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A trip factor design for the green vehicle routing: A milk collection process case

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Abstract **–** The total milk production worldwide increased by approximately 1.3% in 2019 compared to the previous year, reaching around 51 million tons. Due to the increase in milk production, global milk imports decreased by 1.3% to 1.4 million tons in 2019, while milk exports increased by 10.5% to 1.9 million tons by TEPGE 2020 dataset. This project aims to enable a dairy and milk-producing business to collect milk from different supply points and return it to the company under the specified constraints, paying attention to fuel consumption and CO2 emissions. It involves creating daily transportation routes, determining which points to collect milk from, the quality of milk to be obtained, and the capacities of the collecting vehicles, all aimed at making the company's resources more efficiently utilized. Based on the provided TEPGE data, milk production increases proportionally with the world population, and with this increase, it is necessary to reach more people. Therefore, it is essential to reduce fuel consumption and CO2 emissions both for the economy and the environment. In this problem, a solution will be developed by incorporating the constraints used in the Milk Collection Problem rather than the conventional Vehicle Routing Problem. The goal is to minimize costs and provide a solution that minimally pollutes the environment for companies engaged in milk transportation.

Keywords – Milk Collection, Green Vehicle Routing, Optimization, Emissions, Fuel Consumption

I. Introduction

Milk and dairy products hold a significant place as a primary source of nutrition worldwide. One of the major challenges faced by businesses operating in this sector is ensuring the efficiency of the milk collection process. Traditional methods of milk collection, often starting from the nearest location, may not always prioritize minimizing CO2 emissions and fuel consumption, potentially leading to increased fuel costs for businesses.

Therefore, optimizing the milk collection process through "Green Vehicle Routing" becomes crucial. This routing method offers the most environmentally friendly route for the vehicle, minimizing CO2 emissions. This approach provides several advantages to businesses, with the most prominent being the reduction of fuel costs and minimizing the environmental impact.

We aim to optimize the route taken when collecting milk from various suppliers for milk producers. In addition to addressing the Traditional Vehicle Routing problem, specific constraints used in the Milk Collection Problem will be incorporated. This model will enable businesses to utilize their resources more efficiently, ultimately reducing CO2 emissions and fuel consumption.

This paper will benefit businesses engaged in milk transportation. It will make the milk collection process more efficient, reduce costs, and increase profit margins. Additionally, by mitigating environmental effects, businesses can enhance their sustainability.

The concluding report of this project extensively examines how the milk collection process can be optimized using green vehicle routing, considering new factors that impact the process. Model creation, constraint identification, and the resulting route planning constitute the primary focal points of this paper.

II. Materials and Method

Revaluation of the Green Vehicle Routing Problem necessitates a focus on critical parameters to minimize environmental impact and enhance energy efficiency. These parameters encompass the type of route, traffic conditions, aerodynamic resistance, road slope, climatic conditions, vehicle weight, rolling resistance, and fuel type. Each parameter holds significant importance in the context of environmental sustainability and energy conservation throughout the green vehicle routing process.

In this project, factors affecting the Green Vehicle Routing Problem have been defined as trip factors, and the project's primary contribution is presented as follows:

- Fuel Type
- Route Type
- Traffic Type
- Weather Resistance
- Road Slope (Elevation)
- Climate Condition
- Truck Weight
- Rolling Resistance

Fuel Type:

Research has yielded carbon emission ratios for different fuel types, as illustrated in Figure 1. This study specifically focuses on Ethanol and Gasoline, and it is evident that Gasoline leads to higher carbon emissions.

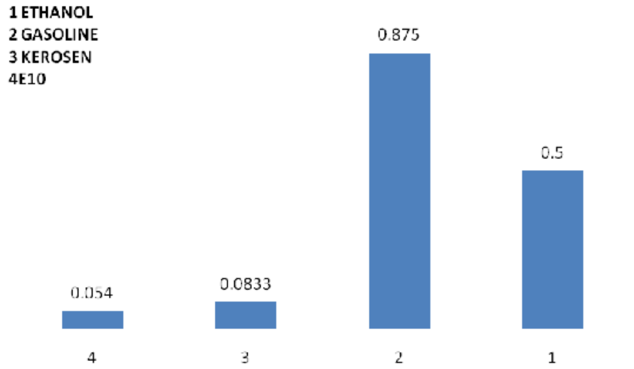

Figure 1. Carbon emission values for various types of fuels [8]

Table 1. Fuel Type Categories

Fuel Type	**Value**
Diesel	2
CNG	1

Rolling Resistance:

Rolling resistance is a resistance force that acts against the motion of a moving vehicle on all of its wheels. This resistance arises because the road and the wheels experience some compression, causing the wheels to continually encounter the need to overcome this deformation. This resistance is referred to as rolling resistance.

Table 2. Average rolling resistance coefficients for various types of vehicles [5]

Vehicle Type	Surface		
	Concrete	Hard Soil	Sand
Car	0.015	0.08	0.30
Truck	0.012	0.06	0.25
Tractor	0.02	0.04	0.20

As evident from the table above, sand has the highest rolling resistance among the surfaces listed. The scale here is arranged in descending order.

Table 3. Rolling Resistance Categories

Rolling Resistance	**Value**
Concrete	1
Hard Soil	2
Sand	3

Vehicle Weight:

In his research, Coyle [5] obtained results from measurements conducted with six different vehicle combinations and across two different routes. Fuel consumption is observed to increase in tandem with the total weight of the vehicle, indicating a definitive relationship between total weight and fuel consumption. Coyle's study focused on quantifying the relationship between fuel consumption and total weight in both operational scenarios. To account for the increase in carbon emissions as weight increases, we have established a descending scale for the truck masses we have identified at specific intervals.

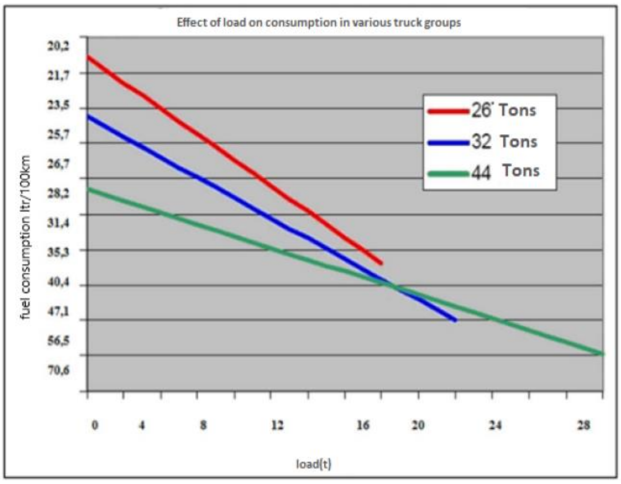

Figure 2. The impact of load on fuel consumption in various truck groups [5]

Table 4. Vehicle Weight Categories

Weight(tons)	Value
20	1
28	2
36	3
44	4
52	5

Climate Condition:

Research findings have revealed that the use of air conditioning in vehicles has a positive impact on fuel consumption. The power required to operate the vehicle's air conditioning compressor is significant, potentially exceeding the engine power needed for a medium-sized vehicle to maintain a constant speed of 56 km/h (35 mph). In a conventional engine, a 400 W load can lead to a reduction in fuel efficiency of approximately 0.4 km/L (1 mpg). If all light-duty vehicles in the United States were to achieve a modest 0.4 km/L (1 mpg) increase in fuel efficiency, the country could realize annual savings exceeding 6 billion dollars [4]. Consequently, a scale has been established in descending order, reflecting the increase in carbon emissions when the air conditioning is on.

Table 5. Climate Condition Categories

Climate Control (Turning Air Conditioning On/Off)	Value
Air Condition Off	1
Air Condition On	2

Road Slope:

When a vehicle starts ascending a slope, it encounters a resistance proportional to its weight, known as road slope resistance. Road slope are expressed as percentages. For instance, a 5% road slope means that the road ascends 5 meters for every 100 meters of horizontal distance. Likewise, at higher altitudes, a truck's effective engine power decreases by 40-50% (Agudelo et al., 2009), torque diminishes by 1.5-1.7 times (Surcel and Michaelsen, 2009), acceleration time and distance increase by 2.5-3.0 times (Gafarov, 2014), and specific fuel consumption rises by 40% [3].

Table 6. The Effects of Elevation on Engine Power and Fuel Consumption [3].

Elevation Above Sea Level (m)	0	500	1000	1500	2000	2500	3000	3500	4000
Decrease in Engine Power (%)	0	6	11.3	16.5	21.5	26	30.8	35	39.2
Increase in Fuel Consumption (%)	0	3	6	12	17	19	25	35	40

When we make a distinction based on the data presented in the table, it becomes evident that as we ascend above sea level, engine power increases, and this escalation has a direct impact on fuel consumption and, subsequently, carbon emissions. With these insights in mind, it has been determined that vehicles at elevations ranging from 0 to 500 meters above sea level have the least influence on fuel consumption. Consequently, numbering has been applied in ascending order from bottom to top.

Table 7. Road Slope Categories

Road Slope (Elevation Above Sea Level)	Value
4000+	9
3500 - 4000	8
3000-3500	7
2500-3000	6
2000-2500	5
1500-2000	4
1000-1500	3
500-1000	2
0-500	1

Aerodynamic Resistance Categories:

Aerodynamic resistance refers to the force generated by air striking the projected area of a moving vehicle. The density of the air through which the vehicle travels is directly related to the friction coefficient, the projected area, and the square of the speed [2]. Weather conditions encompass factors such as temperature, humidity, precipitation, and snow. Hot weather may result in increased utilization of the vehicle's cooling system, consequently raising energy consumption. Rainy and snowy conditions can make road surfaces slippery, posing safety hazards. Therefore, climate conditions must be considered when choosing a route. In our country, there are seven regions, but based on data from the "Turkey Wind Atlas," there are five distinct regions considered as the "Combined Region" and are used to represent Aerodynamic Resistance. Our objective is to minimize the objective function, and thus, values have been assigned in ascending order from bottom to top. This reflects the lowest aerodynamic resistance in the "South-eastern Anatolia" region in Turkey, which also has the least impact on carbon emissions.

Table 8. Aerodynamic Resistance Categories

Aerodynamic Resistance	Value
Combined Region(Ege, Marmara, Akdeniz)	5
Central Anatolia	4
Black Sea	3
Eastern Anatolia	2
Southeastern Anatolia	1

Traffic Type Categories:

One of the most significant challenges of our time is traffic congestion. The constant stop-and-go of vehicles not only affects fuel consumption positively but also has a direct impact on carbon emissions. Our traffic-related factor is divided into five categories. Our goal is to minimize the objective function; hence, values have been assigned in ascending order from bottom to top, reflecting the lower impact of highway traffic.

Table 9. Traffic Density Categories

Traffic Density	Value
Heavy Trafik	5
Moderate Trafik	4
City Trafik	3
Rural Trafik	2
Highway Trafiği	1

Road Type: Dr. Siamak and A. Ardekani [1] conducted research on the varying fuel consumption and CO2 emissions of vehicles operating on Portland Asphalt Concrete and Asphalt Concrete under urban driving conditions. The primary goal of the study is to formulate cost-reduction recommendations for materials utilized on alternative urban roadways. In this context, there are six distinct road types. Our aim is to minimize the objective function, and as such, values have been assigned in ascending order from top to bottom, reflecting the minimal impact of the divided road on carbon emissions."

Table 10. Road Type Categories

Road Type	Value
Divided Road	1
Asphalt	2
Concrete	3
Stabilized	4
Soil	5
Paved	6

III. RESULTS

The dataset we used for our study was prepared by Jaramillo in 2011.

Based on this dataset, we can observe the minimization formula and explanations used below [7].

$$\min CO_2 Emission\ (g) = \sum_{i=0}^{n}\sum_{j=0}^{n}\sum_{k=1}^{K} d_{ij} . \left[\left(\frac{e_{f}-e_{e}}{Q}\right) .q_{ij}^{k} + e_{e1} .x_{ij}^{k}\right] \quad (1)$$

L	Coordinates x	Coordinates y	q_{ij}	d_{ij} 0	1	2	3	4	5	6	7	8	9	10
0	15	6	0	0	84	75	90	23	59	57	42	33	100	74
1	85	54	2		0	50	43	61	61	39	43	61	23	81
2	90	4	2			0	89	54	89	66	42	72	73	111
3	56	87	3				0	74	38	34	63	57	31	48
4	37	15	1					0	51	40	18	25	79	71
5	24	65	2						0	24	50	27	63	21
6	46	54	3							0	30	25	46	46
7	53	24	3								0	30	62	71
8	26	38	2									0	71	45
9	86	77	4										0	78
10	8	80	1											0

Figure 3. Jaramillo Dataset

result =

0	2.2500	3.5000	2.5000	3.2500	2.1250	2.6250	1.5000	2.5000	2.6250	2.8750
2.2500	0	2.2500	2.2500	2.1250	2.1250	3.3750	2.7500	3.5000	2.1250	2.7500
3.5000	2.2500	0	3.3750	2.1250	2.5000	2.6250	2.5000	1.5000	2.5000	3.1250
2.5000	2.2500	3.3750	0	2.2500	2.3750	2.8750	2.7500	2.3750	2.0000	3.2500
3.2500	2.1250	2.1250	2.2500	0	1.5000	2.3750	2.5000	2.5000	2.6250	2.1250
2.1250	2.1250	2.5000	2.3750	1.5000	0	3.0000	2.5000	2.8750	2.6250	2.1250
2.6250	3.3750	2.6250	2.8750	2.3750	3.0000	0	2.5000	2.0000	2.6250	2.2500
1.5000	2.7500	2.5000	2.7500	2.5000	2.5000	2.5000	0	2.5000	2.2500	2.8750
2.5000	3.5000	1.5000	2.3750	2.5000	2.8750	2.0000	2.5000	0	1.5000	2.0000
2.6250	2.1250	2.5000	2.0000	2.6250	2.6250	2.6250	2.2500	1.5000	0	2.2500
2.8750	2.7500	3.1250	3.2500	2.1250	2.1250	2.2500	2.8750	2.0000	2.2500	0

Figure 4. Trip factor

- d_{ij} distance between points i and j
- q_i weight at point i (non-negative)
- c_{ij} travel cost between i and j
- Q_k vehicle capacity
- k_k vehicle identification number
- K_k vehicle number
- N_k customer number

The revised form of Equation 1, after adding the trip factor that would increase CO_2 emissions, is as follows, utilizing all parameters given in Figure 5.

$$\text{minCO}_2\text{Emission(G)} = \sum_{i=0}^{n}\sum_{j=0}^{n}\sum_{k=0}^{K}\left[\left(\frac{ef-ee}{Q}\right)(dij^k - 0{,}3 + tfij^k)\right] - tf_{ij}^k\left(\frac{ef-ee}{Q}\right) \quad (2)$$

IV. DISCUSSION

First of all, green vehicle routing planning can reduce fuel consumption for transportation companies. More efficient route planning can lower fuel costs, thus increasing the profit margin for businesses. This can be economically significant for businesses and is open to discussion.

Furthermore, green vehicle routing has positive effects on environmental sustainability. The reduction in CO_2 emissions minimizes environmental damage and promotes green transportation. This can be a crucial topic for environmentally-conscious businesses.

However, the implementation of green vehicle routing planning may face certain challenges. These challenges, as mentioned in our study (such as road slope, road type, etc.), can be discussed. These obstacles may hinder the effective implementation of green vehicle routing strategies.

In conclusion, optimizing the milk collection process through green vehicle routing can offer economic and environmental benefits to businesses. Nevertheless, considering the potential difficulties and challenges, careful planning and evaluation are essential.

V. CONCLUSION

This paper aims to optimize the route when collecting milk from various suppliers located in different locations. In addition to the traditional Vehicle Routing Problem, constraints specific to Milk Collection Problem will be incorporated. This model will result in more efficient utilization of business resources, reducing CO_2 emissions, and minimizing fuel consumption.

We will provide benefits to businesses involved in milk transportation. The milk collection process will become more effective, costs will decrease, and profit margins will increase. Due to its environmental impacts, businesses will enhance sustainability.

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