movement to its final destination [6], as for instance in the case of an Urban Consolidation Center (UCC) providing supplies to industrial areas, e.g., raw materials, spare parts etc. Urban Consolidation Centers (UCCs) are Distribution Centres (DC) that are situated in relatively close proximity to the geographic area they serve covering the freight flows of a whole city, or of specific urban or inner-city areas, industrial sites etc. [7] and [8]. Those Logistics Centres (LC) enhance supply chain efficiency by providing transportation and other value-added logistics services such as, multimodality between two transport modes, shared fleet usage, aggregation of loads, highly loaded vehicles, high level of service with optimal delivery scheduling, minimization of the distance travelled and reduction of empty returns. Last-mile logistics depends on structural factors such as the transportation network, the location and capacity of warehouses and supply chain facilities; commercial/market factors related to product and transport demand and supply chain strategies and activities of companies; functional/operational factors associated with vehicle and route planning; as well as policy factors pertaining to government measures and regulations [9]. Collaborations might be a solution for last mile operations and improvements at urban level in social, economic and environmental terms [10]. A common ground for cultivating community-based services is the creation of distribution centers/terminals, e.g. UCCs [8] and [11], able to consolidate items transported by various operators and link properly the operations between long-distance transport and the last-mile. This will enable further cooperation between organizations via the common use of the infrastructure and vehicles for goods distribution or via outsourcing of transport and/or logistics activities, e.g. collaborations between manufacturing (suppliers) and third-party logistics (3PL) (carrier) companies called "transport pooling or shared contract-logistics" [11].

Fleet management is also a quite critical domain when it comes to logistics efficiency. In the European Union (EU), road transport is still by far the predominant mode of transport, with the Heavy-Duty Vehicles (HDVs) representing only 4% of the on-road fleet, while being responsible for 30% of road transport CO2 emissions [12]. However, it is claimed that high-capacity vehicles can decrease the transport cost per unit of load due to fewer required on-road vehicles. There is much that can be done, either by providing regulation constraints for vehicles concerning social and environmental issues, such as the commitment in a binding time window of service, congestion or road-user charges, access rules etc., or by fostering the deployment and uptake of environment-friendly vehicles that produce lower greenhouse gas and pollutant emissions. Besides, ICT systems are a major field contributing to logistics effectiveness and efficiency, since the computerized procedures in freight distribution result in cost reduction from 5 up to 20% while at the same time increasing substantially the level of service [13]. The performance of the last mile is determined by the level of service, the cost of transport and the environmental impact it has, while it is strongly interrelated with the geographical location and the market needs of the operation area [14].

Taking into account these aspects, this article investigates and evaluates the expected impact of the transport and logistics activities of Thriasio Logistics Centre in Greece. A strategic and an operational level of analysis are both conducted and the scope of the current research is twofold; First, a computational simulation in GIS is carried out aiming to present a last mile distribution network dealing with organized transport pooling and vehicle routing operations starting from the LC. The simulation evaluates the efficiency and the impact of the logistics network in terms of cost, customer service, as well as environmental impact. Second, a strategic analysis aims to assess the overall success potential of the logistics complex in relation with economic, social, political/legal, technical and environmental factors. The strategic context of evaluation is covered by means of a SWOT analysis which points out the strengths and weaknesses of the LC and identifies key opportunities and possible threats. The remainder of the paper is organized as follows: Section 2 presents a short literature review about the concepts of last mile distribution and vehicle routing, while Section 3 gives an overview of Thriasio Logistics Centre case and its main operational characteristics. Section 4 focuses on the background and methodology used for this study. Section 5 reports the results and the analysis of the expected impact of the LC on the provider and customer level but also on the region's economy and sustainability. Finally, some concluding remarks are drawn in Section 6.

2 | Short Literature Review – The Vehicle Routing Problem

The Vehicle Routing Problem (VRP) is the most widespread application for simulating and optimizing urban transport and logistics activities, considered for more than 50 years an important operational research and decision-making chapter in transportation and supply chain due to its efficiency and its great outcomes in real-world situations [15]. The goal of VRP is to determine the optimal routes performed at the least cost and the optimal sequence of customers, minimizing the distance traveled by vehicles, the fleet of vehicles and/or delivery time [16]. VRP is an extension of the Traveling Salesman Problem (TSP). It was formulated as a mathematical programming model by Dantzig and Ramser [17]. The problem aimed to solve a real implementation of the optimal routing of a fleet of gasoline trucks between a bulk liquid terminal and a large number of stations. The Dantzig-Ramser's approach was improved a few years later by Clarke and Wright [18] which proposed a real heuristic algorithm. Later, application of VRP was extended to other problems. Dulac et al. [19] and Chapleau et al. [20] proposed solutions for school bus routing in urban areas. The movement of goods to a large city was also investigated in 1990. Hans and Souleyrette [21] have discussed and analyzed the combination of GIS and network-based modeling in Urban Transportation Planning (UTP). Weigel and Cao [22] attempted to solve real-world routing problems by using GIS and optimization techniques. Due to the spatial nature of transportation planning, GISs are recognized as powerful tools for the analysis of transport and logistics problems, plans and policies [23].

VRP family entails a variety of applications and variants. The Capacitated Vehicle Routing Problem (CVRP) is the most common vehicle routing application considering vehicles with limited capacity. An extension of the CVRP where both capacity and maximum distance constraints are imposed is the Distance-constrained Capacitated Vehicle Routing Problem (DCVRP). One of the main VRP variants which is also an extension of the CVRP and widely acclaimed, is the VRP with Time Windows (VRPTW), setting a specific time interval in which the delivery (and/or the pick-up) must be occurred [24]. This VRP application will be used within this study. Other well-known VRP variants that have been modelled pertain to simultaneous pick-up and delivery of goods, namely the VRP with Pick-up and Delivering (VRPPD), to visiting backhaul customers such as vendors in the distribution routes i.e. the VRP with Backhauls (VRPB), to Green Vehicle Routing (GVRP), as well as to heterogeneous fleet

Apostolopoulos and Kasselouris | J. Appl. Res. Ind. Eng. 9(2) (2022) 230-248

of vehicles, i.e. The Heterogeneous Fleet Vehicle Routing Problem (HFVRP), road freight transportation and logistics [15]. In recent decades, extensive studies on VRP models have been reported.

3 | Case Study Presentation: Thriasio Logistics Centre

Nowadays, offering value-added logistics services relies on properly organizing urban freight transport flows, by capitalizing on advanced technological systems and utilizing infrastructure and vehicle equipment. Freight Villages (FVs) could act as the backbone of sustainable urban logistics development based on three domains; a) social: more efficient and high-quality services; b) economic: cost reduction through minimizing vehicle trips and vehicle kilometers and/or empty returns; c) environmental: less emissions, noise and congestion [25]. A Freight Village (FV), also named LC and/or DC, is an entity offering and conducting effective transport and logistics services and activities, adjusting to the needs of the related stakeholders, the local city ecosystems and the environment [26] and [27]. In this research, a case in a strategic place (*Fig.1*) at urban/regional level of Greece is examined, satisfying common city needs such as provision of both consolidation and distribution services, high potential of freight storage and throughput capacity, large geographical coverage and direct transport network connectivity. Thriasio Freight Village/Logistics Centre is a large-scale complex, located outside residential grid, with multimodal and intermodal capabilities, exploiting both a railway terminal and a fleet of 400 trucks that can operate in parallel to gather and carry all sorts of the regional product demand [28].

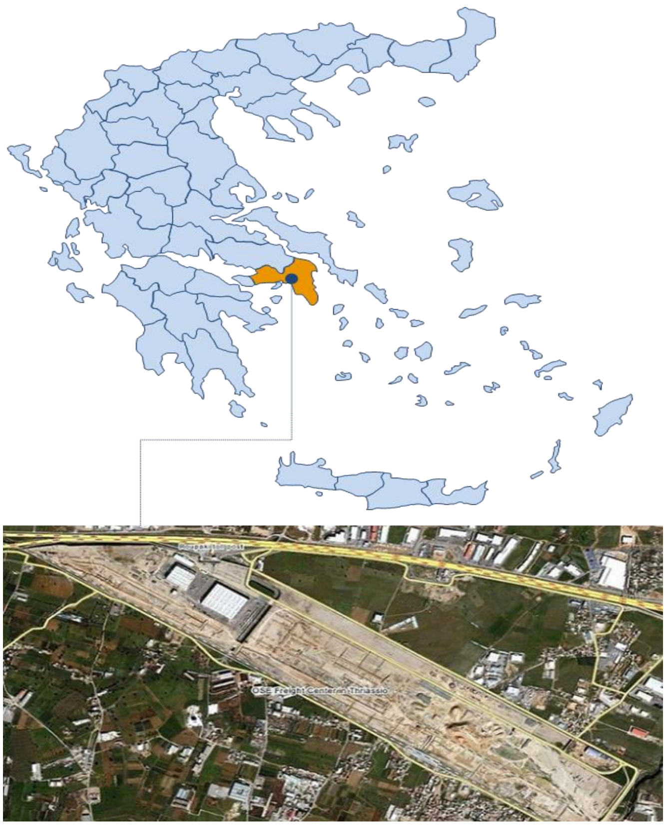

Fig. 1. Location of thriasio logistics centre in Greece.

Thriasio complex is under its last construction phase, whilst already contains a huge sorting site, large cargo storage areas and modern warehousing facilities, as well as two five-storey vehicle terminals and five new office buildings for operation and management activities [29]. It is expected to be fully operational within 2021, and capable to provide a broad range of auxiliary services including customs brokering, heavy vehicle maintenance, waste management and recycling. The foreseen concentrated freight activities by various operators could help achieving significant social, environmental, economic and spatial benefits for the urban population of the capital. The goods warehousing and transport operations are administrated by TrainOSE, a subsidiary of Hellenic Railways Organization. TrainOSE offers an intermodal Cargo Shuttle (iCS) service, aiming to provide, via the truck fleet, on a daily basis, an integrated door-to-door transport between Athens and Thessaloniki axis, by covering the market demands of the two cities and implementing pricing policy that will enable high quality services at competitive costs. In line with that, freight coming inside full containers at Thriasio railway station by rail, are collected at the distribution center facilities, sorted by external partners i.e. shippers/carriers, loaded onto trucks and transported to potential customers [30]. The following Table summarizes key operational characteristics of the LC at Thriasio.

Table 1. Characteristics of thriasio logistics centre.

Variable	Description	Value
Size and usable space	Total space area of warehouses, sites, offices and other uses.	235,000 m^2
Maximum capacity	Potential storage capacity of the facility stated in number of handling units (pallets).	250,000 pallets
Transport equipment	Fleet of trucks / fleet of train wagons.	400 / 50
Handling time	Time needed for loading / unloading per container unit.	20min
Distance from city centre	Number of kilometres from city centre to the facility.	28.9 km
Distance from industrial /commercial zones	Number of kilometres from the DC to the nearest and farthest industrial zone or commercial area.	4.7 km / 55.5 km
Expandability	% expansion potential compared to the current capacity.	50%
Connection to primary motorway network	Direct or indirect access to closest highway and proximity.	<0.5km / direct
Connection to primary railway network	Direct or indirect access to closest railway and proximity.	Inside / direct
Connection to port	Direct, indirect or no access and proximity with Piraeus Port.	23 km / direct
Connection to airport	Direct, indirect or no access and proximity with Athens International Airport.	44 km / direct

4 | Methodology

Thriasio Logistics Centre could be considered as a large-scale UCC, representing the starting point of a collective distribution network serving customers at urban and/or industrial areas. UCCs are designed to provide bundled and organized delivery options. In this context, the transport operations of the LC are elaborated from a transport carrier perspective, in order to evaluate and analyse the expected impacts at operational and strategic level. At operation level, the methodology entails the design of a pooled distribution network and scenarios analysis of vehicle routing in GIS [31] towards the estimation and assessment of critical parameters/indicators. The organized distribution network could be relevant to a Small-Medium Enterprise (SME) of a transport operator, located at the Thriasio Logistics Centre providing transport pooling services and delivering orders to customers located in specific key areas of Attica, with an available shared fleet of homogenous vehicles. For this purpose, the connectivity of Thriasio Logistics Centre with the industrial zones of the Metropolitan Region of Attica, is considered. ArcGIS software is used for the modeling of the network and the VRP resolution.

The GIS analysis was selected in order to associate spatial data i.e. road network data with other related inputs such as logistics attributes, fleet characteristics and operational parameters e.g., demand, vehicle capacity and speed, fuel consumption, transport cost, handling time etc.; visualize the connectivity of the network as well as display the routes. However, addressing the needs and challenges arising from the logistics operations of Thriasio complex requires also an organizational level of analysis that classifies those features and perspectives and leads to effective decision-making responses. At the strategic level, a standard, comprehensive and effective evaluation tool, based on a multi-stakeholder decision making structure, is a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis [32]. Hence, the viability of the LC is assessed against relevant strategic criteria through a SWOT analysis. The outcomes

Apostolopoulos and Kasselouris | J. Appl. Res. Ind. Eng. 9(2) (2022) 230-248

and the conclusions could be useful for planners, researchers and practitioners, in their efforts to adopt future sustainable strategies across a wide spectrum of vectors in freight transport and urban logistics in Greece and worldwide.

The presented twofold approach aims to investigate all components of the logistics system i.e. infrastructure, network, services and vehicles, through the integration of two alternative, yet complementary types of analysis in urban logistics, including five (5) steps explained briefly below:

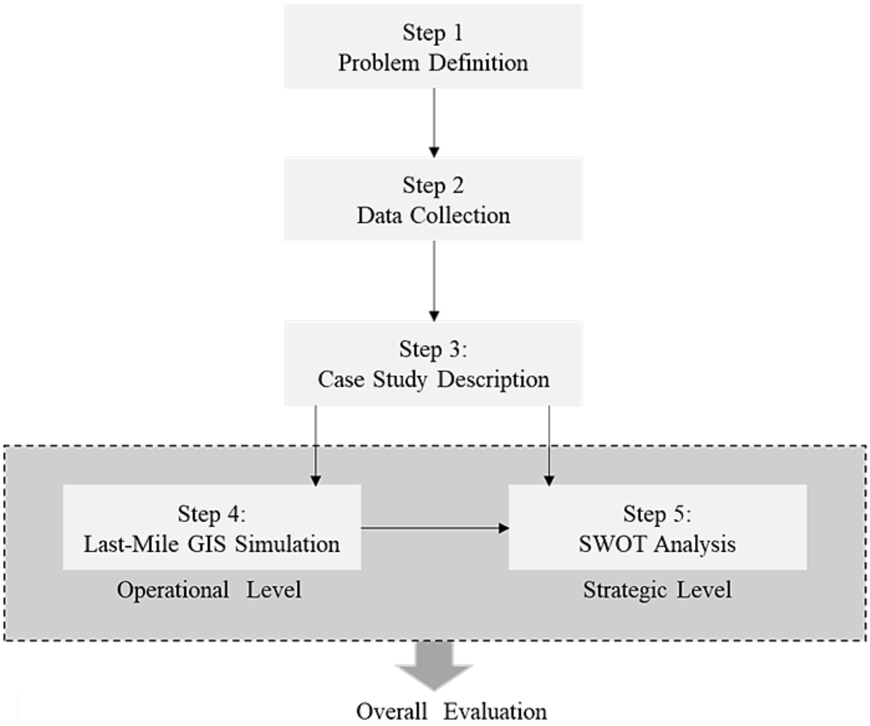

Fig. 2. Proposed 2-level and 5-step methodological approach.

Conceptualization & definition of the specific urban logistics problem: With a view to address the effervescent topic of sustainable urban freight transport and logistics, in particular in Greece, the anticipated operation of a large logistics complex in the Attica region was selected for primary pre-functional evaluation that will lay the foundations of potential solutions to be adopted at strategic and operational level.

Data Collection: An extensive number of technical reports and research articles as well as national plans and data sources were taken into account in order to obtain key insights about the current state of Thriasio Logistics Centre and the logistics sector in Greece.

Case Study Description: The main characteristics and activities of Thriasio Logistics Centre and industrial/commercial areas of Attica are presented and highlighted.

Last-Mile Logistics in GIS: Building upon specific scenarios of transport pooling and goods distribution from Thriasio Logistics Centre to industrial areas, this step deals with the operational level of analysis including the design of the distribution network, the definition of the logistics processes, the vehicle routing simulation, a sensitivity analysis for examining the influence of key variables on the transport and the use of suitable indicators for performance evaluation.

SWOT Analysis: Under the consideration of key related factors and the perspectives of all involved stakeholders, the potential enablers and barriers for realising the transport pooling potential as well as facilitating synergies and multimodal schemes in urban logistics from the operation of Thriasio Logistics Centre have been identified.

4.1 | Last-Mile Logistics – GIS Design of the Pooled Delivery Network and VRP Formulation

As a first step, a transport network in GIS environment is designed for modelling the last mile operations of the Thriasio Logistics Centre in relation with the industrial areas of Attica region. Then, a simulation approach is followed in order to solve the VRP, based on spatial network data as well as on a set of vehicle properties and logistics attributes. According to the modelling approach, a transport carrier enterprise located at Thriasio Logistics Centre (the depot) provides transport pooling services and delivering orders to customers located within the industrial zones of Attica (service stops), using an available fleet of similar vehicles with specific capacity. The geo-referenced road data for the construction of the transport and last-mile delivery GIS-based network were downloaded from OpenStreetMap (OSM) platform [33] in shapefile format and imported in ArcMap for the design. Then, the VRPTW is simulated by the ArcGIS Network Analyst [34], in order to determine which requests should be satisfied by each route and also in what sequence they will be visited, by setting as a primary goal to minimize the overall operating cost for the fleet of vehicles that best fulfill the deliveries. To this end, an Origin-Destination (O-D) matrix of the shortest-path costs between the industrial areas and Thriasio location is created. The optimal solution is calculated based on a tabu-seach metaheuristic algorithm of ArcGIS.

In an attempt to present a real-world application as accurately as possible, the current status of specific land uses pertaining to industrial activities in Attica was investigated. This exercise helped us to have an overview of their location and connectivity with Thriasio Logistics Centre as well as of their size and business potential. Relevant information for the industrial zones and commercial areas of Attica was gathered, based on research from previous technical studies, review of both scientific and grey literature and historical data of industrial, logistics or statistical associations. The industrial zones typically cover large geographical density and market penetration of the urban context in Attica region. According to the survey, land areas can be classified as industrial zones when a broad range of industrial and/or manufacturing activities are being performed within them. However, there are also fully organized industrial and manufacturing sites, which have been constructed in compliance with a strategic urban and spatial planning, based on techno-economic, social and developmental criteria. Areas that involve a significant industrial sector as well as large-scale industrial and/or commercial activities in Attica region are the industrial zones of Metamorfosis, Kifisia, Acharnes, Agios Stefanos, Krioneri, Magoula, Elefsina, Aspropyrgos, Peristeri, Eleonas, Faliro, Koropi and Peania as well as the industrial parks of Keratea, Schisto and Ano Liosia Kapoutsi and Kakkavas [35]. This resulted in considering a total number of 16 industrial areas in the VRP model.

More specifically, after properly editing the OSM data in ArcGIS for compatibility to simulation purposes, a simplified network was created containing only the motorways and the primary and secondary roadways of Attica. Given that each transport network consists of two kinds of elements; a set of points (nodes) which are potential location stops and a set of linear parts (arcs) joining these points, which represent the trajectory and distance between each two nodes [36]; the developed network comprises a number of 15090 junctions (arcs) and of 37684 linked edges (nodes). In this context, specific nodes of the distribution network should be defined as the starting point of the LC and the order points of potential customers, representing the origin and destination of the transport flows. Hence, one of those edges represents the location of the FV of Thriasio whilst the order stops were placed in 16 edges within the industrial/commercial zones, which have been selected to be the centroids of the zones. The transportation requests are considered as tasks on those specific edges, although companies are located densely along a street segment of the industrial areas. As already stated, the distances of the edges of the industrial zones from Thriasio specific edge as well as the distance between each two of them in the network are calculated by an O-D Matrix. The distances of the industrial areas from Thriasio Logistics Centre are shown in *Table 3*. As already stated, apart from transport network objects and infrastructure

Apostolopoulos and Kasselouris | J. Appl. Res. Ind. Eng. 9(2) (2022) 230-248

characteristics, numerous logistics attributes, fleet characteristics and policy measures affect the last-mile distribution comprising necessary inputs in the model, including but not limited to:

– *The vehicle properties; the size and type of vehicles i.e. vehicle capacity, speed and fuel consumption.*
– *The customer/market demand.*
– *The handling activities e.g., the time required for loading/unloading of vehicles.*
– *The service policy e.g., a specific time interval for the deliveries could be imposed by the customer or by the city's logistics planning measures.*
– *The fleet its own, i.e. the total number of vehicles as well as the routes performed by vehicles.*
– *The costs of the transportation and logistics activities.*

We note here that several simplified assumptions have been taken into account to facilitate the VRP simulation process. First of all, the model assumes that the deliveries in the industrial areas are performed on a daily basis, but in compliance with imposed time windows considered as governmental policy measures and/or customer-oriented scheduling strategies of the transport carriers. Based on common practice, a delivery time window between 8 a.m. and 10 a.m. is adopted. Moreover, in order to evaluate the level of service in terms of on-time successful customer deliveries, the handling activities at customer locations and their required time are also taken into account in the model. The time duration required for unloading the vehicles at each demand stop is composed of a fixed time interval of 10 min for vehicle positioning and parking inside the industrial area, plus 1 min per each load unit handled. The simulation starts after consolidation of loads at the sorting site of Thriasio Logistics Centre, thus the loading time of the vehicles is assumed to zero.

Regarding the vehicle aspect, key fleet characteristics such as the vehicle capacity, vehicle speed and fuel consumption are inputs in the model. Urban freight is more polluting than long-distance freight transport because vehicles are on average older and perform a large number of short trips and stops. According to ACEA surveys (2020), 59% of road transport in the country is performed by vehicles older than 10 years, while also the average truck age is above 20 years [37]. This is the last place among the EU countries, leading to a negative impact on quality of services, transport costs and emissions. Due to the fact that high-capacity vehicles allow a 50% increase in truck loads and lower costs by 20% per tonne-kilometre, it could be claimed that those vehicles could contribute to lower emissions, decreased urban traffic and even further reduced transportation costs due to economies of scale [38]. In addition, the vast majority of transport carrier companies in Greece possess a small fleet of vehicles of 1 up to 5 trucks [39]. Based on those two facts, it was assumed for the model that a small haulage firm operates five 5 large articulated (>33t) HDVs. For the vehicle speed, a mean value of 50km/hr was taken, considering the average speed limits of HDVs in Europe. For the simulation and calculation of each parameter we assume all trips are made by a representative EURO VI truck. An average mileage of approximately 100,000 km annually was considered.

Demand is related with the points of the network which are customer locations and represents the transportation requests that should be satisfied daily. For these specific nodes, a demand should be assigned. The demand and delivery unit of the model, after sorting and consolidation activities of cargo at Thriasio, is the standard europallet, as defined by the European Pallet Association (EPA). These pallets have dimensions of 1200x800 mm and can lift an average load of 1500 kg [40]. Truckload per pallet is considered equally-weighted to simplify the analysis. The vehicle is classified to a length of bodywork at 13.6m. The capacity of the vehicle is thirty-three (33) Europallets, which is exactly the same with a 45' feet Pallet Wide/High Cube Container (*Fig. 4*).

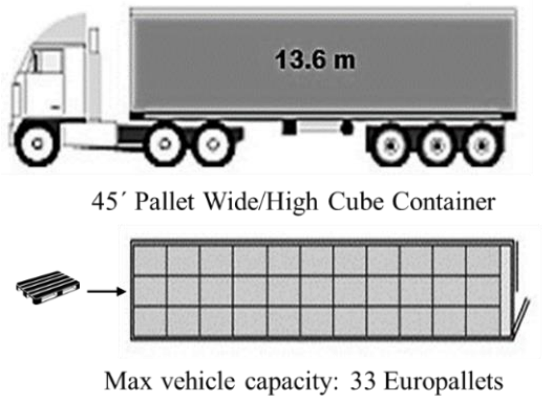

Fig. 4. Model vehicle of the analysis.

Due to lack of customer demand data, a simplified approach was followed to allocate potential demand values in the model related with the number of companies settled in each industrial region. In this regard, the average number of enterprises/companies with industrial and manufacturing or wholesale business activity currently in these sites was roughly estimated from statistical data [41]. Subsequently, a weighting-factor analysis for estimating demand has been introduced. Weights have been used to describe the ratio of enterprises' records per area compared to the total enterprises' records. The sum of weights across all areas is obviously equal to 1. The method involves the computation of a weight for each population of companies in the industrial areas independently and then the multiplication of the weights with the maximum vehicle capacity, resulting in an estimate of total demand. However, at the end of the day, the method produced adjusted demands, due to a demand constraint imposed in order to serve in a fair and just way all customers. In this context, freight demand is subject to an upper bound associated with the total capacity of all vehicles and the total number of customers, concerning that demand must not exceed the average demand of 10 pallets for each customer per travel. The spatial and demand characteristics of the industrial zones required for the analysis are presented in *Table 2*.

Table 2. Characteristics of industrial/commercial zones.

Area	Distance	Enterprises	Weights	Calculated Demand	Final Adopted Demand
Metamorfosis	17.5 km	100	0.1212	20	10
Kifisia	21.0 km	25	0.0303	5	5
Acharnes	18.8 km	25	0.0303	5	5
Agios Stefanos	30.3 km	70	0.0848	14	10
Krioneri	28.7 km	40	0.0485	8	8
Magoula	5.5 km	50	0.0606	10	10
Elefsina	8.3 km	40	0.0485	8	8
Aspropyrgos	4.7 km	100	0.1212	20	10
Peristeri	20.3 km	20	0.0242	4	4
Eleonas	24.1 km	40	0.0485	8	8
N.Faliro	27.3 km	10	0.0121	2	2
Koropi	45.5 km	80	0.0970	16	10
Peania	35.7 km	70	0.0848	14	10
Keratea	55.5 km	40	0.0485	8	8
Schisto	16.1 km	80	0.0970	16	10
Ano Liosia	9.6 km	35	0.0424	7	7
TOTAL	-	825	1.0	165	125

Although customer service is an integral part of logistics efficiency, cost reduction is also essential to keep within the budget and increase profits. Transport cost is affected by: i) distance-related costs e.g., vehicle costs and toll costs, ii) time-related operating costs pertaining to the handling activities as well as to personnel costs i.e., the wages of the truck drivers, resulting in a total cost per unit time allocated to each specific route or trip. The whole transport costs entail also iii) fixed costs relating to depreciation, insurance and taxes etc. Total distance-related (travel) costs are mainly divided into fuel costs, tire and maintenance costs, and toll costs. Fuel cost usually accounts for the largest proportion of transportation costs [42]. An average cost of 0.6 € per kilometre (€/km) was considered, in order to estimate fuel costs, based on the average diesel price of 1.30 €/lit, during the last 5 years in the fuel market in Greece [43]. We also assume an average fuel consumption of approx. 45.5lit/100 km for performing a mixed loaded and empty route in medium congestion conditions [44]. For tire and maintenance costs, which represent a relatively small share of the total transport costs, we consider the values adopted by the European Commission [45] that result in a spending of 0.17 and 0.146 additional euros on tires and maintenance respectively for every euro spent on fuel during a trip. Toll costs exist only in specific nodes relating to the toll stations of "Attiki Odos" motorway, accounting for 11.30 €, based on the price policy of the motorway infrastructure provider. All distance-related costs are taken to be constant between all arcs in the developed network. It should be stated here that due to the high uncertainty of estimating relevant values, personnel costs and fixed costs were not considered in the model. Moreover, it is argued that vehicle occupancy should overpass 80% (very higher than the industry average of about 50% [46]) in order to contribute to an effective transport in terms of time and cost, while in parallel using for the operations the lowest number of vehicles from the available fleet and managing to satisfy all orders.

The environmental impact is examined through estimating the CO2 emissions of the used vehicles. CO2 emissions lying under this analysis pertain only to the tailpipe emissions during operation of the freight vehicles. Estimation is based on an intensity ratio of kg CO2, eq per pallet. An average distance emission factor of 0.6626 kg CO2 eq/km for an articulated (>33t) diesel truck is considered [47]. The set of the most important assumptions have been made, are presented in *Table 3*.

Assumption	Value/Status	Description
Last-Mile Vehicle Routing	Daily	All deliveries refer to daily level starting at 08:00.
Network	GIS	Road network geo-referenced, 15.090 junctions and 37.684 edges.
Customer Demand	Weighted	Generated with weighting factor analysis considering relation with the average number of enterprises per area / must not exceed vehicle capacity / given in number of pallets.
Depot	1	Thriasio Logistics Centre [LC / FC / FV / DC / large-scale UCC].
Customers	16	Points within the 16 industrial/commercial areas (centroids).
Vehicles	5	A homogenous fleet type whereby all vehicles have the same loading capacity.
Vehicle Speed	50 km/h	Mean value – Average speed limits of HDV > 3.5 ton in Europe assumed.
Vehicle Capacity	33	Vehicles have a fixed limited capacity of 33 Europallets.
Fuel Consumption	0.6 €/km	Applicable for an average market diesel price of € 1.32/ lit. Reference value in agreement with EU logistics reports.
Cost	Distance-related	A cost function considering distance-based transport costs was inserted in the VRP model.
Emission Factor	0.6626 kg $CO_{2,eq}$/km	Average value for an articulated diesel HDV over 33 ton.
Travel Time	di/υ	Mean value of travel time between two nodes with trip distance di.
Open Time	8.00 a.m.	The earliest start time of service to an area.
Fixed Time Interval	10min	The standard customer stop time.
Unit Time Interval	1min	The service time required for unloading each load unit.
Close Time	10.00 a.m.	The slower service or return time to the distribution center.
Loading Time Interval	-	Vehicles start the scheduled departure time (equal to zero).

Table 3. Key assumptions for last-mile GIS & vehicle routing analysis.

The vehicle routing simulation deals with the optimization goal of minimizing the total distance traveled in order to reduce costs. The performance of the pooled last-mile network supported by the LC, is assessed against a set of three indicators in three different critical domains, noted below:

Table 4. Last-mile indicators.

Domain	Indicator
Level of service	Satisfied deliveries within imposed time window.
Cost	Transport costs of the performed activities.
Environmental impact	CO2 vehicle emissions.

5 | Analysis & Results

5.1 | Last-Mile Logistics – VRP Simulation

This part presents the results obtained from the proposed vehicle routing model for last mile distribution described in the above Section 4.1, considering the designed GIS network, a service time window of 8.00 a.m.-10.00 a.m., weighted demand values and specific model vehicle characteristics. The main transportation network between Thriasio FV and affiliated industrial sites in Attica region along with the optimal routes of the reference scenario are illustrated in *Fig. 5*. All deliveries are satisfied within the time window by the 4 out of the 5 vehicles of the fleet. Results show that all vehicles prefer the central road arteries of the network to make the deliveries than using the smaller roads within the urban fabric or “Attiki Odos” motorway due to high toll expenses.

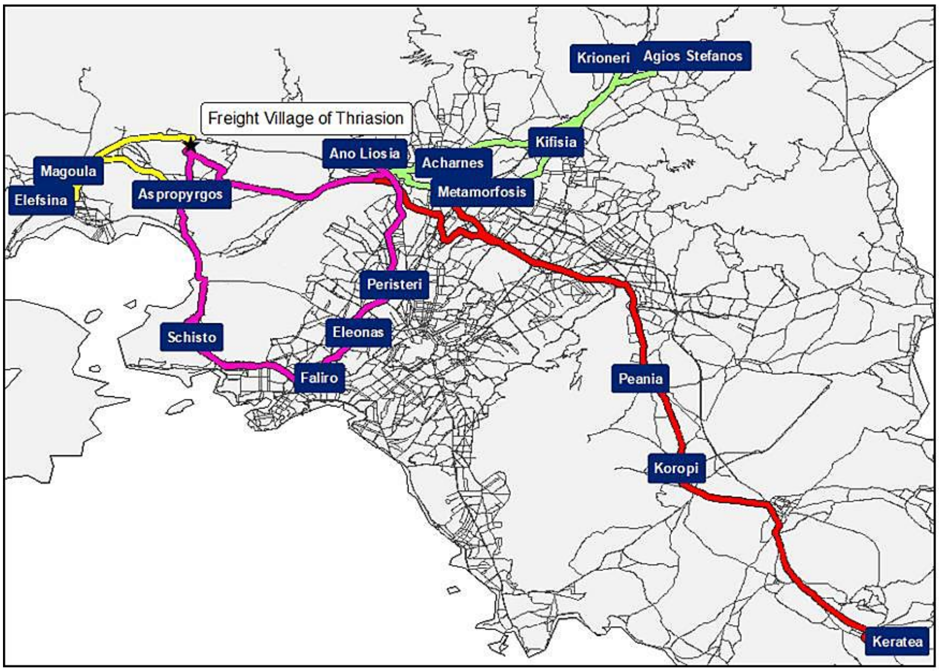

Fig. 5. Transportation network and reference scenario.

Table 5 summarizes the quantified results of the scenario for distance, total time, cost, CO2 emissions and utilisation of each vehicle per route performed. Total travelled distance is equal to 279.1 km. The fuel costs incurred from the vehicle routing of the specific fleet account for €167.5, while the distance-related costs calculated by the model are equal to €220.4 leading to a unit cost of €1.8 per pallet for the company, while the occupancy of vehicles is high for all projected routes resulting in an average value over 94%. The vehicle emissions of the fleet are calculated to 184.94 kg CO2 eq, which corresponds to approximately 1.48 kg CO2 eq per pallet.

Apostolopoulos and Kasselouris | J. Appl. Res. Ind. Eng. 9(2) (2022) 230-248

Table 5. Vehicle routing – reference scenario results.

Route [#]	Distance [km]	Total Time [min]	Cost [€]	Emissions [kg]	Occupancy [%]	Sequence
1	64.7	159	51.09	42.87	94%	Ano Liosia, Peristeri, Eleonas, Faliro, Schisto
2	66.7	153	52.67	44.20	100%	Agios Stefanos, Krioneri, Kifisia, Metamorfosis
3	120.9	218	95.46	80.11	100%	Acharnes, Peania, Koropi, Keratea
4	26.8	90	21.16	17.76	85%	Magoula, Elefsina, Aspropyrgos

5.2 | Sensitivity Analysis

In order to determine how and whether varying values of a specific variable such as vehicle speed, vehicle capacity, fuel price, affect the dependent variables of vehicle routing namely routes, satisfied deliveries, costs and emissions, a sensitivity analysis was carried out using simulation scenarios for the designed model of Thriasio Logistics Centre last-mile operations. Sensitivity Scenario 1 (SS1) – Vehicle Speed: an increased vehicle speed equal to 80 km/hr is considered (based on the max EU speed imits for HDVs), while all other independent variables remain constant, in order to examine the effect on the vehicle routing and associated outputs. The results obtained by the model are quite similar, with all orders being delivered on time by the same number of vehicles, while some differencies are occurred for 3 out of the 4 routes in the served customer locations, presented in the Table below. The 4 out of 5 vehicles used, have travelled a total distance of 300.4 km in a timeframe 110 min shorter than the reference scenario. The costs calculated by the model are slightly higher, equal to €237.2 representing a unit operational cost of €1.9 per pallet, while total emissions of the used fleet are calculated to 199.04 kg CO2 eq, corresponding to 1.59 kg CO2 eq per pallet.

Table 6. Vehicle routing – SS1 results.

Route [#]	Distance [km]	Total Time [min]	Cost [€]	Emissions [kg]	Occupancy [%]	Sequence
1	127.5	168	100.67	84.48	97%	Keratea, Koropi, Peania, Peristeri
2	82.8	144	65.38	54.86	97%	Acharnes, Eleonas, N.Faliro, Schisto, Ano Liosia
3	63.3	120	49.98	41.94	100%	Metamorfosi, Kifisia, Krioneri Agios Stefanos
4	26.8	78	21.16	17.76	85%	Aspropyrgos, Elefsina, Magoula

Sensitivity Scenario 2 (SS2) – Vehicle Capacity/Fuel Consumption: in this case, the use of a fleet of smaller trucks with max carrying capacity equal to 25 pallets is taken and potential effects on the vehicle routing variables are investigated. Smaller trucks are more flexible in urban areas and economic in terms of fuel consumption but a larger number (fleet) of vehicles is required to meet demand. In this context, a constant fuel consumption rate of 34.5 lit/100 km for the available fleet of the 5 vehicles is assumed [44], resulting in an average fuel cost of approx. 0.45 €/km.

Table 7. Vehicle routing – SS2 results.

Route [#]	Distance [km]	Total Time [min]	Cost [€]	Emissions [kg]	Occupancy [%]	Sequence
1	63.2	131	37.43	41.88	100%	Metamorfosis, Kifisia, Agios Stefanos
2	78.3	149	46.37	51.88	100%	Ano Liosia, Krioneri, Schisto
3	61.4	129	36.36	40.68	100%	Acharnes, Magoula, Aspropirgos
4	63.4	138	37.55	42.01	88%	Peristeri, Eleonas, N.Faliro, Elefsina
5	91.0	149	53.89	60.30	80%	Koropi, Peania

In this scenario, the 5 available vehicles cannot satisfy all deliveries within the imposed window. More specifically 15 out of 16 demand stops were served on time in the 5 routes performed by the vehicles, while it was not feasible by the model to serve the customer located in Keratea (location demand of 8 pallets requires an extra itinerary) between 8.00 a.m.-10.00 a.m. The total distance traveled by the 5 vehicles is 357.3 km. Total costs required for the satisfied deliveries account for €211.6 or €1.8 per pallet, while total emissions of the used fleet are calculated to 236.75 kg CO2 eq, corresponding to 2.02kg CO2 eq per pallet. Results show the higher environmental impact of smaller vehicles.

The fact that the last-mile distribution to the industrial areas relies on a transportation system in which the vast majority of industrial areas are geographically scattered across Attica region in a way being directly and easily connected to the highway network, renders larger vehicles better choice for the transport. The whole logistics potential of the Freight Centre (FC) can be grounded on a distribution approach considering the parallel operations of 80 similar SMEs/companies with a fleet of 5 vehicles located at Thriasio.

The FC is assessed from the carrier perspective against the operational level criteria of service quality, cost and environmental impact, towards facilitating consolidation practices, efficiency of deliveries and economies of scale. In this context, Thriasio Logistics Centre can play a key role when it comes to sustainable planning of logistics to industrial and commercial zones, due to the fact that the various operators that will be settled at Thriasio Logistics Centre may improve their logistics performance owing to the concept of economies of scale. Thus, a positive impact is most probably expected from the FC transport operations in terms of cost reduction, congestion reduction in urban areas, air quality and road safety improvement.

Economies of scale in transportation refer to economies of distance, economies of vehicle capacity, economies of fleet size, whereas in logistics refer to economies of facilities and infrastructure [48]. Thriasio Logistics Centre can serve as a major contributor to fulfill all these aspects. It should be noted here that another significant factor that may affect considerably the operations is customer demand. We have excluded a sensitivity analysis for demand from the simulation scenarios due to the high uncertainty, though. In addition, increased values of diesel price could be taken into account to estimate their potential impact on the fuel costs of the vehicles in the model.

5.3 | SWOT Analysis

A SWOT analysis was carried out for the Thriasio Logistics Centre, to figure out those significant components reflecting the impact of its development and operation and point out key outcomes that may emerge. The SWOT analysis assisted in identifying beneficial areas, challenging issues, and potential problems, thus allowing to get a picture from a holistic perspective of transport planning activities. Hence, it could form a solid basis for achieving key overarching goals and objectives and implementing sustainable strategies, capitalizing also on a long-term and multi-level approach that will take into account the opportunities and threats arising for the transport and logistics activities of Thriasio Logistics Centre at urban, regional and national level in Greece.

The preparation of the SWOT analysis was based on the consideration of a broad range of critical and interconnected economic, social, policy and environmental factors supported by a set of qualitative and quantitative data which enable comprehensive decision-making. The SWOT framework analyses each component with regard to a sustainable urban logistics strategy. *Table 8* summarizes the key outcomes of the SWOT analysis of the Thriasio Logistics Centre in Greece. The outcomes are further elaborated.

Apostolopoulos and Kasselouris | J. Appl. Res. Ind. Eng. 9(2) (2022) 230-248

Table 8. SWOT analysis for thriasio logistics centre in Greece.

Strengths	Weaknesses
•Ease of accessibility and high connectivity - direct connection to Piraeus port, AIA airport and forming part of the Trans European Transport Network (TEN-T). • Point-to-point and terminal-to-terminal transport and market coverage capabilities (multimodality). • Availability of large storage and throughput capacity as well as high class infrastructure facilities and sufficient transport equipment with high load factors. • Offers a lot of additional services apart from handling of loading units and goods transportation. • Extremely large geographical coverage due to its location and proximity of industrial/commercial areas as well as possibility of expansion to meet growing demand. • The complex is partially self-financing, generating revenue in the form of fees from users of the infrastructure. • Companies that have small and low-quality warehouses move to new well-designed facilities where they may reap the benefits of "economies of scale".	• Administration and coordination of transport and logistics management activities are made by a single organization, thus requiring high capital investments and high operating costs by an external user. • Opposition of suppliers due to high degree of competition between companies • Insufficiency of synergies and collaborations in the supply chain sector of the region currently. • Inefficient operation of numerous freight transport and logistics services providers. • No active engagement and support of citizens and multiple actors/stakeholders in the Thriasio Logistics centre operations. • Prone to accidents owing to concentration of large amounts of dangerous goods within the facilities. • The centralization of logistics activities may increase the vulnerability of the road network in the vicinity of the Thriasio complex.
Opportunities	**Threats**
• Support of synergies and consolidation strategies for urban deliveries as well as creation of clustering business networks will render multimodal and intermodal transport economically viable • Greece is dominated by the service sector and uses outsourcing at 70% in national transport activities • The covid-19 pandemic triggers great investment interest in urban logistics with high potential impact on economic growth and contribution to revenue generation for enterprises and city ecosystems. • Cultivation and promotion of organized and more sustainable last-mile freight transport with direct impact on fewer vehicles on the road and reduced emissions. • EU policies and new logistics business models at urban level permit to achieve high level of service by means of synergies and UCCs • Advances in technology (IoT, blockchain, ITS) facilitate last mile operations, reduce transport costs and make on time delivery possible • Upgrade of transport networks, aiming at the promotion of regional development and social cohesion	• Lack of a solid national regulatory framework for urban logistics - Needs further development, update and improvement towards simplifying procedures and authorization/licensing systems of logistics • Volatility of market and transport prices - supply risk • Reliance on the existing fleet of trucks in Greece having an average age over 20 years and most of them small capacity • Scarcity of incentives for transit cargo management and other added value services • Not fully developed operating railway network in Greece, with low utilization rates, many single-track line parts, relatively limited electrification/modernization and a large number of level crossings, resulting in extremely high dependency on road freight transport (over 98%) at urban level but for long distances as well. • Lack of certification and standardization schemes to efficiently support transport and logistics operations. • Lack of political will for rationalization and liberalization of the logistics sector leads to the partial release of freight transport in the country.

5.3.1 | Strengths

One of the major advantages of Thriasio Logistics Centre is the strategic geographic location of the facility, which is an asset for the region, thus rendering it suitable for the city's railway and highway mixed-mode freight transportation. The complex has direct connectivity with the main road network of Attica and easy accessibility by freight transport carriers and high-capacity vehicles. The FC incorporates the largest national railway terminal which consolidates a set of various logistics activities inside its area e.g., transshipment, sorting etc., while offering also direct connection to the Trans European Transport Network (TEN-T). It is very close to the port of Piraeus and connected both by road and rail. Given that the wider Athens metropolitan area accommodates a vast amount of commercial, industrial and logistics companies, Thriasio Logistics Centre comprises an integrated FC with capabilities of extremely broad geographical coverage and further expansion.

With regards to the operational aspects, its facilities have sufficient capacity and the required infrastructure, transport and mechanical equipment for unlocking growth potential. The transport and logistics companies located at Thriasio aim to organize and expand their transport operations collectively, since they are now settled to new, well-designed and larger space areas where they will take advantage of economies of scale. The operational costs are to a certain extent self-financed by the administrating organisation, whilst additional revenue streams will be generated also from rental fees. Economies of scale are considered to be important and viable.

5.3.2 | Weaknesses

From an economic perspective, an important factor that hinders the growth of the freight centre is the high investment cost needed by the external transport operators and logistics companies for using the land, the equipment and the infrastructure provided by the complex. The overall coordination is strongly dependent on a single organization, the largest national industrial landowner which undertakes the development and management activities, thus monopolizing the internal logistics centre administration and market design and shapes the strategy for consolidation of freight flows. An economies of scale approach is needed by suppliers and carriers in order to effectively support transport pooling. However, a first shortcoming that could contribute negatively to the economic growth of the freight centre is the high degree of competition between suppliers, which may hinder the consolidation strategies and activities. In addition, suppliers may put pressure on operating companies and customers regarding product availability and pricing policies.

A couple of weaknesses that are also important because they are considered as major risks for the local community as well as the services providers are; firstly, the centralization of logistics activities which may increase the vulnerability of the road network in the vicinity of the Thriasio complex thus affecting the logistics performance, and, secondly, the large amounts of dangerous goods concentrated within the facilities, which rise dramatically the possibility of an accident. On top of that, various freight transport and logistics services providers are characterised by inefficient operations at urban level, which may lead to low customer satisfaction. Lastly, the operations of the logistics centre require more active participation of the local community in terms of citizen and stakeholder engagement.

5.3.3 | Opportunities

The creation of Thriasio Logistics Centre provides unique opportunities for the future. First of all, an increased promotion of synergies and consolidation strategies as well as the development of clustering business networks in urban logistics will ensure the economic viability and enable the multimodality of freight transport. Taking into consideration that the share of 3PL companies for transport activities is about 70% in Greece, the freight centre could play a key role for sustainable urban logistics planning in Attica region. The adoption of new sustainable business models pertaining to e-commerce logistics, green & reverse logistics etc. will foster city logistics synergies and deployment of large-scale UCCs and will cause a dramatic restructuring of the supply chains in the urban context that may result in reliable, flexible and tailored services. In addition, the technological capabilities of Industry 4.0 such as IoT and Blockchain can further be exploited to support supply chains in ensuring just-in-time deliveries, the highest level of quality and considerable cost reduction. The economic impact of the current covid-19 crisis on the supply chain has propelled great investment interest in urban logistics which can be the catalyst for transport and logistics transformation towards business growth and generation of revenues for enterprises and city ecosystems in the greater Athens metropolitan area.

The freight centre is capable of providing organized and more sustainable last-mile logistics generating further urban, societal and environmental benefits for the Attica region such as reduced traffic and emissions and improved air quality. The potential operability by all freight transport modes is very important aspect that will play a key role in the logistics efficiency. Overall, taking into consideration the entire logistics and distribution potential in a radius of approximately 50-60 km from its location, the operation of Thriasio Logistics Centre will cultivate the economic environment for the upgrade and improvement of all transport networks of Attica, leading to regional development and social cohesion.

Apostolopoulos and Kasselouris | J. Appl. Res. Ind. Eng. 9(2) (2022) 230-248

5.3.4 | Threats

One major problem in Greece is that the national policy and regulation framework is not well-established and does not provide a solid basis to enforce or facilitate the sustainable development of supply chain and logistics in the urban areas. Hence, the importance of optimized and simplified procedures as well as robust authorization and licensing systems in logistics is relatively high for the economy and the prosperity of the city, which is mostly reliant on the services sector. In addition, the proliferation of certification and standardization schemes for transport and logistics operations is needed to assist in promoting acceptable social and environmental practices in urban logistics. On top of that, the present low number of synergies and collaborations in the supply chain sector can make things even more difficult. The overall poor performance of urban logistics in the country relies also heavily on the existing bureaucracy and rule of law.

Regarding transport infrastructure in Greece, a problem is that the railway network is currently not fully developed and characterised by low utilization rates, many single-track line parts, relatively limited electrification and modernization and a large number of level crossings, contributing to a dominant use of road freight transport with a share of over 98% for the national transport activities, affecting transport multimodality. Another major issue lies under the fact that the transport and logistics activities currently in Greece rely on a very old fleet of trucks with an estimated average age over 20 years, whilst most of them are also small capacity vehicles. In addition, the volatility of market, energy and transport prices may pose a great risk for the freight centre and the supply chain operations as a whole.

A huge problem for the transport pooling concept and last-mile distribution in Greece is the lack of political will for the rationalization and liberalization of the logistics sector, which has led to the partial release of freight transport in the country that may further demote the optimal utilization of resources and logistics efficiency. There is need for designing a sustainable urban logistics strategy that considers multiple actors in both public and private sectors, resulting in closer cooperation of government with the local authorities as well as suppliers, and motives for the logistics sector.

6 | Conclusions

This paper tried to show and evaluate the case of a large LC in Greece serving the needs of the main industrial areas close to the urban context, based on a twofold approach using GIS simulation and SWOT analysis. The study identified key benefits and problems that may play a key role in the evolution of Thriasio Logistics Centre and the logistics sector as a whole in Greece. The analysis indicated that transport activities are strongly associated with a set of critical factors affecting considerably the logistics performance of Thriasio Logistics Centre. More specifically, the freight transport performance pertains to the specific vehicle characteristics (capacity, cost, utilization, fleet, age, vehicle type) and transport demand (volume of moving loads and number of customers), the network (geographic locations, connectivity, functional capabilities, network infrastructure, the served areas), the logistics facilities (usable space, services, operational capabilities, warehouses) along with the available equipment and infrastructure, as well as the potential synergies and economies of scale from the enterprises located at Thriasio. The main advantage is that Thriasio is situated in a key area which is in direct connectivity with road and rail freight transport modes as well as closely to the biggest port of Greece, suitable to serve not only the industrial demand flows presented in this study but also to support much greater freight flows, operational capacities and market needs. Due to the fact that transportation is the most expensive process of supply chain and logistics, the greatest challenge to tapping into the logistics potential of Thriasio Logistics Centre lies in increasing the rate of synergies, creating clustered business networks and managing critical factors collectively, such as facility usage costs, carrying capacity utilization, vehicle emissions, fuel economy and trips per day. Overall, this study concludes that Thriasio Logistics Centre can serve effectively as an organized logistics distribution network for the last mile deliveries to the industrial areas of Attica region, contributing to significant cost reduction for the transport companies and lower environmental impact for the region.

The analysis drew also the conclusion that there is much that can be done at national and local level in order to promote and support effectively supply chain operations. An effective collaboration between all involved stakeholders in logistics in order to establish policies and demonstrate processes that can positively contribute to more cost-effective, cleaner and faster deliveries is required. According to the national logistics action plan, the legal framework and technology constitute the two main focal points in the spotlight. In particular, the regulatory framework should be reformed and updated in order to address the significant shortcomings it has in terms of authorization and licensing of companies, standardization and rationalization of freight transport and logistics activities, but most importantly in order to impose sustainable practices and measures that follow the current trends of decarbonization and digitalization in the supply chain.

The economic recovery from the crisis caused in the supply chain by the global covid-19 pandemic needs also to be put in the transformation agenda, facilitating further the development of e-commerce and contactless deliveries. The adoption of new, technologically advanced and clean vehicles i.e. Electric Vehicles (EVs) and hydrogen-fuel vehicles, the creation of new distribution centers and better exploitation of new and existing logistics facilities as well as the upgrade and modernization of the national road and rail network can provide great help to achieve multiple environmental and socio-economic benefits in the logistics sector of the region. A good illustration of this is the planned creation of a new UCC in Eleonas to serve the needs of urban areas with smaller electric trucks that can operate for 24 hours a day within the center of Athens, aiming to encounter parking, traffic, nuisance and air pollution problems inside urban fabric. Furthermore, better space management and infrastructural network options in tandem with the roll-out of new vehicles will enhance the operational capacity of the transport carriers. Last but not least, given that the ICT capabilities are receiving significant attention in logistics, the integration of Industry 4.0 (and 5.0) must be expedited faster to make on-demand logistics more efficient and sustainable, and improve the quality of transport and logistics activities. In general, several cities nowadays are testing new ways in freight operations towards the digital transformation of the sector and the implementation of climate-adaptive, environmentally-friendly and safe practices. In line with that, the city logistics concept needs a holistic change in order to respond effectively to the ongoing challenges of rising needs, more demanding customer expectations, climate change and environmental risks and problems, as well as demographic and socio-economic issues of the urban population. The findings of the analysis can provide great help to local authorities, municipal bodies, logistics companies and experts for effective planning and implementation of actions towards sustainable and viable practices and new business models in urban logistics of the region.

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