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GJHSS-B Classification: LCC: TD791.2, TD795.7

REROUTINGMUNICIPALWASTECOLLECTIONINMALTAANEXAMINATIONOFWASTECOLLECTIONROUTESWITHPROPOSEDNEWSYSTEMSUSINGGISMETHODOLOGY

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Rerouting Municipal Waste Collection in Malta. An Examination of Waste Collection Routes with Proposed New Systems using GIS Methodology

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Keywords: municipal solid waste, collection route, geographic information systems, network analyst, route optimization, transport emissions, carbon dioxide.

I. Introduction

The management of waste consists of several steps which are sequentially performed. Generally, these consist of collection, transport, and treatment either for recycling or reusing purposes or for pre-treatment prior to landfill disposal [1]. Therefore, waste collection, transfer and transport provide a basic function in all waste management systems [2]. A distinction should be made between the three roles played by transport in waste management. Eistad et al., 2009 refer to the collection stage "as the collection of waste by a truck while following a route in a residential or commercial area until the truck is full and/or the collection route ends". Transport, on the other hand, refers to the moving of the full truck to the point of unloading. Transfer then takes place when waste is reloaded and consolidated from small transport units into a large unit using floor or bunker and sometimes in conjunction with compression, wrapping, or sorting. Following the transfer, waste is transported by means of a train, a tractor-trailer unit or a barge depending on the origin, destination, and type of waste [3].

Municipal Waste Management (MSW) incorporates several interrelated aspects which need complete cooperation and collaboration for an efficient delivery [4]. Additionally, the management of this type of waste is one of the most challenging in view that it involves the public and therefore it allows for the generator to frequently meet the waste management representatives [[5].

This research is focused on the collection phase MSW. collection. This is, in fact, the most expensive functional element in the entire waste management process, reaching as high as 85 percent of all costs in the total MSW management system. Most of these costs are fuel related since solid waste collection processes are mainly carried out by utilizing trucks with fuels [4]. Furthermore, the trucks emit pollutants into the atmosphere, predominantly carbon dioxide, nitrogen oxides and sulphur dioxide, that are toxic for human beings and cause acid rain and global warming.

In Malta, a carbon footprint study noted that the introduction of a separate organic waste collection and facilities like a mechanical biological treatment plant leads to substantial savings in GHG emissions, however, transport emissions reach 14 percent of total emissions which is significantly higher than the European average which generally reaches 5 percent [6]. The same research, noted that currently there is no fixed collection route for waste collection. Routes are left to the drivers who devise a route simply on their experience. Often, however, routes change according to

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the driver resulting in a change of schedule in the waste collected. Additionally, no form of optimization is present and therefore room for improvement is clearly present. Therefore, the problem requires a quantitative and subjective approach instead of relying on the perceptions of drivers. Route optimization is one of the most common measures undertaken to reduce GHG emissions in relation to collection and transport [7]. Furthermore, the optimization of routes, together with developing courses which are better suited for a particular locality's needs, leads to a reduction in collection time by 10 to 15 minutes [8].

II. Materials and Methods

The methodology structure that is used in this research, consists of four general steps:

- Fieldwork Study and Data Collection;
- Data analysis;
- Route optimisation and GIS Analyst;
- The evaluation of the performance of the proposed scenarios;

The methodology diagram with a detailed description is shown in Figure 3.

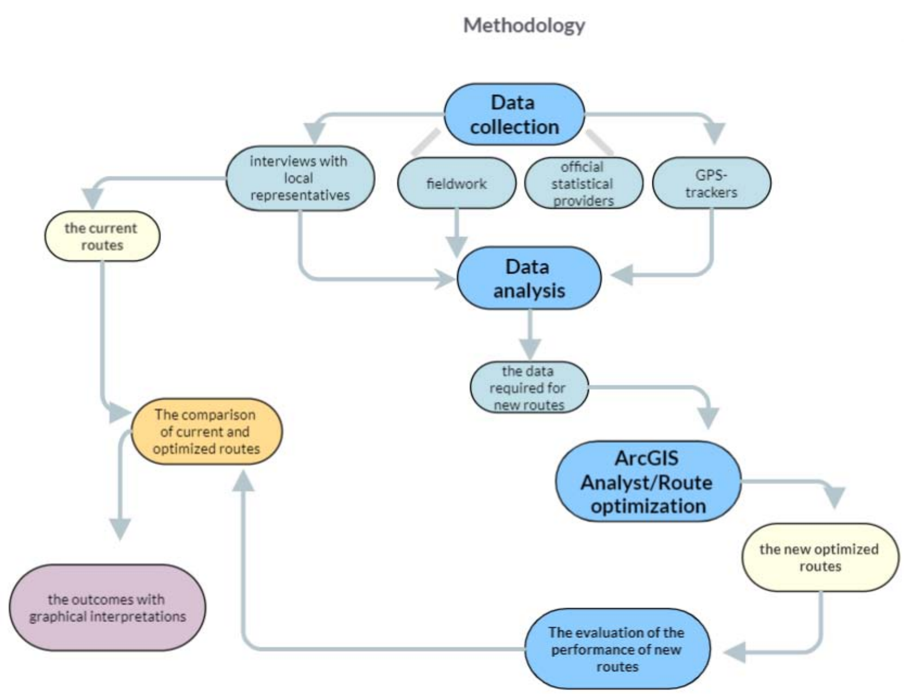

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Figure 1: The Methodology with a Detailed Description

a) *Fieldwork Study and Data Collection*

In the research, two localities were selected for the pilot study - Mellieħa and Attard due to different topographies: the town of Mellieħa stands on a group of hills on the main island (the estimated terrain elevation above sea level is 150 meters) while the relief of Attard town is mostly flat in nature (the estimate terrain elevation above sea level is 78 meters). Therefore, the two case studies offer different challenges that can then be applied as an example for other localities that have similar topographical characteristics.

Waste collection occurs six days per week except on Sundays. It includes the collection of organic, recyclable, and mixed waste. The same route is used for the collection of different types of waste. In the research, the collection route for mixed waste is analyzed. Mixed waste collection takes place on Tuesday and Saturday.

An overview of waste management practices in Mellieħa and Attard is required to enhance the efficiency of the collection of MSW. Waste management data was collected for the period January 2021 - January 2022=. Maps from local municipalities, digital data from various official providers including the Malta National Statistics Office, ArcGIS Business Analyst and WasteServ Malta Ltd, interviews/meetings with local council representatives and fieldwork were the main data sources used for the route optimization. ArcGIS Business Analyst provides an overview of waste typology sectors. However, this information is not used in the calculations. This source was used in the research since it was difficult to obtain the information from official providers.

Detailed interviews with the local council representatives of Attard and Mellieħa were conducted to gain a deeper understanding of the MSW collection practices in two localities, methods and modes of waste transportation and collection, number, type and capacity of vehicles, schedule of transportation and collection waste, vehicles staff in the municipal solid waste collection process teams of the two cities.

Existing solid waste collection routes were obtained by GPS trackers Garmin GPSmap62 that were placed in waste collection vehicles. GPS tracker Garmin has high-sensitivity and helix antenna, WAAS/EGNOS-enabled GPS receiver with HotFix® satellite prediction, GPSMAP 62 has unparalleled reception to determine the position precisely and quickly and maintains its GPS location (95 % accuracy) [9].

Each street was checked and analysed in terms of one/two- way movement while doing fieldwork. Both localities were visited more than 15 times during summer, winter and autumn to observe the traffic situation and waste collection process. The collected data is presented in Table 1.

Table 1: Collected Data for Route Optimisation in Attard and Mellieħa

Collected Data	Source of Data	Website
road networks and characteristics of the streets (width, length, one/two-way), geographical boarders;	maps from local municipalities, fieldwork.	*Online Database: https://workflow.gov.mt/*
traffic situation;	fieldwork, ArcGIS traffic service;	
characteristics of the current municipal waste collection practices;	interview/meeting with local council representatives.	
the current waste collection routes (their distance and time);	GPS trackers Garmin GPS map62;	
population size, population density, total households, household size;	The Malta Statistics Office;	https://msa.gov.mt /
waste characteristics, waste typology sectors, waste generation rate;	WasteServ Malta Ltd (the company responsible for the waste collection service), ArcGIS Business Analyst;	https://wsm.com.mt/
type and number of collection vehicles; vehicle capacity and average fuel consumption;	interview/meeting with local council representatives.	

Source: Authors'' own

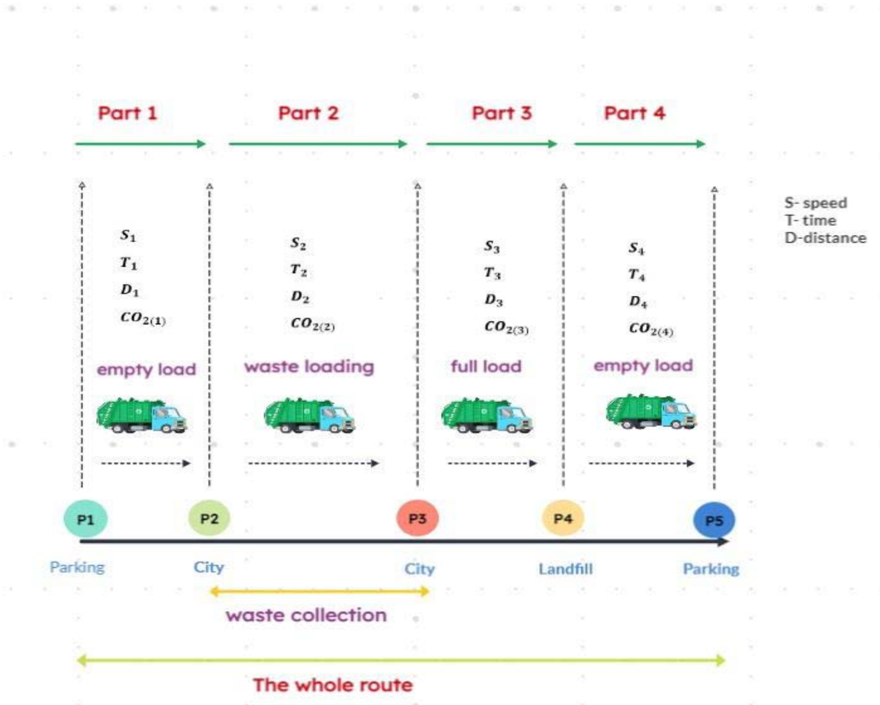
b) Data Analysis

To achieve the aim of the research, "to examine the current routes utilized in two localities of Malta for MSW collection and then use Geographic Information Systems (GIS) to optimize the present collection system," the following actions were taken:

1. *Statistical Analysis of Demographic and Waste Data:* Population size, population density, total house-holds, household size, waste characteristics, and waste generation were statistically analyzed to understand the factors influencing waste generation and collection needs. This comprehensive analysis helped identify key demographic and waste factors crucial for optimizing the waste collection routes.
2. *Measurement of Street Characteristics:* The length and width of streets were manually measured using Google Maps, and each street was analyzed individually. Based on these measurements, streets were categorized as passable, non-passable, and occasionally impassable. This categorization provided essential information for routing analysis, ensuring that routes could accommodate collection vehicles efficiently. Moreover, turn delays, restricted turns, temporary road closures, and dead ends were analyzed.
3. *Traffic Data Collection and Analysis:* A web map of traffic provided by ArcGIS was utilized, offering near-real-time and historical traffic data feeds.

Additionally, traffic conditions were observed directly during fieldwork to assess real-time situations and historical trends. This traffic analysis was vital for minimizing delays and optimizing route efficiency by incorporating realistic traffic patterns.

4. *Mapping Existing Waste Collection Routes:* Existing solid waste collection routes and the location of the landfill were mapped using GPS trackers (Garmin GPSmap62). The routes were divided into segments based on destination points. For instance, Figure 2 demonstrates an example of route classification in Attard, providing a clear visualization of existing waste collection paths and their segmentation.



Source: Authors'' own

Figure 2: Route Classification based on the Destination Points in Attard

5. *Calculation of Speed Mode, Emissions, and Fuel Consumption:* Speed mode, travel time and distance, fuel consumption, and emissions of carbon dioxide (CO_2), nitrogen oxides (NO_x), and particulate matter (PM) were calculated for each segment of the route. These calculations were based on the road type and truckload level. Since fuel consumption changes incrementally depending on the truck's load, higher loads typically result in greater fuel consumption, leading to varying levels of CO_2, NO_x, and PM emissions. The following formula (Figure 3) was used to calculate average speed.

$$s = \frac{d}{t} \qquad (1)$$

Figure 3: Speed formula.

where is s= speed, d= distance travelled, t= time elapsed.

6. *Topography Consideration:* Topography was considered in fuel consumption calculations. Attard, being mostly flat, has a lower fuel consumption rate (28 liters per 100 km) compared to Mellieħa (30 liters per 100 km), which is situated on a group of hills. Fuel consumption data from Volvo Truck Corporation, based on road type and load level, was used to adjust fuel consumption rates in both localities, factoring in topography, load level, and road type (Tables 2 and 3).

Table 2: The Rates of Fuel Consumption in Mellieħa.

Route Name	Level of Load	The Type of the Road	The Rate of Fuel
segment 1	empty load	arterials, distributors	27
Segment 2	loading	local access roads.	30
segment 3	full load	arterials, distributors	35
segment 4	loading	local access roads.	30
segment 5	full load	arterials, distributors	35
segment 6	empty load	arterials, distributors	27

Table 3: The Rates of Fuel Consumption in Attard.

Route Name	Level of Load	The Type of the Road	The Rate of Fuel
segment 1	empty load	arterials, distributors	27
segment2	loading	local access roads.	28
segment 3	full load	arterials, distributors	35
segment 4	empty load	arterials, distributors	27

7. *Traffic Congestion Consideration:* Traffic congestion was also considered in fuel consumption estimates. In congested traffic, vehicles typically burn between 0.6 to 1.2 liters of fuel per hour [10]. The congested streets in Attard include Triq Il-Pitkali, Triq in-Nutar Zarb, Triq iż-Żagħfran, Triq Il-Mosta, Triq Is-Salina, Triq Il-Fortizza Tal-Mosta (partly), and Triq Tal-Labour at 6:30 a.m. In Mellieħa, the congested streets are Triq il-Mellieħa, Triq Il-Marfa, Triq Il-Kbira, Triq Qasam Barrani, and Tul Il-Kosta at 6:30 a.m. Due to these traffic conditions, an additional 0.8 liters were added to the total fuel consumption in Attard, while one liter was added in Mellieħa.

c) Route optimszation and GIS Analyst

Geographic Information Systems (GIS) are sophisticated information systems used for tracking, managing, analysing, presenting, and storing data with a spatial distribution. GIS includes a spatially geo-referenced database that encompasses the critical parameters necessary for effective solid waste management [11]. These parameters include the locations of landfills, city maps, transportation and collection road networks, and transfer stations [12]. GIS provides a powerful tool for optimising solid waste management by integrating diverse spatial data and offering robust analytical capabilities. Its ability to enhance decision-making through spatial analysis, efficient routing, and scenario planning makes it indispensable for modern waste management strategies [11].

The route optimisation process included several key steps. The first step was the determination of collection points, which were generated based on the streets where waste collection occurs, ensuring comprehensive coverage of the service area. Secondly, the location of the landfill was identified, serving as the primary disposal point for the collected waste. Thirdly, the start and end points of each route were established to facilitate efficient waste collection operations. Additionally, the starting times for each route were selected to optimise traffic flow.

Traffic situations and road networks were analyzed using ArcGIS, incorporating both historical and real-time traffic data to minimise delays. The optimised routes were then determined using the Network Analyst extension in the GIS application. Routes were simulated multiple times, considering temporary road closures and non-passable streets. The use of non-passable streets was minimised to ensure optimal vehicle movement.

The selection criteria for the most optimised routes were determined based on specific segments of the route, considering the optimal time-to-distance ratio and minimization of travel time. Stop points were automatically allocated by the GIS application using the Network Analyst extension. Each collection point represented a specific address, but the actual addresses were modified to protect data privacy.

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In summary, the route optimisation process ensured efficient waste collection through a structured methodology incorporating GIS analysis and the Network Analyst extension. This approach minimised delays and improved route efficiency while adhering to privacy regulations.

d) The Evaluation of the Performance of the Proposed Scenarios

The analysis output provided comprehensive data on travel time, distance, and stop frequency. Daily and annual computations were conducted to ascertain the aggregate emissions of CO_2, nitrogen oxides, and particulates. Annual expenses were computed based on 314 operational days in 2022, factoring in the absence of waste collection on Sundays. Furthermore, seasonal variations in fuel consumption were considered, with an anticipated increase during summer (by up to 1 litre), attributed to heightened waste generation. Conversely, in Attard, a decrease of up to 1 litre during winter, autumn, and spring was observed due to GPS tracker implementation in August. Mellieħa exhibited a similar trend with fuel consumption escalation during summer, following GPS tracker installation in November.

A comparative analysis was conducted between proposed and current routes, evaluating enhancements in daily and annual travel metrics. Potential reductions in fuel consumption were examined, consequently leading to decreased emissions of CO_2, nitrogen oxides, and particulates.

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

III. Results

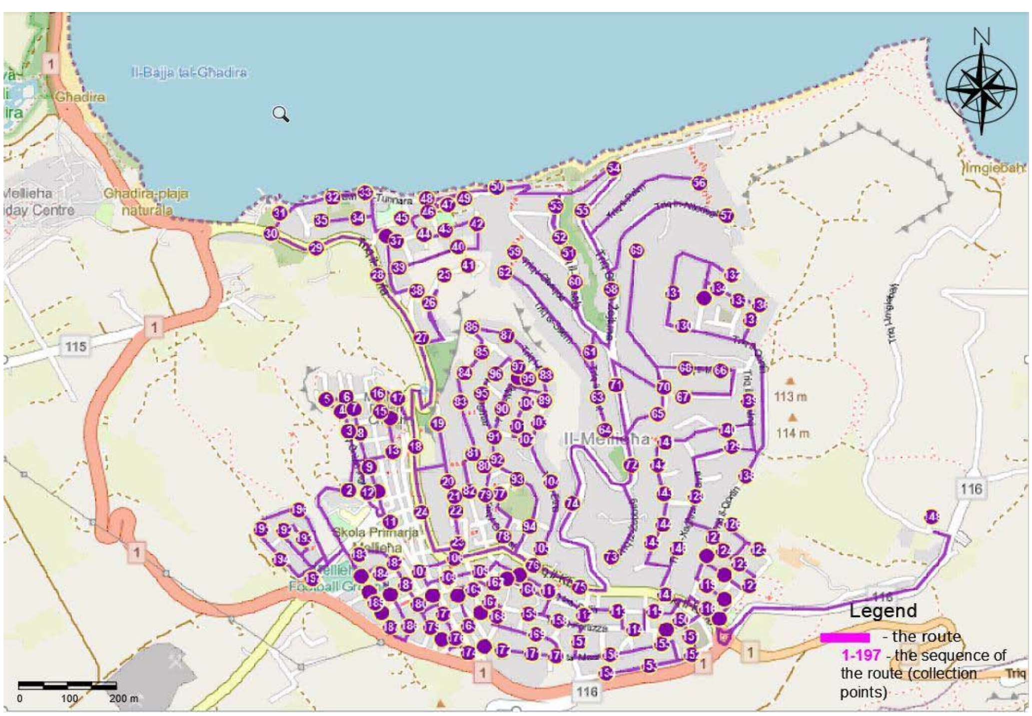
This section presents the development of new collection routes in two localities in Malta in detail including their evaluation and the comparisons with the existing collection routes.

The data was collected using GPS trackers Garmin GPSmap62, through fieldwork and face-to-face interviews with the local council representatives of Attard and Mellieħa.

a) Route Modeling for the Optimisation of Waste Collection and Transportation in Mellieħa

i. *Proposed Scenario in Mellieħa and Assessment of its Performance*

Based on travel mode (trucking time), traffic data and restrictions adopted in ArcGIS Network Analyst, such as temporary road closure during schooling time, turn delays and restricted turns, optimal routes are developed. Figure 4 represents the optimised route for the second segment of the route. While Figure 5 indicates the total route in Mellieħa. Optimised routes for the 5 segments of the route are shown in Appendix A. The detailed route is described in Appendix B.



Source: Authors'' own

Figure 4: The Second Segment of the Optimized Route in Mellieħa

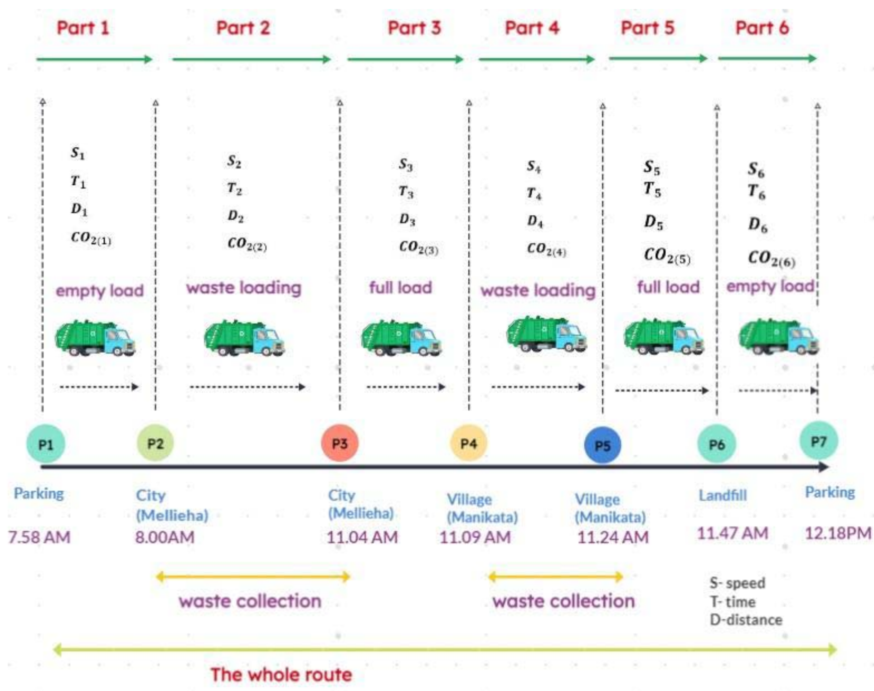


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Figure 5: The proposed route in Mellieħa

Travelled time, distance and the number of stops were obtained in the output of analysis. The data regarding the segments of the route are shown in Table 4. Overall traveling time and distance, as well as the number of stops along the route, were computed as the sum of route segments, while average speed was determined as the mean of route segments. The total duration of the route is 4 hours 21 minutes including 3 minutes at the landfill. The total distance is 66.75 km.

Table 4: The Calculations of the Proposed Scenario in Mellieħa

Route Name	Stop Count	Time (Minutes)	Distance (Kilometers)	Average Speed
Segment 1	2	2	0.688	20
Segment 2	195	184	36.97	12
Segment 3	2	5	2.24	26.88
Segment 4	2	15	2.42	9.6
Segment 5	2	23	11.2	29
Segment 6	2	28	13.24	28
Total route	205	257	66.75	20.4

Source: Authors' own

The amount of fuel consumed varies significantly depending on traffic conditions, road types, driving style, and the vehicle's load level. Fuel consumption and emissions were calculated based on the values for Volvo engines, as presented in Appendix C. The total fuel consumption for the route is 21.17 liters (Table 5). The corresponding emissions include 55.04 kg of CO_2, 148.19 g of nitrogen oxides, and 2.12 g of particulate matter.

Table 5: Fuel Consumption and Emission Calculations of the Proposed Scenario in Mellieħa.

Route Name	Level of Load	Distance (kilometers)	Fuel Consumption	CO2 kg/litre	NOx g/litre	PM g/litre
Segment 1	empty load	0.688	0.19	0.48	1.30	0.02
Segment2	loading	36.97	11.00	28.60	77.00	1.10
Segment 3	full load	2.24	0.78	2.04	5.49	0.08
Segment 4	loading	2.42	0.70	1.82	4.90	0.07
Segment 5	full load	11.2	4.40	11.44	30.80	0.44
Segment 6	empty load	13.24	4.10	10.66	28.70	0.41
Total route		66.758	21.17	55.04	148.19	2.12

Source: Authors' own

ii. *The Comparison of Current and Optimised Routes in Mellieħa*

The current waste collection route distance in Mellieħa is 78.4 km and the time needed is 5 hours 18 minutes while the proposed collection route length is 66.7 km and the time needed is 4 hours 17 minutes. The current route of waste collection in Mellieħa covers a total of 24,617 kilometers and 99,852 minutes annually while the proposed route is 20,943 kilometers and 80,698 minutes annually. Thus, the proposed route will save up to 3,673 kilometers and 19,154 minutes annually (15 percent and 19 percent improvements compared to the current route).

The current route fuel consumption is 25.03 litres per day while the proposed route fuel consumption is 21.7 litres per day. Annual fuel consumption reaches up to 7,859 litres whereas the proposed route burns 6,647 litres of fuel. Hence, the potential savings are 1,212 litres of fuel annually.

Carbon dioxide, nitrogen oxides, and particulates are formed by the combustion of fuel. The amount of carbon dioxide, nitrogen oxide, and particulates produced by the current route is 65.07 kg; 175.18 g and 2.5 g respectively while the proposed route produces 55 kg of carbon dioxide, 148 g of nitrogen oxide and 2.1 g of particulates. The emissions of carbon dioxide, nitrogen oxide, and particulates reach 20,413 kg; 55,006 g; and 785 g annually by the current route whereas the proposed route emits 17,282 kg of carbon dioxide, 46,531 g of nitrogen oxide and 665 g of particulates on annual basis. Subsequently, the application of the proposed route will lead to the saving of 3,149 kg of carbon dioxide, 8,474 g of nitrogen oxide and 119.3 g of particulates reduction annually (up to 15 percent improvement compared to the current route). Detailed calculations are provided in Tables 6-7.

Table 6: The Comparison of Current and Proposed Routes in Mellieħa for Time and Distance Criteria.

	Route Name	Time (minutes)	Distance (kilometers)
Current route	Segment 1	2	0.688
	Segment2	240	46.85
	Segment 3	4	2.24
	Segment 4	15	2.42
	Segment 5	22	11.28
	Segment 6	35	14.95
	Total route	318	78.428
	Route Name	Time (minutes)	Distance (kilometers)
proposed route	Segment 1	2	0.688
	Segment2	184	36.97
	Segment 3	5	2.24
	Segment 4	15	2.42
	Segment 5	23	11.2
	Segment 6	28	13.24
	Total route	257	66.758

Source: Authors'' own

Table 7: The comparison of current and proposed routes in Mellieħa for time, distance, fuel consumption and emission criteria.

	Current Route	Proposed Route	Improvement from Current Route	Improvement on Current Route %
Distance(km), day	78.4	66.7	11.7	15
Distance(km), year	24617.6	20943.8	3673.8	15
Time (min), day	318	257	61	19
Time (min), year	99852	80698	19154	19
Fuel Consumption(litre), day	25.03	21.17	3.86	15
Fuel Consumption(litre), year	7859.42	6647.38	1212.04	15
CO2 kg/litre, day	65.07	55.04	10.03	15
CO2 kg/litre, year	20431.98	17282.56	3149.42	15
NOx g/litre, day	175.18	148.19	26.99	15
NOx g/litre, year	55006.52	46531.66	8474.86	15
PM g/litre, day	2.5	2.12	0.38	15
PM g/litre, year	785	665.68	119.32	15

Source: Authors' own

b) Route Modeling for the Optimization of Waste Collection and Transportation in Attard

IV. Discussion

EconEconomic growth, rapid urbanisation, population growth, and improved community living standards have significantly accelerated the rate of waste generation worldwide. Malta faces a demographic challenge that could affect economic growth and fiscal spending for the next two decades. The percentage of the population aged 65 and older is increasing, while the percentage of those aged 0-14 is decreasing. Additionally, Malta has experienced steady economic growth due to its favorable tax environment. If progressive immigration policies are implemented and economic growth continues at the current rate, the population is projected to increase by 60% over the next seventeen years, leading to higher consumption and greater waste generation.

Local municipalities are generally responsible for waste management in cities, struggle to provide effective systems for residents. They often face problems that exceed their capacity due to a lack of organization, financial resources, and the complexity of the system. Waste collection is the most expensive component of the waste management process, accounting for up to 75% of total costs in the Municipal Solid Waste (MSW) management system. Most of these costs are related to fuel consumption, as solid waste collection is primarily carried out by fuel-powered trucks. These trucks emit pollutants into the atmosphere, predominantly carbon dioxide, nitrogen oxides, and sulfur dioxide, which are toxic to humans and contribute to acid rain and global warming.

The aim of this research was to analyse the current routes used in two localities of Malta for Municipal Solid Waste collection and then leverage GIS to optimise the existing collection system. To accomplish this aim, a comprehensive methodology was developed encompassing four main steps: fieldwork study and data collection, data analysis, GIS analysis and route optimization, and evaluation of the proposed scenarios' performance.

Data was collected using Garmin GPSmap62 GPS trackers, fieldwork, and face-to-face interviews with local council representatives in Attard and Mellieħa. The optimised routes were determined using ArcGIS and the Network Analyst extension, taking into account road restrictions, traffic conditions, and street characteristics. Travel distance, time, fuel consumption, and emissions were calculated based on the load levels of the trucks. The application of Network Analyst demonstrated substantial cost savings by reducing fuel expenses, kilometers driven, and total travel time.

In Attard, the current waste collection route covers 44.1 km and requires 3 hours and 44 minutes daily, while the proposed collection route spans 37.73 km and takes 2 hours and 56 minutes. Thus, the proposed route will save up to 2,000 kilometers and 15,072 minutes annually, representing a 14% reduction in distance and a 21% improvement in time compared to the current route. The proposed route will result in annual savings of 593 liters of fuel and reduce emissions by 1,545 kg of carbon dioxide, 4,161 g of nitrogen oxide, and 59 g of particulates.

In Mellieħa, the current waste collection route covers 78.4 km and takes 5 hours and 18 minutes daily, while the proposed collection route spans 66.7 km and requires 4 hours and 17 minutes. Consequently, the proposed route will save up to 3,673 kilometers and 19,154 minutes annually, representing a 15% reduction in distance and a 19% improvement in time compared to the current route. The proposed route will result in annual savings of 1,212 liters of fuel and reduce emissions by 3,149 kg of carbon dioxide, 8,474 g of nitrogen oxide, and 119.3 g of particulates.

In summary, the route optimization was successfully achieved in both localities. The results clearly demonstrate that the proposed routes are more efficient in terms of collection time and distance traveled. These improvements are directly correlated with decreased fuel consumption, leading to a reduction in carbon dioxide, nitrogen oxide, and particulate emissions.

V. Conclusions and Recommendations

This research effectively optimized waste collection routes in two localities of Malta using GIS. The findings unequivocally indicate that the proposed routes are more efficient in terms of collection time and distance traveled. These improvements are highly correlated with decreased fuel consumption, leading to a significant reduction in carbon dioxide, nitrogen oxide, and particulate emissions.

Based on the findings of this research, the following recommendations are proposed to enhance the efficiency of waste collection in Malta:

Waste Collection Schedule: Traffic congestion was observed during fieldwork, particularly in the morning, creating significant difficulties for residents and vehicles and hindering efficient waste collection. Shifting the waste collection schedule to evening or nighttime hours could improve efficiency by avoiding traffic jams and minimizing the negative impact of leaving waste outside for extended periods. Spain is an example of a country that collects waste efficiently in the evening or night.

Utilising ArcGIS Network Analyst Extension: ArcGIS, with its Network Analyst extension, is a valuable tool for route optimization. Applying this tool could improve the efficiency of not just municipal solid waste collection but also construction waste collection. Other types of waste collection can also be considered.

Adaptability of the Models: The proposed models are highly adaptable and could be applied in various locations within the country and beyond, particularly in developing countries facing significant challenges in solid waste management. However, accurate knowledge of the waste generation rate, road network, and road restrictions is required to achieve optimal results.

Practical Applications: The research offers a straightforward decision to the current problem. The models that were developed in the research have practical applications. It is expected that local municipalities will consider the results of the research physically and empirically while making decisions regarding the waste collection process.

Future Research Directions

Multiple Truck Routes: Developing routes using multiple trucks could increase the efficiency of the waste collection process. However, this recommendation depends on the budget allocated for waste collection, as utilising multiple trucks may be more expensive than using a single truck.

Evening or Night-Time Optimisation: The proposed models could be modified and simulated for evening or nighttime hours. This shift would enhance the performance of the waste collection process by avoiding congestion.

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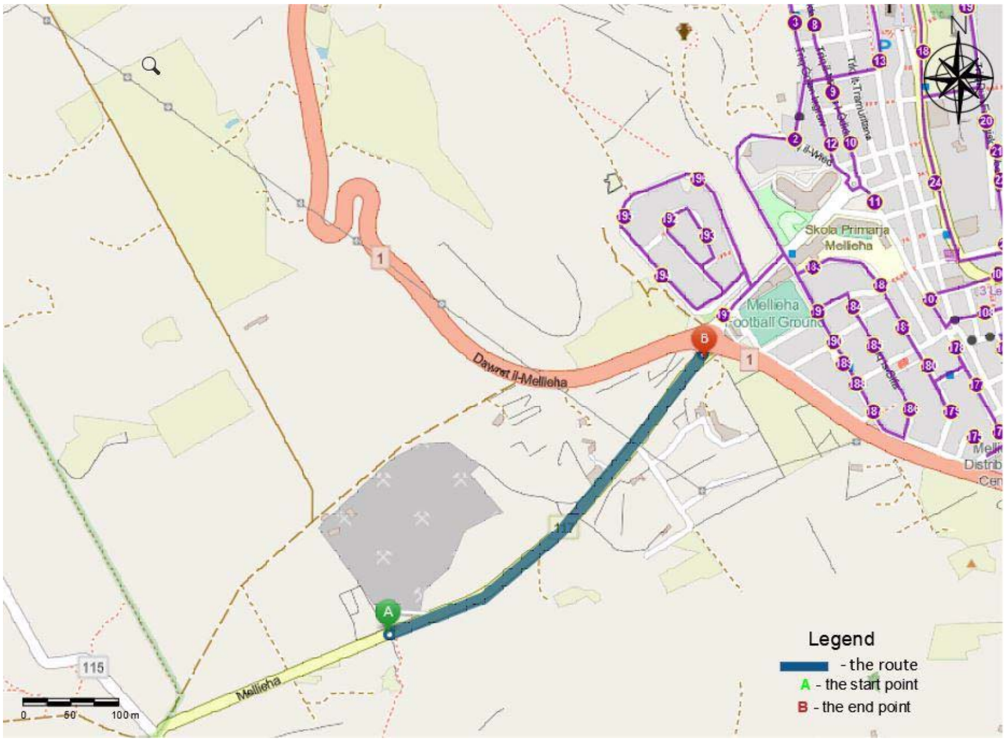
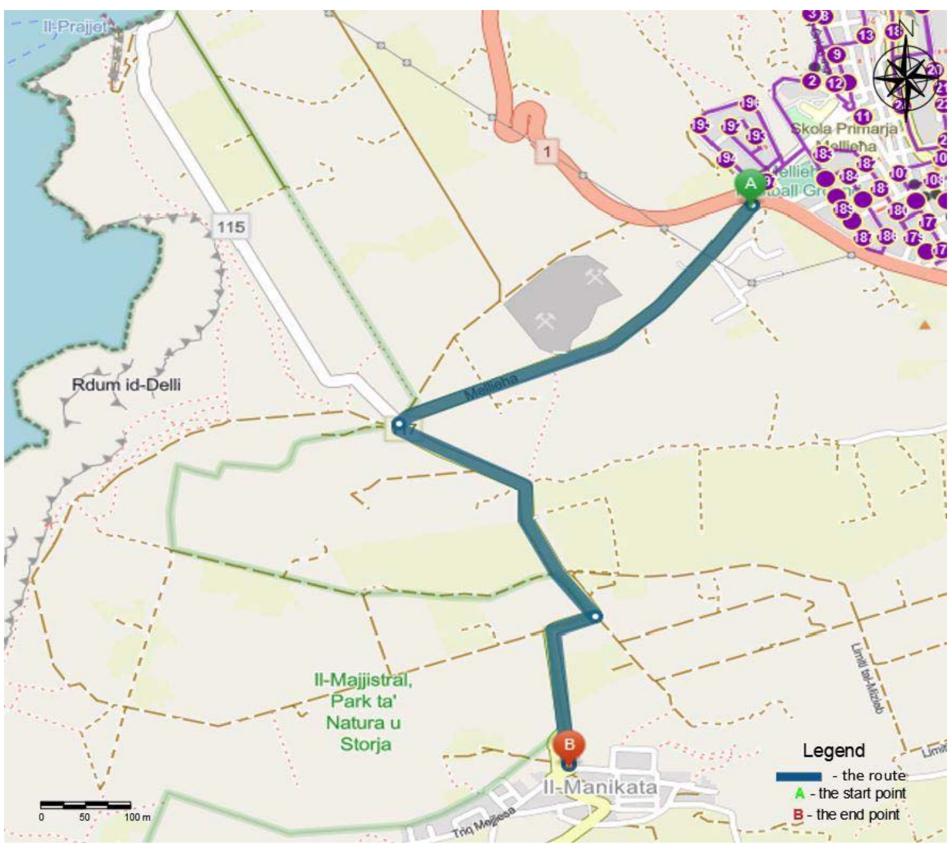
Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A



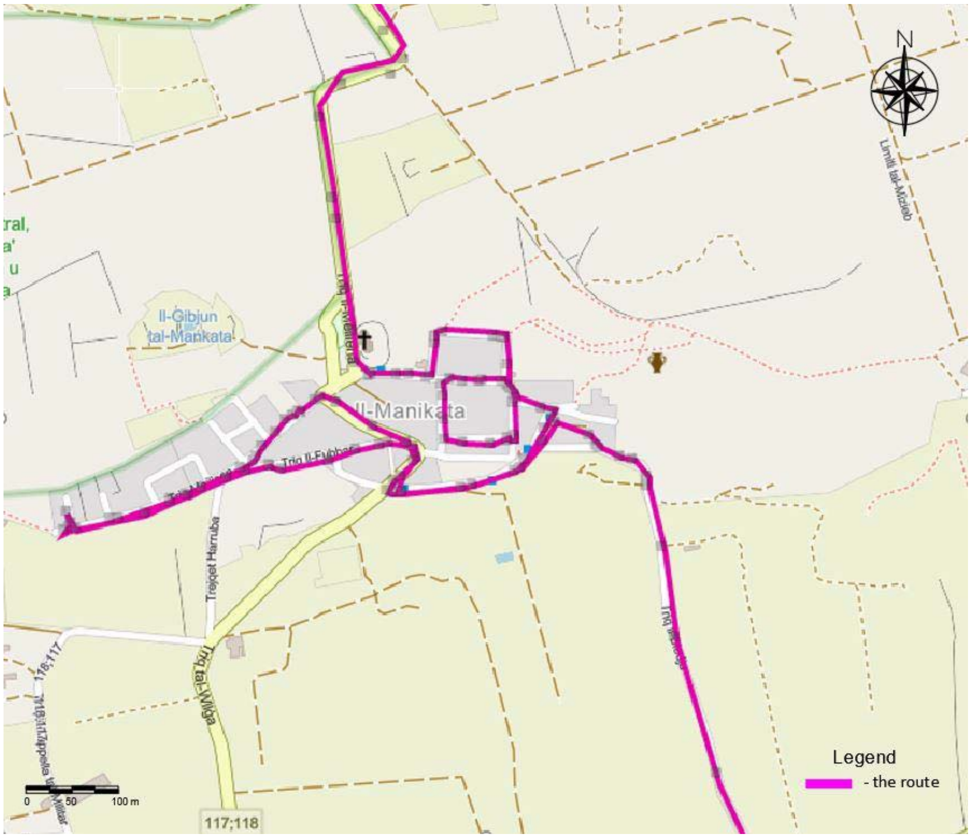
Source: Authors' own

Figure A1: The First Segment of the Optimized Route in Mellieħa



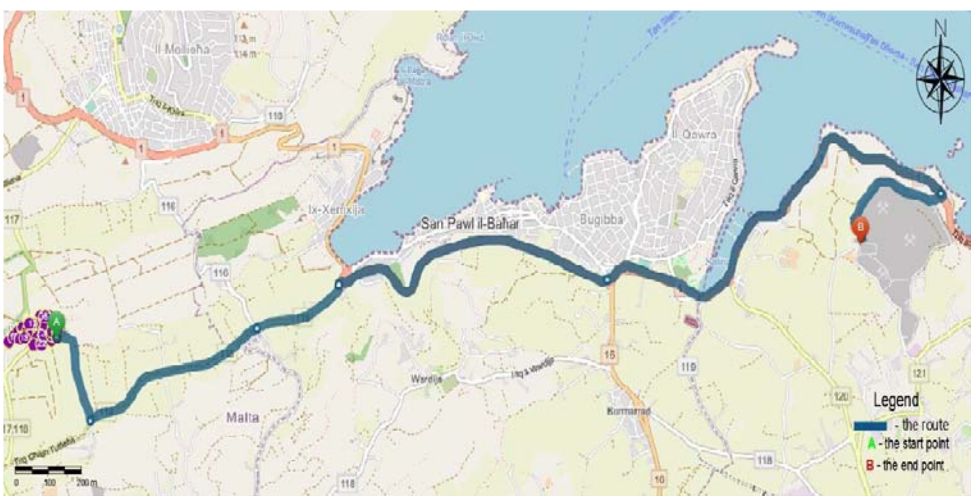
Source: Authors' own

Figure A2: The Third Segment of the Optimized Route in Mellieħa



Source: Authors' own

Figure A3: The Fourth Segment of the Optimized Route in Mellieħa



Source: Authors' own

Figure A4: The Fifth Segment of the Optimized Route in Mellieħa

Source: Authors' own

Figure A5: The Sixth Segment of the Optimized Route in Mellieħa

Appendix B

Table B1: The Proposed Route in Mellieħa.

Route Name	Sequence	Travel Distance from Previous Stop (Kilometers)	Address
Start Depot - 1 - Route1	1	0	Address 1
Start Depot - 1 - Route1	2	0.43583	Address 2
Start Depot - 1 - Route1	3	0.19057	Address 3
Start Depot - 1 - Route1	4	0.07226	Address 4
Start Depot - 1 - Route1	5	0.06558	Address 5
Start Depot - 1 - Route1	6	0.06372	Address 6
Start Depot - 1 - Route1	7	0.05423	Address 7
Start Depot - 1 - Route1	8	0.07942	Address 8
Start Depot - 1 - Route1	9	0.11259	Address 9
Start Depot - 1 - Route1	10	0.0854	Address 10
Start Depot - 1 - Route1	11	0.10931	Address 11
Start Depot - 1 - Route1	12	0.14212	Address 12
Start Depot - 1 - Route1	13	0.23691	Address 13
Start Depot - 1 - Route1	14	0.10184	Address 14
Start Depot - 1 - Route1	15	0.04496	Address 15
Start Depot - 1 - Route1	16	0.06632	Address 16
Start Depot - 1 - Route1	17	0.07825	Address 17
Start Depot - 1 - Route1	18	0.17582	Address 18
Start Depot - 1 - Route1	19	0.29804	Address 19
Start Depot - 1 - Route1	20	0.18468	Address 20
Start Depot - 1 - Route1	21	0.05987	Address 21
Start Depot - 1 - Route1	22	0.0471	Address 22
Start Depot - 1 - Route1	23	0.10133	Address 23
Start Depot - 1 - Route1	24	0.22883	Address 24
Start Depot - 1 - Route1	25	0.9564	Address 25

Start Depot - 1 - Route1	26	0.0492	Address 26
Start Depot - 1 - Route1	27	0.20551	Address 27
Start Depot - 1 - Route1	28	0.29058	Address 28
Start Depot - 1 - Route1	29	0.27474	Address 29
Start Depot - 1 - Route1	30	0.15214	Address 30
Start Depot - 1 - Route1	31	0.06624	Address 31
Start Depot - 1 - Route1	32	0.1728	Address 32
Start Depot - 1 - Route1	33	0.1015	Address 33
Start Depot - 1 - Route1	34	0.13441	Address 34
Start Depot - 1 - Route1	35	0.11152	Address 35
Start Depot - 1 - Route1	36	0.26123	Address 36
Start Depot - 1 - Route1	37	0.06373	Address 37
Start Depot - 1 - Route1	38	0.24963	Address 38
Start Depot - 1 - Route1	39	0.16911	Address 39
Start Depot - 1 - Route1	40	0.19214	Address 40
Start Depot - 1 - Route1	41	0.03327	Address 41
Start Depot - 1 - Route1	42	0.10485	Address 42
Start Depot - 1 - Route1	43	0.1233	Address 43
Start Depot - 1 - Route1	44	0.0775	Address 44
Start Depot - 1 - Route1	45	0.08821	Address 45
Start Depot - 1 - Route1	46	0.08391	Address 46
Start Depot - 1 - Route1	47	0.06388	Address 47
Start Depot - 1 - Route1	48	0.08458	Address 48
Start Depot - 1 - Route1	49	0.11594	Address 49
Start Depot - 1 - Route1	50	0.2616	Address 50
Start Depot - 1 - Route1	51	0.48044	Address 51
Start Depot - 1 - Route1	52	0.05711	Address 52
Start Depot - 1 - Route1	53	0.10759	Address 53
Start Depot - 1 - Route1	54	0.24538	Address 54
Start Depot - 1 - Route1	55	0.18496	Address 55
Start Depot - 1 - Route1	56	0.49137	Address 56
Start Depot - 1 - Route1	57	1.03836	Address 57
Start Depot - 1 - Route1	58	0.56074	Address 58
Start Depot - 1 - Route1	59	0.61258	Address 59
Start Depot - 1 - Route1	60	0.36105	Address 60
Start Depot - 1 - Route1	61	0.24549	Address 61
Start Depot - 1 - Route1	62	0.50647	Address 62
Start Depot - 1 - Route1	63	0.50511	Address 63
Start Depot - 1 - Route1	64	0.10069	Address 64
Start Depot - 1 - Route1	65	0.23984	Address 65
Start Depot - 1 - Route1	66	0.351	Address 66
Start Depot - 1 - Route1	67	0.28427	Address 67
Start Depot - 1 - Route1	68	0.38975	Address 68
Start Depot - 1 - Route1	69	0.4961	Address 69

Start Depot - 1 - Route1	70	0.47331	Address 70
Start Depot - 1 - Route1	71	0.27427	Address 71
Start Depot - 1 - Route1	72	0.26031	Address 72
Start Depot - 1 - Route1	73	0.33632	Address 73
Start Depot - 1 - Route1	74	0.67878	Address 74
Start Depot - 1 - Route1	75	0.45007	Address 75
Start Depot - 1 - Route1	76	0.15626	Address 76
Start Depot - 1 - Route1	77	0.30813	Address 77
Start Depot - 1 - Route1	78	0.16551	Address 78
Start Depot - 1 - Route1	79	0.14581	Address 79
Start Depot - 1 - Route1	80	0.09734	Address 80
Start Depot - 1 - Route1	81	0.05901	Address 81
Start Depot - 1 - Route1	82	0.12906	Address 82
Start Depot - 1 - Route1	83	0.30083	Address 83
Start Depot - 1 - Route1	84	0.10242	Address 84
Start Depot - 1 - Route1	85	0.08901	Address 85
Start Depot - 1 - Route1	86	0.10537	Address 86
Start Depot - 1 - Route1	87	0.11773	Address 87
Start Depot - 1 - Route1	88	0.17804	Address 88
Start Depot - 1 - Route1	89	0.07428	Address 89
Start Depot - 1 - Route1	90	0.20845	Address 90
Start Depot - 1 - Route1	91	0.09088	Address 91
Start Depot - 1 - Route1	92	0.08146	Address 92
Start Depot - 1 - Route1	93	0.08682	Address 93
Start Depot - 1 - Route1	94	0.18687	Address 94
Start Depot - 1 - Route1	95	0.63836	Address 95
Start Depot - 1 - Route1	96	0.07883	Address 96
Start Depot - 1 - Route1	97	0.09921	Address 97
Start Depot - 1 - Route1	98	0.05029	Address 98
Start Depot - 1 - Route1	99	0.05749	Address 99
Start Depot - 1 - Route1	100	0.07604	Address 100
Start Depot - 1 - Route1	101	0.07738	Address 101
Start Depot - 1 - Route1	102	0.07216	Address 102
Start Depot - 1 - Route1	103	0.08529	Address 103
Start Depot - 1 - Route1	104	0.21469	Address 104
Start Depot - 1 - Route1	105	0.22405	Address 105
Start Depot - 1 - Route1	106	0.31518	Address 106
Start Depot - 1 - Route1	107	0.12945	Address 107
Start Depot - 1 - Route1	108	0.11933	Address 108
Start Depot - 1 - Route1	109	0.10127	Address 109
Start Depot - 1 - Route1	110	0.14952	Address 110
Start Depot - 1 - Route1	111	0.10166	Address 111
Start Depot - 1 - Route1	112	0.15086	Address 112
Start Depot - 1 - Route1	113	0.12289	Address 113

Start Depot - 1 - Route1	114	0.11051	Address 114
Start Depot - 1 - Route1	115	0.12509	Address 115
Start Depot - 1 - Route1	116	0.22379	Address 116
Start Depot - 1 - Route1	117	0.0489	Address 117
Start Depot - 1 - Route1	118	0.07935	Address 118
Start Depot - 1 - Route1	119	0.06884	Address 119
Start Depot - 1 - Route1	120	0.11803	Address 120
Start Depot - 1 - Route1	121	0.09702	Address 121
Start Depot - 1 - Route1	122	0.10142	Address 122
Start Depot - 1 - Route1	123	0.0875	Address 123
Start Depot - 1 - Route1	124	0.06865	Address 124
Start Depot - 1 - Route1	125	0.15161	Address 125
Start Depot - 1 - Route1	126	0.11177	Address 126
Start Depot - 1 - Route1	127	0.09985	Address 127
Start Depot - 1 - Route1	128	0.1939	Address 128
Start Depot - 1 - Route1	129	0.24688	Address 129
Start Depot - 1 - Route1	130	0.66543	Address 130
Start Depot - 1 - Route1	131	0.15791	Address 131
Start Depot - 1 - Route1	132	0.31105	Address 132
Start Depot - 1 - Route1	133	0.19159	Address 133
Start Depot - 1 - Route1	134	0.09208	Address 134
Start Depot - 1 - Route1	135	0.07277	Address 135
Start Depot - 1 - Route1	136	0.07394	Address 136
Start Depot - 1 - Route1	137	0.04926	Address 137
Start Depot - 1 - Route1	138	0.54147	Address 138
Start Depot - 1 - Route1	139	0.25462	Address 139
Start Depot - 1 - Route1	140	0.15436	Address 140
Start Depot - 1 - Route1	141	0.20085	Address 141
Start Depot - 1 - Route1	142	0.08969	Address 142
Start Depot - 1 - Route1	143	0.09143	Address 143
Start Depot - 1 - Route1	144	0.09879	Address 144
Start Depot - 1 - Route1	145	0.06878	Address 145
Start Depot - 1 - Route1	146	0.20737	Address 146
Start Depot - 1 - Route1	147	0.17209	Address 147
Start Depot - 1 - Route1	148	1.11101	Address 148
Start Depot - 1 - Route1	149	1.17521	Address 149
Start Depot - 1 - Route1	150	0.0797	Address 150
Start Depot - 1 - Route1	151	0.06385	Address 151
Start Depot - 1 - Route1	152	0.07764	Address 152
Start Depot - 1 - Route1	153	0.13444	Address 153
Start Depot - 1 - Route1	154	0.1364	Address 154
Start Depot - 1 - Route1	155	0.32648	Address 155
Start Depot - 1 - Route1	156	0.16395	Address 156
Start Depot - 1 - Route1	157	0.16442	Address 157

Start Depot - 1 - Route1	158	0.11654	Address 158
Start Depot - 1 - Route1	159	0.09606	Address 159
Start Depot - 1 - Route1	160	0.17451	Address 160
Start Depot - 1 - Route1	161	0.07295	Address 161
Start Depot - 1 - Route1	162	0.05379	Address 162
Start Depot - 1 - Route1	163	0.09681	Address 163
Start Depot - 1 - Route1	164	0.09133	Address 164
Start Depot - 1 - Route1	165	0.10143	Address 165
Start Depot - 1 - Route1	166	0.06377	Address 166
Start Depot - 1 - Route1	167	0.04451	Address 167
Start Depot - 1 - Route1	168	0.07533	Address 168
Start Depot - 1 - Route1	169	0.16041	Address 169
Start Depot - 1 - Route1	170	0.12242	Address 170
Start Depot - 1 - Route1	171	0.07301	Address 171
Start Depot - 1 - Route1	172	0.09681	Address 172
Start Depot - 1 - Route1	173	0.06027	Address 173
Start Depot - 1 - Route1	174	0.05284	Address 174
Start Depot - 1 - Route1	175	0.08784	Address 175
Start Depot - 1 - Route1	176	0.0619	Address 176
Start Depot - 1 - Route1	177	0.08272	Address 177
Start Depot - 1 - Route1	178	0.06843	Address 178
Start Depot - 1 - Route1	179	0.1398	Address 179
Start Depot - 1 - Route1	180	0.07971	Address 180
Start Depot - 1 - Route1	181	0.07615	Address 181
Start Depot - 1 - Route1	182	0.07677	Address 182
Start Depot - 1 - Route1	183	0.12679	Address 183
Start Depot - 1 - Route1	184	0.16966	Address 184
Start Depot - 1 - Route1	185	0.07024	Address 185
Start Depot - 1 - Route1	186	0.11942	Address 186
Start Depot - 1 - Route1	187	0.11151	Address 187
Start Depot - 1 - Route1	188	0.05454	Address 188
Start Depot - 1 - Route1	189	0.03799	Address 189
Start Depot - 1 - Route1	190	0.03776	Address 190
Start Depot - 1 - Route1	191	0.05416	Address 191
Start Depot - 1 - Route1	192	0.41136	Address 192
Start Depot - 1 - Route1	193	0.1004	Address 193
Start Depot - 1 - Route1	194	0.25263	Address 194
Start Depot - 1 - Route1	195	0.11217	Address 195
Start Depot - 1 - Route1	196	0.16058	Address 196
Start Depot - 1 - Route1	197	0.2599	Address 197

Source: Authors' own through ArcGIS

Appendix C

Table C1: Emission Factors per Litre Fuel Consumed, Volvo Dennis Eagle 2009.

Typical values, based on certification measurements, for the more common Volvo engines, with EU certification diesel fuel						
Car Standard	Law from	Volvo from	NOx g/litre	PM g/litre	HC g/litre	CO2 kg/litre
Euro 5	2009	2005	7	0.10	0.00	2.6

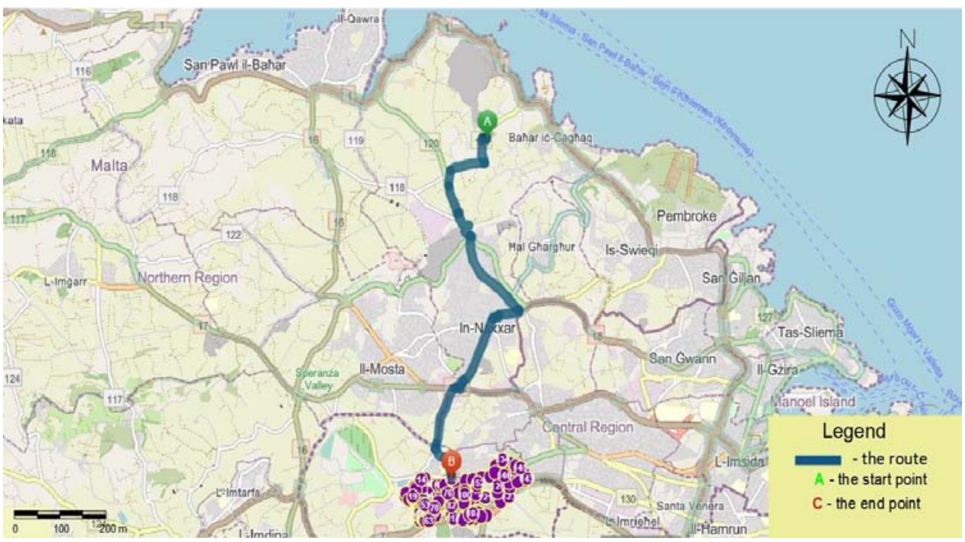
Source: Volvo Trucks, www.volvo.com, accessed 16.12.2023

Table C2: Typical Fuel Consumption in Litres per 100 km, Volvo Dennis Eagle 2009.

	Payload in Tons	Total Weight in Tons	Litres / 100 km Empty	Litre / 100 km Full Load
Truck	14	24	25-30	30-40

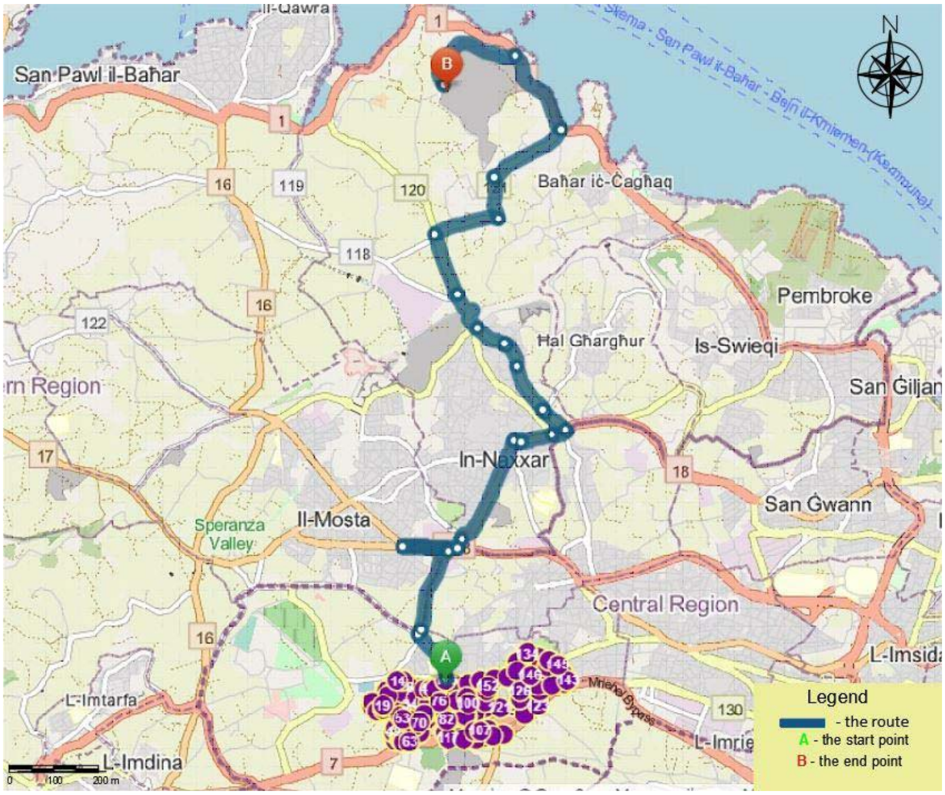
Source: Volvo Trucks, www.volvo.com, accessed 16.12.2023

Appendix D



Source: Authors' own

Figure D1: The First Segment of the Optimized Route in Attard.



Source: Authors' own

Figure D2: The Third Segment of the Optimized Route in Attard.

Source: Authors' own

Figure D3: The Fourth Segment of the Optimized Route in Attard.

Appendix E

Table E1: The Proposed Route in Attard.

Route Name	Sequence	Travel Distance from Previous Stop (Kilometers)	Address
Start Depot-1-Route 1	1	0	Address 1
Start Depot-1-Route 1	2	0.19	Address 2
Start Depot-1-Route 1	3	0.06	Address 3
Start Depot-1-Route 1	4	0.06	Address 4
Start Depot-1-Route 1	5	0.07	Address 5
Start Depot-1-Route 1	6	0.07	Address 6
Start Depot-1-Route 1	7	0.05	Address 7
Start Depot-1-Route 1	8	0.06	Address 8
Start Depot-1-Route 1	9	0.06	Address 9
Start Depot-1-Route 1	10	0.08	Address 10
Start Depot-1-Route 1	11	0.08	Address 11
Start Depot-1-Route 1	12	0.09	Address 12
Start Depot-1-Route 1	13	0.03	Address 13
Start Depot-1-Route 1	14	0.12	Address 14
Start Depot-1-Route 1	15	0.03	Address 15
Start Depot-1-Route 1	16	0.11	Address 16
Start Depot-1-Route 1	17	0.08	Address 17
Start Depot-1-Route 1	18	0.04	Address 18
Start Depot-1-Route 1	19	0.15	Address 19
Start Depot-1-Route 1	20	0.2	Address 20
Start Depot-1-Route 1	21	0.2	Address 21
Start Depot-1-Route 1	22	0.2	Address 22
Start Depot-1-Route 1	23	0.07	Address 23
Start Depot-1-Route 1	24	0.07	Address 24
Start Depot-1-Route 1	25	0.05	Address 25
Start Depot-1-Route 1	26	0.08	Address 26
Start Depot-1-Route 1	27	0.13	Address 27
Start Depot-1-Route 1	28	0.06	Address 28
Start Depot-1-Route 1	29	0.08	Address 29
Start Depot-1-Route 1	30	0.05	Address 30
Start Depot-1-Route 1	31	0.04	Address 31
Start Depot-1-Route 1	32	0.09	Address 32
Start Depot-1-Route 1	33	0.05	Address 33
Start Depot-1-Route 1	34	0.19	Address 34
Start Depot-1-Route 1	35	0.11	Address 35
Start Depot-1-Route 1	36	0.03	Address 36
Start Depot-1-Route 1	37	0.09	Address 37
Start Depot-1-Route 1	38	0.06	Address 38

Start Depot-1-Route 1	39	0.04	Address 39
Start Depot-1-Route 1	40	0.14	Address 40
Start Depot-1-Route 1	41	0.05	Address 41
Start Depot-1-Route 1	42	0.1	Address 42
Start Depot-1-Route 1	43	0.04	Address 43
Start Depot-1-Route 1	44	0.12	Address 44
Start Depot-1-Route 1	45	0.14	Address 45
Start Depot-1-Route 1	46	0.05	Address 46
Start Depot-1-Route 1	47	0.06	Address 47
Start Depot-1-Route 1	48	0.06	Address 48
Start Depot-1-Route 1	49	0.09	Address 49
Start Depot-1-Route 1	50	0.07	Address 50
Start Depot-1-Route 1	51	0.19	Address 51
Start Depot-1-Route 1	52	0.04	Address 52
Start Depot-1-Route 1	53	0.04	Address 53
Start Depot-1-Route 1	54	0.02	Address 54
Start Depot-1-Route 1	55	0.03	Address 55
Start Depot-1-Route 1	56	0.04	Address 56
Start Depot-1-Route 1	57	0.07	Address 57
Start Depot-1-Route 1	58	0.02	Address 58
Start Depot-1-Route 1	59	0.03	Address 59
Start Depot-1-Route 1	60	0.06	Address 60
Start Depot-1-Route 1	61	0.03	Address 61
Start Depot-1-Route 1	62	0.03	Address 62
Start Depot-1-Route 1	63	0.04	Address 63
Start Depot-1-Route 1	64	0.04	Address 64
Start Depot-1-Route 1	65	0.07	Address 65
Start Depot-1-Route 1	66	0.07	Address 66
Start Depot-1-Route 1	67	0.2	Address 67
Start Depot-1-Route 1	68	0.02	Address 68
Start Depot-1-Route 1	69	0.1	Address 69
Start Depot-1-Route 1	70	0.04	Address 70
Start Depot-1-Route 1	71	0.12	Address 71
Start Depot-1-Route 1	72	0.08	Address 72
Start Depot-1-Route 1	73	0.02	Address 73
Start Depot-1-Route 1	74	0.09	Address 74
Start Depot-1-Route 1	75	0.09	Address 75
Start Depot-1-Route 1	76	0.03	Address 76
Start Depot-1-Route 1	77	0.15	Address 77
Start Depot-1-Route 1	78	0.06	Address 78
Start Depot-1-Route 1	79	0.2	Address 79
Start Depot-1-Route 1	80	0.12	Address 80
Start Depot-1-Route 1	81	0.03	Address 81
Start Depot-1-Route 1	82	0.03	Address 82

Start Depot-1-Route 1	83	0.04	Address 83
Start Depot-1-Route 1	84	0.09	Address 84
Start Depot-1-Route 1	85	0.05	Address 85
Start Depot-1-Route 1	86	0.05	Address 86
Start Depot-1-Route 1	87	0.03	Address 87
Start Depot-1-Route 1	88	0.03	Address 88
Start Depot-1-Route 1	89	0.02	Address 89
Start Depot-1-Route 1	90	0.04	Address 90
Start Depot-1-Route 1	91	0.05	Address 91
Start Depot-1-Route 1	92	0.18	Address 92
Start Depot-1-Route 1	93	0.07	Address 93
Start Depot-1-Route 1	94	0.05	Address 94
Start Depot-1-Route 1	95	0.05	Address 95
Start Depot-1-Route 1	96	0.08	Address 96
Start Depot-1-Route 1	97	0.09	Address 97
Start Depot-1-Route 1	98	0.09	Address 98
Start Depot-1-Route 1	99	0.03	Address 99
Start Depot-1-Route 1	100	0.02	Address 100
Start Depot-1-Route 1	101	0.14	Address 101
Start Depot-1-Route 1	102	0.06	Address 102
Start Depot-1-Route 1	103	0.06	Address 103
Start Depot-1-Route 1	104	0.02	Address 104
Start Depot-1-Route 1	105	0.5	Address 105
Start Depot-1-Route 1	106	0.05	Address 106
Start Depot-1-Route 1	107	0.1	Address 107
Start Depot-1-Route 1	108	0.09	Address 108
Start Depot-1-Route 1	109	0.2	Address 109
Start Depot-1-Route 1	110	0.11	Address 110
Start Depot-1-Route 1	111	0.1	Address 111
Start Depot-1-Route 1	112	0.08	Address 112
Start Depot-1-Route 1	113	0.03	Address 113
Start Depot-1-Route 1	114	0.05	Address 114
Start Depot-1-Route 1	115	0.04	Address 115
Start Depot-1-Route 1	116	0.07	Address 116
Start Depot-1-Route 1	117	0.2	Address 117
Start Depot-1-Route 1	118	0.15	Address 118
Start Depot-1-Route 1	119	0.85	Address 119
Start Depot-1-Route 1	120	0.05	Address 120
Start Depot-1-Route 1	121	0.28	Address 121
Start Depot-1-Route 1	122	0.45	Address 122
Start Depot-1-Route 1	123	0.19	Address 123
Start Depot-1-Route 1	124	0.42	Address 124
Start Depot-1-Route 1	125	0	Address 125
Start Depot-1-Route 1	126	0.09	Address 126

Start Depot-1-Route 1	127	0.09	Address 127
Start Depot-1-Route 1	128	0.09	Address 128
Start Depot-1-Route 1	129	0.05	Address 129
Start Depot-1-Route 1	130	0.06	Address 130
Start Depot-1-Route 1	131	0.1	Address 131
Start Depot-1-Route 1	132	0.31	Address 132
Start Depot-1-Route 1	133	0.09	Address 133
Start Depot-1-Route 1	134	0.18	Address 134
Start Depot-1-Route 1	135	0.13	Address 135
Start Depot-1-Route 1	136	0.1	Address 136
Start Depot-1-Route 1	137	0.1	Address 137
Start Depot-1-Route 1	138	0.1	Address 138
Start Depot-1-Route 1	139	0.25	Address 139
Start Depot-1-Route 1	140	0.14	Address 140
Start Depot-1-Route 1	141	0.1	Address 141
Start Depot-1-Route 1	142	0.32	Address 142
Start Depot-1-Route 1	143	0.08	Address 143
Start Depot-1-Route 1	144	0.09	Address 144
Start Depot-1-Route 1	145	0.09	Address 145
Start Depot-1-Route 1	146	0.59	Address 146
Start Depot-1-Route 1	147	0.09	Address 147
Start Depot-1-Route 1	148	0.24	Address 148
Start Depot-1-Route 1	149	0.13	Address 149
Start Depot-1-Route 1	150	0.26	Address 150
Start Depot-1-Route 1	151	0.06	Address 151
Start Depot-1-Route 1	152	0.05	Address 152
Start Depot-1-Route 1	153	0.14	Address 153
Start Depot-1-Route 1	154	0.12	Address 154
Start Depot-1-Route 1	155	0.17	Address 155
Start Depot-1-Route 1	156	0.09	Address 156

Source: Authors' own through ArcGIS

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

References Références Referencias

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