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EVALUATING THE CONSOLIDATION OF DISTRIBUTION FLOWS USING A DISCRETE EVENT SUPPLY CHAIN SIMULATION TOOL: APPLICATION TO A CASE STUDY IN GREECE

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ABSTRACT

Horizontal collaboration (HC) is an innovative strategy aimed at reducing distances traveled through better resource utilization and consolidated product flows. Especially concerning urban freight movements, often summarized in the concept of City Logistics, cooperation between actors on the same supply chain level can be an effective concept to ensure efficiency and sustainability. The aim of this paper is to evaluate possible business opportunities for collaborative freight operation via discrete event simulation. Certain key performance indicators (KPIs) addressing both economic and environmental aspects are used in order to present and evaluate the execution of delivery tours in the city center of Athens and its outskirts. The primary data used for this evaluation are real-life data from Greek third party logistics (3PL) operators and the results show the current impact of two collaboration scenarios involving an Urban Consolidation Center.

1 INTRODUCTION

As the number of residents continues to grow, suppliers are confronted with new problems. This is due to the fact that the infrastructure does not grow at the same rate as the population (Taniguchi and Russel 2001). Additional space to expand road networks is often limited or does even not exist (Civitas Wiki consortium 2015). For this reason, various transport logistic approaches for the consolidation of freight flows are currently being discussed and tested, some of which are intended to help relieve congestion in cities on the one hand and to increase the productivity of means of transport on the other hand. The transportation of goods in urban areas is often summarized in the concept of City Logistics, defined as "finding efficient and effective ways to transport goods in urban areas while taking into account the negative effects on congestion, safety, and environment" (Savelsbergh and van Woensel 2016, p.1). Some of the solutions that have already been developed include road pricing, the prohibition of certain vehicles in certain roads or areas, or lane management, which is the flexible use of lanes in certain situations (Civitas Wiki consortium 2015). Also, collaborative supply chain strategies comprise promising approaches to reduce the negative effects of road freight transportation (Leitner et al. 2011; Pomponi et al. 2015). In this context, HC is "a business agreement between two or more companies at the same level in the supply chain or network in order to allow ease of work and co-operation towards achieving a common objective" (Bahinipati et al. 2009, p.880).

One promising HC concept to reduce the negative externalities of urban road freight transportation involving an advanced level of company interaction is the construction of an Urban Consolidation Center (UCC). A UCC is a “logistics facility that is situated relatively close to the area that it serves (be that a city center, an entire town or a specific site) from which consolidated deliveries are carried out within that area" (Allen et al. 2007, p.18).

In order to evaluate the consolidation of distribution flows, discrete-event simulation (DES) is used, as we are investigating scenarios that have not yet been converted into real-life situations. Wenzel et al. (2010) state that DES can be used throughout the entire logistics process and that processes between different companies can also benefit from it. Moreover, DES serves as an analytical and forecasting tool for complex systems. Collaborative logistics planning in the final stage of the supply chain is such a complex system due to the large number of variables. By using DES, the advantages and disadvantages of collaboration scenarios can be shown. With the help of a simulation model, results of various scenarios can be investigated. This allows to assess which scenario is most promising and should be considered in further detail.

This paper deals with the investigation of different HC scenarios using real-life data from Greek 3PL operators. These 3PL companies distribute fast moving consumer goods (FMCG) to retail stores in urban areas. The aim is to increase the transport efficiency in Athens, Greece. With the help of the simulation, different HC scenarios have been evaluated. Comparing the results from these scenarios has allowed for assessing which scenarios deliver benefits and minimize cost increases. For the scenario comparison, different performance indicators are available, e.g., the number of tours, the number of drops per tour, the distance travelled, or the loading factor. A first approach to evaluate HC in Greece using simulation was developed by Rabe et al. (2016), which involved direct horizontal collaboration with shared vehicles. The results now show the current impact of two collaboration scenarios involving a UCC. Instead of directly serving customers located within city borders from different delivery points, consolidated final customer deliveries from one or several companies are completed from these satellite facilities. This allows for using smaller delivery trucks with higher vehicle utilization levels (Savelsbergh and van Woensel 2016).

2 SIMULATION OF HORIZONTAL COLLABORATION

New solutions for the challenges of city logistics are constantly being investigated. Approaches to underground logistics concepts have been developed in the Netherlands. Through simulation, van Duin (1998) identifies weak points in these approaches. Another approach uses simulation to design automated underground transport systems using automatic guided vehicles around Schiphol Airport (van der Heijden et al. 2002). A further study by van Duin et al. (2014) investigates whether distributing goods across the water to the city of Amsterdam can be a potential future solution considering the busy traffic of the pleasure crafts and touring boats on the canals.

One of the first publications on research to use simulation for exploring the potential of HC in city logistics was done by McDermott in 1975. The core of this work is to solve a Vehicle Routing Problem in New York City and the savings potential of freight forwarders by HC is determined. The City Business District is divided into ten zones, each with a consolidation center. For a simulated day, the required number of tours, the number of vehicles, the distance traveled, and the working time for each zone is determined, from which assumed costs can be calculated. The simulation experiments clearly show the savings potential through consolidation. While recent publications mostly discuss the solution of Multi Depot Vehicle Routing Problems to not only open up the possibility of determining the potential savings on the route, but also for determining good locations for the depots, the work described here deals with an approach in which a given area is arbitrarily divided into several zones.

Van Duin et al. (2012) deal with the question of how to stop the decline of distribution centers and make their use more attractive. The aim of this simulation is to investigate the profitability of distribution centers in terms of environmental and economic aspects in a fictitious scenario. The model is based on a Vehicle Routing Problem with Time Windows, which is solved by a genetic algorithm. A multi-agent model is used to perform the simulations. A variety of input data are used for the simulation, such as costs for the use of the distribution center, tolls, or government subsidies. Although the results show that distribution centers are not financially rewarding, the authors remain true to the assumption that this is a reasonable concept to prevent congestion and emissions. It should also be noted that the use of distribution centers makes sense if the goods transported are not time-critical (just-in-time) deliveries. An overview of further approaches to optimization problems in HC, such as vehicle routing problems that can be solved by combining simulation and metaheuristics, can be found in Serrano-Hernández et al. (2017).

Another model also describes distribution centers close to the city, but takes new elements into consideration. Here, the focus is on the increasing number of vehicles in inner cities and the associated lack of parking spaces. This results in incorrectly parked cars that could block the transport vehicles. Finally, the authors conclude that the introduction of urban districts makes sense in order to minimize costs and reduce environmental impact. However, they also come to the conclusion that further models need to be created which take other aspects of city logistics into account (Ornaknow and Taniguchi 2012).

3 DESCRIPTION OF THE BUSINESS CASE AND SOLVING APPROACH

This paper is aiming at assessing freight operation schemes in urban areas involving a UCC. The examined business cases include the current freight delivery schemes adopted by 3PL operators and retailers using a case based in Athens, versus the use of a UCC in the outskirts of the city. The metropolitan area of Athens, Greece, has been selected for our case study, because it is the most populous and largest city in Greece and because there is immense road traffic in the narrowly developed center of Athens. The area can be specified by the ZIP codes from 10xxx to 19xxx. Both the area with ZIP codes beginning with 18xxx and the islands of Attica are excluded for further exploration, because we are focusing on city logistics. Figure 1 demonstrates the area under investigation.

Figure 1: The area under investigation in Greece.

The UCC scenarios can be defined as a two-echelon network. There is a first level (from the Hubs to the UCCs) and a second level (from the UCCs to the end customers) for the creation of routing plans. The UCC concept enables the shipper to use full-truck-load transport for long haul to the consolidation point outside the city. Afterwards, routes are created for smaller vehicles to deliver inside the city. Furthermore, during the cross-docking process which is performed in the UCC, the deliveries are grouped by the ZIP Codes of the recipients' delivery points. Thus, it is expected that the vehicles that perform the final phase of the delivery are visiting an increased number of delivery points in nearby areas. Two different scenarios have been developed and examined, which are described below. For each scenario, an as-is and a to-be case are examined. In the as-is case, the 3PL companies execute individually without adopting any collaborative schemes and in the to-be case, the distribution flows are consolidated via one or two UCC(s).

3.1 First UCC Scenario

The first scenario includes five warehouses in the suburban area each with a different amount of end customers, leading to 8537 customers in the urban area (Table 1). For the to-be case, the choice of the UCC's location was formulated in a previous publication as a two-echelon location routing problem (Gruler et al. 2017). Ultimately, however, the stakeholders must decide which location is to be chosen in reality, taking into account market-oriented factors (e.g., the development of the area), business factors (e.g., state subsidies, costs for new construction or rental development), and infrastructure factors (e. g., transport connections). Figure 2 shows the locations of the warehouses and the UCC.

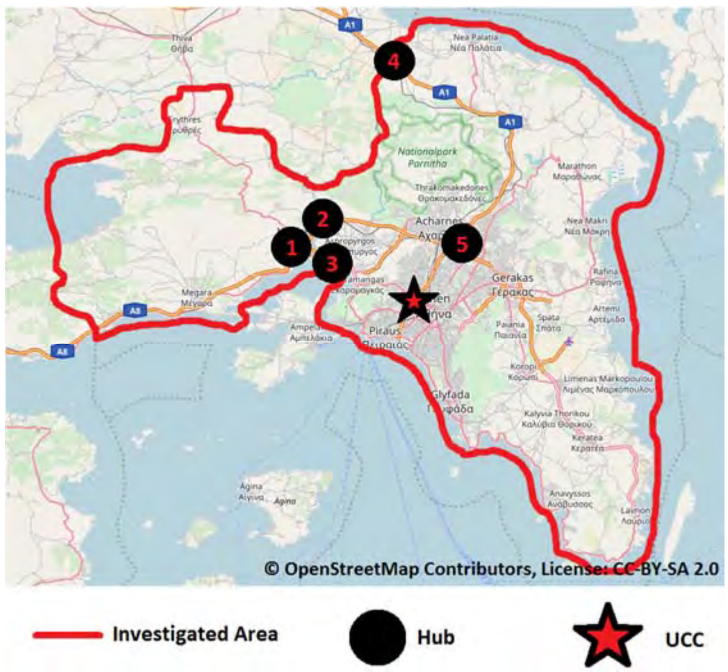

Figure 2: First UCC scenario to be evaluated.

To evaluate the as-is situation, simulation experiments are performed using the four 3PL datasets. After the pre-processing, the data are used to generate the simulation model. Table 1 gives an overview about the four as-is scenario models and the to-be scenario considering a UCC.

Table 1: Overview of the initial situation for the first UCC scenario (Observed period: 01.07.2014 to 07.01.2015).

Company	# Warehouses	# Customers	# Zipcode areas	# Transport orders
3PL_A	2	1650	285	7724
3PL_B	1	765	174	691
3PL_C	1	186	120	114
3PL_D	1	5936	209	7406
1st UCC scenario	5 Warehouses, 1 UCC	8537	285	15935

3.2 Second UCC Scenario

For the second scenario, the western part of Athens is excluded. The north-eastern part has the greatest potential for optimization, because the large geographic reach of this area combined with the limited customer network results in a low loading factor. For this reason, the initiation of a UCC could increase the loading factor of the trucks and reduce the total distance traveled, since the bundling of goods flows requires fewer vehicles. Each UCC supplies a certain area, defined by ZIP codes. In this way, the customer's orders could be clearly divided into the individual regions and assigned to the UCCs in the order list. Figure 3 illustrates the locations of the two UCCs and the associated areas. Table 2 gives an overview of the four as-is scenario models and the to-be scenario considering two UCCs.

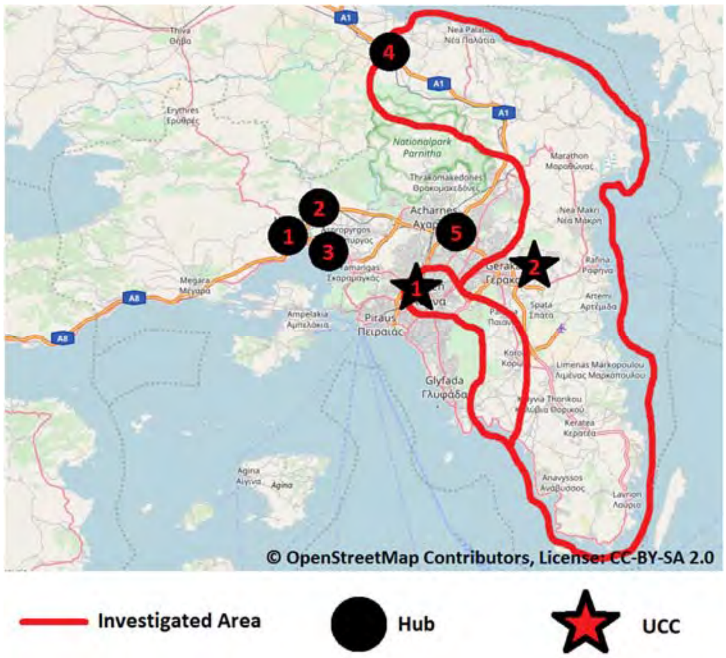

Figure 3: Second UCC scenario (selected areas) to be evaluated.

Table 2: Overview of the initial situation for the second UCC scenario for selected areas (Observed period: 01.07.2014 to 07.01.2015).

Company	# Warehouses	# Customers	# Zipcode areas	# Transport orders
3PL_A	2	497	97	3133
3PL_B	1	260	20	463
3PL_C	1	42	29	93
3PL_D	1	1732	62	4814
2nd UCC scenario	5 Warehouses, 2 UCCs	2531	97	8503

The different scenarios are implemented in a data-driven supply chain simulation tool, SimChain. In order to investigate sustainability aspects in supply chains, SimChain was used within the E-SAVE project (Rabe et al. 2012; Gutenschwager et al. 2013). Technically, the commercial discrete event simulation system PlantSimulation (2018) is used as the basis for SimChain. SimChain consists mainly of three core elements: a graphical user interface used for model development, a database in which all data and simulation results are stored and a DES supply chain simulation framework based on PlantSimulation. All model elements are generated automatically in PlantSimulation using building blocks from a predefined template library. A more detailed description of the design principles of SimChain is given by Gutenschwager and Alicke (2004). Figure 4 shows a screenshot of a simulation model in SimChain.

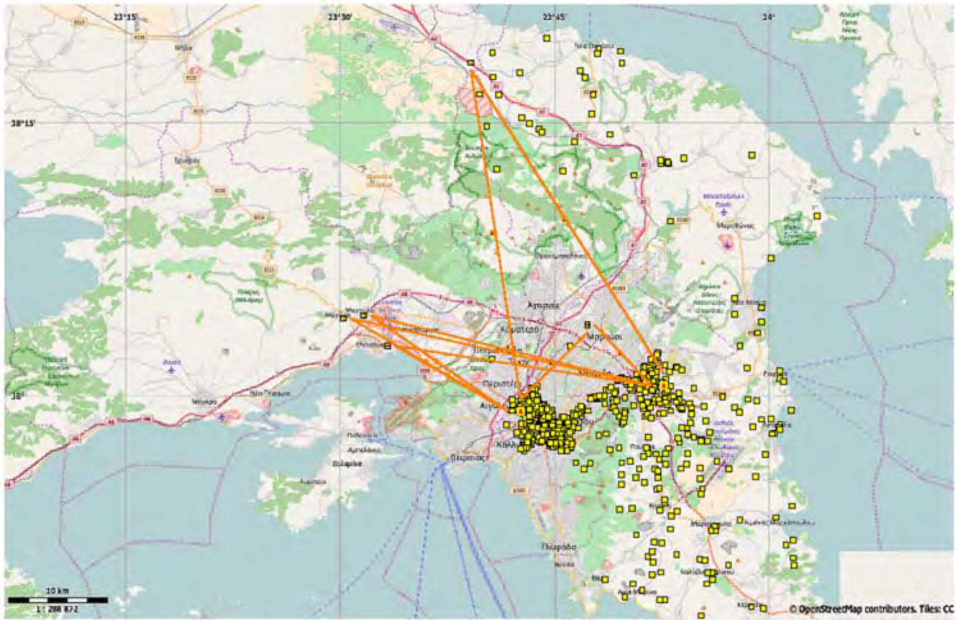

Figure 4: Screenshot of an instantiated simulation model (second scenario) in SimChain.

3.3 Parameters and Assumptions

The following Parameters and assumptions have been made:

- **SKUs:** Within the simulation, the unit for SKU to calculate truck capacity and utilization is considered to be one box. A regular EURO pallet is assumed to accommodate 50 boxes. The dimensions of one box are defined as 45 cm × 30 cm × 21.5 cm. This assumption was made in order to be able to calculate the volume per transport order in detail and thus the total loading factor of each truck, since usually a transport order is less than a full pallet.
- **Carrier:** In accordance with the FMCG industry standards, boxes for transportation are used. We assume that customers do not share boxes; each box is unambiguously assigned to a customer.
- **Vehicle type:** In the as-is case, the delivery is operated using small trucks with a capacity of 750 boxes. For the to-be scenario, we also consider articulated trucks with a capacity of 1650 boxes.
- **Vehicles:** If a transport order exceeds the maximum capacity of a vehicle, another vehicle is sent to fulfil the order on the same day. The functionality to generate additional vehicles was implemented to meet the requirements of last mile delivery for the 3PL companies.
- **Trip distance:** The distance for each trip is calculated using the weighted Euclidean distance. The calculations are validated with actual geographic data for the case of the Athens Metropolitan Area (Rabe et al. 2017).
- **Service time:** For a van, the service time per stop (unloading time) is set to 12 minutes fixed plus 1.8 seconds per box. The fixed time includes parking time, documentation, and cash on delivery. The average driving speed for a van is set to 48.3 km/h (Jung et al. 2017).

3.4 Key Performance Indicators

In order to evaluate the different HC scenarios, certain KPIs addressing both economic and environmental aspects are used (Table 3).

Table 3: Key performance indicators to evaluate the simulation results.

Indicator	Description	Unit
Number of tours	The total number of deliveries performed. It is calculated by summing up the total number of the trips performed. This value corresponds to the number of vehicles.	trips
Number of drops	The total number of drops performed. It is calculated by summing up the total number of drops performed.	drops
Drops per trip	The average drops that a vehicle performs per trip. This is calculated by dividing the total number of drops by the total number of trips.	drops/trip
Total distance travelled	The total distance travelled for all trips. It is calculated by summing up the total number of kilometers traveled.	km
Distance travelled per trip	The average distance travelled per trip. This is calculated by dividing the total number of kilometers traveled by the total number of trips.	km/trip
Number of boxes	Total number of boxes delivered for all trips. It is calculated by summing up the total number of boxes delivered for the total number of trips.	boxes
Boxes per trip	Average number of boxes delivered per trip executed. It is calculated by dividing the total number of boxes delivered by the total number of tours.	boxes/trip
Loading factor	The average loading factor of a vehicle per trip. It is calculated by dividing the freight delivered by the capacity of the vehicle (in boxes).	%
Distance in high density areas	The total distance travelled in high density areas.	km
Share of distance in high density areas	Share of the distance travelled in high density areas.	%

4 RESULTS AND DISCUSSION

The simulation results show that in the *first UCC scenario*, the total number of the delivery trips performed increased by 42% (2709 trips) (Table 4).

Table 4: Simulation results for the first UCC scenario.

Scenario	Description	# Tours	# Drops	Distance (km)	# Boxes
No Collaboration	3PL_A	1893	51984	174038.9	1318384
	3PL_B	385	7401	22184.1	230119
	3PL_C	128	1841	7423.0	33205
	3PL_D	4101	41913	147599.7	2978804
	overall	6507	103139	351398.8	4560512
With 1 UCC	3PL_A_to_UCC1	877		28394.5	
	3PL_B_to_UCC1	211		3308.2	
	3PL_C_to_UCC1	82		1949.8	
	3PL_D_to_UCC1	1864		48338.6	
	UCC1_to_customers	6182	103139	191931.8	4560512
	overall	9216		273922.9	

However, this to-be case includes two-phase delivery trips: a) from the 3PL companies' depots to the UCC and b) deliveries from the UCC to the customers (last mile delivery). Thus, the number of the vehicles in the to-be case was expected to be higher since two different types of vehicles (articulated and rigid) cooperate to perform one delivery trip. A positive aspect is that the vehicles used to enter the city center and perform the last mile delivery decreased by 5% (325 vehicles less). Also, the distance travelled could be decreased. For example, the distance per tour decreased from 54 km to 31 km (Table 5).

Table 5: Post-calculated KPIs on the basis of the simulation results for the first UCC scenario.

Scenario	Description	Drops per tour	Distance per tour (km)	Boxes per tour	Loading factor (%)
No Collaboration	3PL_A	27.5	91.9	696.5	92.9
	3PL_B	19.2	57.6	597.7	79.7
	3PL_C	14.4	58.0	259.4	34.6
	3PL_D	10.2	36.0	726.4	96.8
	overall	15.9	54.0	700.9	93.4
With 1 UCC	3PL_A_to_UCC1		32.4		
	3PL_B_to_UCC1		15.7		
	3PL_C_to_UCC1		23.8		
	3PL_D_to_UCC1		25.9		
	UCC1_to_customers	16.7	31.0	737.71	98.4

In addition to these KPIs, a graphical approach is used to obtain information on how many transports have been made in the Athens metropolitan area. The agglomeration has a density of at least 200 persons/ha (Milakis et al. 2008). To measure the traffic in this area, the map of Athens is simplified to a two-color image. It is monochrome white, with the exception of high-density residential areas marked in black. The route has been marked on the map for each transport between two locations. The ratio of the black or white pixels of this route can be used to determine which sections of the route were completed in the metropolitan area and which in the more attractive regions. The results in Table 6 show the increase of traffic from 29.8% to 42.8% due to the use of the UCC. This can be explained by the location of the UCC, which is not as usual outside the urban area, but in the inner peripheral area. Therefore, the transports to the UCC already lead through this high density area.

Table 6: Distance travelled in high density (HD) areas for the first UCC.

Scenario	Description	Distance (km)	Distance in HD Areas (km)	Share of Distance in HD Areas (%)
No Collaboration	3PL_A	174038.9	45648,3	26.2
	3PL_B	22337.2	9249,6	41.7
	3PL_C	7423.0	3493,1	47.1
	3PL_D	147599.7	46241,94	31.3
	overall	351398.8	104633	29.8
With 1 UCC	to UCC	81991.0	29485.2	39.0
	from UCC	191931.9	114243.7	59.9
	overall	273922.9	117188.9	42.8

In the *second scenario*, the numbers of tours increased because of the above-mentioned two-echelon network structure. However, as these tours are much shorter now, the overall distance decreases (Table 7). The drops per tour, boxes per tour, and loading factor in the 3PL_C scenario are comparatively low (Table

8). This is due to sparsely available data in the observed postal code area, which only provides information about one to four customers per day.

Table 7: Simulation results for the second UCC scenario for selected areas.

Scenario	Description	# Tours	# Drops	Distance (km)	# Boxes
No Collaboration	3PL_A	572	13065	61036.3	331486
	3PL_B	205	2950	7110.6	91101
	3PL_C	93	239	3139.1	2729
	3PL_D	1234	11400	64139.6	857961
	overall	2104	27654	135425.6	1283277
With 2 UCCs	3PL_A_to_UCC1	157		5151.2	
	3PL_B_to_UCC1	127		1841.2	
	3PL_C_to_UCC1	46		1102.7	
	3PL_D_to_UCC1	279		7310.7	
	3PL_A_to_UCC2	206		8892.3	
	3PL_B_to_UCC2	78		975.0	
	3PL_C_to_UCC2	17		688.5	
	3PL_D_to_UCC2	365		15738.2	
	UCC1_to_customers	808	12122	7990,3	543031
	UCC2_to_customers	1090	15532	59960,0	740246
	UCC overall	1898	27654	67950.2	1283277
	overall	3173		109651.1	

Table 8: Post-calculated KPIs for the second UCC scenario for selected areas.

Scenario	Description	Drops per tour	Distance per tour (km)	Boxes per tour	Loading factor (%)
No Collaboration	3PL_A	22.8	106.7	579.5	77.3
	3PL_B	14.4	34.7	444.4	59.3
	3PL_C	2.6	33.8	29.3	3.9
	3PL_D	9.2	52.0	695.3	92.7
	overall	13.1	64.4	609.9	81.3
With 2 UCCs	3PL_A_to_UCC1		32.8		
	3PL_B_to_UCC1		14.5		
	3PL_C_to_UCC1		24.0		
	3PL_D_to_UCC1		26.2		
	3PL_A_to_UCC2		43.2		
	3PL_B_to_UCC2		12.5		
	3PL_C_to_UCC2		40.5		
	3PL_D_to_UCC2		43.1		
	UCC1_to_customers	15.0	9.9	672.1	89.6
	UCC2_to_customers	14.3	55.0	679.1	90.6
	UCC overall	14.6	35,8	676.1	90.2

Compared to the first scenario, the traffic volume in high density areas has not increased in the to-be case. On the contrary, it even fell slightly from 26.7% to 25.3% (Table 9). This can be explained by the fact that the second UCC is outside the defined area and the transports to this UCC and from this UCC to the customers only lead through the city with a minor proportion. The results show how important it is to choose the right location for the UCCs.

Table 9: Distance travelled in high density areas for the second UCC.

Scenario	Description	Distance (km)	Distance in HD Areas (km)	Share of Distance in HD Areas (%)
No Collaboration	3PL_A	61036.3	12012.3	19.7
	3PL_B	7110.6	3115.8	43.8
	3PL_C	3139.1	1166.0	37.1
	3PL_D	64139.6	19899.8	31.0
	overall	135425.6	36193.9	26.7
With 2 UCCs	To UCCs	41700.9	14907.0	35.8
	From UCCs	67950.2	12849.7	18.9
	Overall	109651.1	27756.7	25.3

Within the framework of the simulation experiments, an unforeseen result for the companies has emerged as a by-product. When comparing the processed data and the as-is simulation results for the validation process, an enormous improvement in vehicle utilization and the corresponding number of tours was noted. This is due to the fact that in SimChain tours are created based on the existing orders from the customers. These customer orders are transferred to the SimChain data model and an integrated optimizer is used for route planning. This procedure leads to a merging of existing routes which increases the vehicle utilization. Therefore, another result could also be that there is potential for route optimization. However, this result should be viewed with caution. There is no information available on why the existing loading factor is like that. Reasons could be, e.g., the drivers' working hours, time windows that cannot be achieved with full trucks, or other potential agreements with the customers.

5 CONCLUSION

This paper evaluates possible business opportunities for collaborative freight operation via discrete event simulation. Two different business scenarios including data of 3PL companies have been developed in which the principles of UCCs were implemented. A series of KPIs were calculated to compare the results of the as-is and to-be cases in order to identify whether this collaborative practice can be beneficial in terms of both economic and environmental aspects. As both simulation results have shown, utilizing UCCs will lower the number of tours needed to meet the customer's demands and also decrease the required distance. Moreover, the saved distance mainly results from savings in urban areas. Another advantage of the UCC scenarios is the shorter average length of a tour due to the increased physical closeness between the UCCs and the majority of customers. The physical closeness can be increased even more by adding more UCCs to the scenario as seen in second UCC scenario and will yield even more savings in terms of driven distance and average distance per trip.

The simulation of this evaluation has been limited by the available raw data from the companies. For example, there was no information about the time window in which customers were supplied. The customers' orders were thus fulfilled on a daily basis, which is quite imprecise in the FMCG industry. The investment costs and the costs of operating a UCC in Athens were not taken into account as it was not possible to receive this information. An attempt to estimate the cost of deliveries could be made taking into consideration the distance travelled, the type of vehicle and the personnel costs, however, this would be too much simplification. Additionally, detailed information about the type of vehicle and the type of personnel were also not given.

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