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Modelling the Collection and Delivery of Sheep Milk: A Tool to Optimise the Logistics Costs of Cheese Factories

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Abstract: The milk transformation process, in the last thirty years, moved from on-farm to centralised cheese factories, affecting the management of transport logistics. In Sardinia, the presence of about 12,000 dairy sheep farms, located in rural areas with poor condition of road network, makes collecting milk a significant impact on profit, affecting the costs of milk transportation. Moreover, dairy sheep farming is characterized by seasonal production, this means that the amount of milk that is produced by each farm differs significantly over the year. The objective of this work was to develop a decision support tool that, while optimising milk collection routes, reduced the costs of milk transport, thus improving the density of collection. The tool developed ad hoc in this study used GPS map location and milk volumes of farms to calculate the cost per litre of milk for the regular routing, and to recalculate the same cost for the optimised collecting route. Results showed that this tool improved the efficiency of milk collection, reducing the number of routes and the driving distances. Furthermore, optimising the density of collection, the new routes improved the environmental impact and the transportation costs that are associated with logistic and traceability of raw sheep milk.

Keywords: milk-run; raw milk transport; logistics management; scheduling; vehicle routing problem (VRP)

1. Introduction

The largest producer of milk in the world is the European Union (EU), with 156 billion L [1]. Sardinia is the region of Italy with the largest production of sheep milk (250,867 tonnes per year) [2]. Furthermore, the global dairy industry is expected to increase by 2.4% per annum [3].

In the last decade, technological developments in the dairy industry have kept costs under control in order to guarantee the safety and quality of the products. The key improvements have been the concentration of transformation processes in cheese factories, the automation of the production processes, and advances in the laboratory techniques of quality control.

The constant increase of costs involved in milk collection from farms to cheese factories means that rationalisation of the collection and transportation system is essential. This is of particular importance in the case of sheep milk in Sardinia, because of the small size of the dairy sheep farms, their dispersal over the countryside, and the poor condition of the rural road network. Moreover, dairy sheep farming is characterized by seasonal production, this means that the amount of milk that is produced by each farm differs significantly every month. Improving the transportation of milk represents an important action in order to reduce the environmental impact of the entire post-farm milk chain [4]. Moreover, reducing the energy consumption and the related emissions of carbon dioxide in the milk production system represents an important issue to be analysed further, likewise mobility plans that affect strategies and actions [5,6]. Several studies on milk collection have been carried out [7–12], while no in-depth studies have yet been made of the problems that are involved in collecting and transporting sheep milk to the cheese factories. As a result, there is a lack of scientific data and little information is available to the cheese factory managers to help them to rationalise the overall transportation system. For both organisational and associated technical reasons, these may influence the costs of the entire transformation process [13].

The term Milk-Run has been used in logistics to represent a circular tour of trucks, which derived from the delivery and removal of milk bottles. This system refers to the movement of transport vehicle in logistics, where a set of vehicles needs to supply a defined amount of goods at a given point of time in a pre-planned route. The Milk-Run system was mostly adopted as a part of inter-company transport, but later found its important application into international logistic systems [14–16]. Modelling the logistic of collection and delivery of agricultural products represents an important aspect to improve the traceability system [17,18], and could also be useful to evaluate the carbon emissions impact when the implementation of Precision Livestock Farming (PLF) devices that occurs in dairy chain [19].

Today, developments in communication technologies have totally changed the way in which logistics are managed. These changes have benefited companies by helping them both to reduce costs and to improve the quality of the services that they offer [20]. Logistical management consists of using everyday modern informatics and telecommunication resources [21] to process the amount of information that is required to optimise the milk collection network [7,22–25].

In transport delivery issues, heuristic algorithms are usually applied, producing approximately optimal results. Specifically, in the logistic transport systems management, we refer to a whole class of problems, known as Vehicle Routing Problem (VRP) [26–28]. This approach needs to organise routes, vehicles, and customers, while respecting the constraints that are imposed by the system. VRP allows to reach the goals that are referred to transport logistics, as well as the minimization of the costs and the CO_2 emissions. The oldest logistic problem in the transport history is the Travelling Salesman Problem (TSP), which can be solved by various mathematical models [29–31]. One of the most common methods for solving TSP is represented by the Ant Colony Optimization (ACO) [30,32,33]. This algorithm belongs to a class of mathematical models that are designed from the Nature Engineering, which came from the observation and modelling of natural phenomena. In particular, the ACO takes advantage of the natural character of ants logistics, which allows for the optimization of fleet planning and management.

The objective of this work was to develop and validate a decision support tool to improve the management of sheep milk transportation, and to reduce the carbon dioxide emissions and the costs of the transportation fleet.

2. Materials and Methods

2.1. Development of the Simulation Model

Developing a simulation model to assist in decision making means creating a tool that is able to analyse the phases of milk collection, the related costs, and CO_2 emissions. It also involves evaluating which is the cheapest way of transporting the milk. This is done by identifying the cheapest route to a particular geographical location (i.e., the coordinates of the various participants in the operation). The simulation model also takes into consideration certain limitations imposed by the cheese factories, such as time limitations (the maximum amount of time that vehicles can take for a round trip) and volume (the maximum capacity of the milk tankers).

The costs of the exercise were analysed using as a benchmark the minimum costs for road transport companies operating tankers, published and updated monthly on the Italian Ministry of Infrastructure and Transport website. These costs are subdivided by the daily number of kilometres as a function of the useful load of the vehicle in tonnes, including any possible cost due to motorway tolls (not present in Sardinia) and the costs of the companies supplying the services.

The CO_2 emissions were calculated by taking into account the fuel consumption, based on the load of the tanker, the distance driven, and the emission factor for diesel fuel (3.15 kg CO_2—eq kg^{-1}) [34].

2.2. The Algorithm Applied to the Logistic of Sheep Milk Collection

The algorithm adopted to improve the collection routes was the Ant Colony Optimization (ACO), as developed by Dorigo M. (1992) [35]. The main concept of the ACO is to emulate the natural attitude of the colony of ants (milk trucks in our contest), who starting from their nest (cheese factory) to reach the food (sheep milk) along the shortest. In the first phase, the ants tend to travel distances randomly, until they reach the food, and then along the backward route they release pheromones, so as to report to the other ants the road to reach the food. The amount of pheromones released, then the signal strength is bigger in shorter routes, this allows for the colony to choose the best path among the possible ones.

Below the resolution of the Travelling Salesman Problem (TSP) with ACO algorithm: given a graph G = (C, L), where C is the farm and L the arcs (routes) that connect the farms i and j. The ants (k) explore the various possible solutions by visiting in sequence all of the farms once, and only once, time. The amount of pheromone trail $\tau_{ij}(t)$ maintained on connection l_{ij} is intended to represent the learned desirability of choosing farm j when in farm i. The amount of pheromone deposited on each arc to iteration t is inversely proportional to the distance of the route; it means that in the shortest paths the concentration of pheromone will be bigger. The pheromone values of each arc are updated at each step in order to solve the evaporation phenomenon.

After the path $T_k(t)$, the k-th ant releases a quantity of pheromone that is equal to $\Delta_{ij}^k(t)$ of pheromones on each arc (i, j), belonging to the tour $T_k(t)$.

The probability $p_{ij}^k(t)$ for an ant k being in the farm i to choose to reach the farm j depends on three factors: the fact that the farm j has been previously visited; the intensity of the measure of desirability to reach the farm j that appears to be the inverse of the distance between the farm i and j; and, the amount of pheromone $\tau_{ij}(t)$ released on i and j connection.

Taking these factors into account, the probability $p_{ij}^k(t)$ is equal to:

$$p_{ij}^k(t) = \begin{cases} \frac{[\tau_{ij}(t)]^\alpha [\eta_{il}]^\beta}{\sum_{l \in jk(i)} [\tau_{il}(t)]^\alpha [\eta_{il}]^\beta} \text{ if } j \in jk(i) \\ 0 \text{ if } j \notin jk(i) \end{cases}$$

where α and β are two adjustable parameters that can control the influence of pheromones $\tau_{ij}(t)$ and the coefficient of desirability η_{ij}. If α is equal to zero, then the nearest farm are more likely to be selected, while if β is equal to zero, there is an amplification of the pheromones, where the ants will walk the same path due to a static situation.

2.3. Validation of the Simulation Model

Data from five cheese factories that are located in Sardinia (Italy) were used to validate the simulation model for optimising the collection and transport of sheep milk from the farms. The investigation of the organisation of sheep milk collection was carried out using mapping, geographical location, and a schematic representation of the collection area. The following parameters were used to analyse the collection routes: number of suppliers, total distance (km), time of the trip (h), and quantity of milk produced per day by each farm (L). The "dead distance" (i.e., the distance between the cheese factory and the first farm and the distance between the last farm and the factory) and the "useful distance" (i.e., the distance between the first and last farm) were also calculated.

Smartphones with GPS antenna and the open source application "*GPS-Logger*" were used to monitor the collection routes from the five factories and to identify the exact coordinates of each farm (geographical location) and the routes that were taken by the tankers. The data was used to create a database containing the following information: date and time of the tanker's departure from and arrival at the factory; route; latitude and longitude of the farms; names of the suppliers; and, litres of milk collected from each supplier. Since the routes taken by the tankers vary greatly with the season, the data was collected during the peak milk production period.

3. Results and Discussion

3.1. Development of the Simulation Model Which Provides an Analytical Description of the Phases of Collection and Transport of the Sheep Milk and Their Relative Costs

The improvement of collection routes is related to two distinct elements in the process: the schematic representation of the collection points and their spatial relationship and the identification of the cheapest routes. The collection zone is shown in a "weighted graph", where the cheese factory and the collection points are the nodes, while the time span shows the possible communication routes between the different collection points. To each time span was given a weight based either on the distance between the points or the time taken by the tankers. From the above mentioned representation of the collection area, it was possible to explore all of the possible routes, i.e., those which began and ended at the cheese factory and passed through all of the collection points, as defined by the Hamiltonian Cycle.

The decision support tool for the collection and transport of sheep milk used client–server architecture with the clients using HyperText Transfer Protocol (HTML) and JavaScript (JS). Moreover, the server used Hypertext Preprocessor (PHP) and MySQL database.

The client software for the integrated management of milk run used an Internet browser, in which the HTML code of the server was downloaded by means of a HyperText Transfer Protocol (HTTP) request. In Figure 1, the software interface is shown.

Figure 1. The main software interface for integrated milk collection.

The information is divided up into a main menu where the user can choose between the screen of different collection routes and the screen in which the costs for each individual cheese factory can be inserted.

If the user wishes to create a new route, then this can be done by importing an excel worksheet containing the coordinates of the nodes and their properties, or directly from a GPS trace in KML format (registered on the GPS-Logger application).

When the user clicks on the map a red marker appears, showing the data of a particular supplier, where other information can be entered (Figure 2).

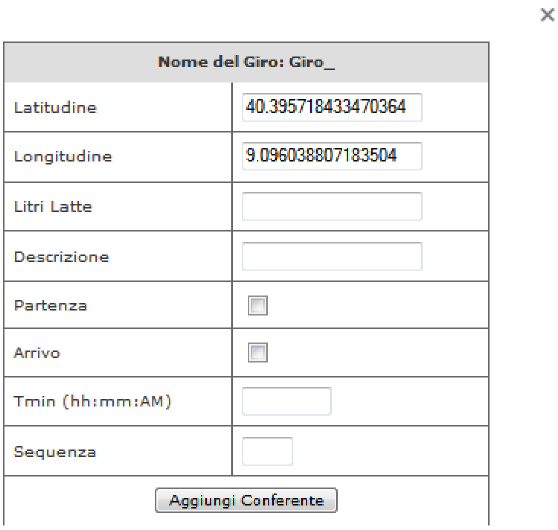

Figure 2. Window for inserting the data of the supplier.

Once the geographical location of the suppliers has been entered, the position is shown on a Google map as small icons (Figure 3). The user can click on these icons to confirm or modify the data of suppliers.

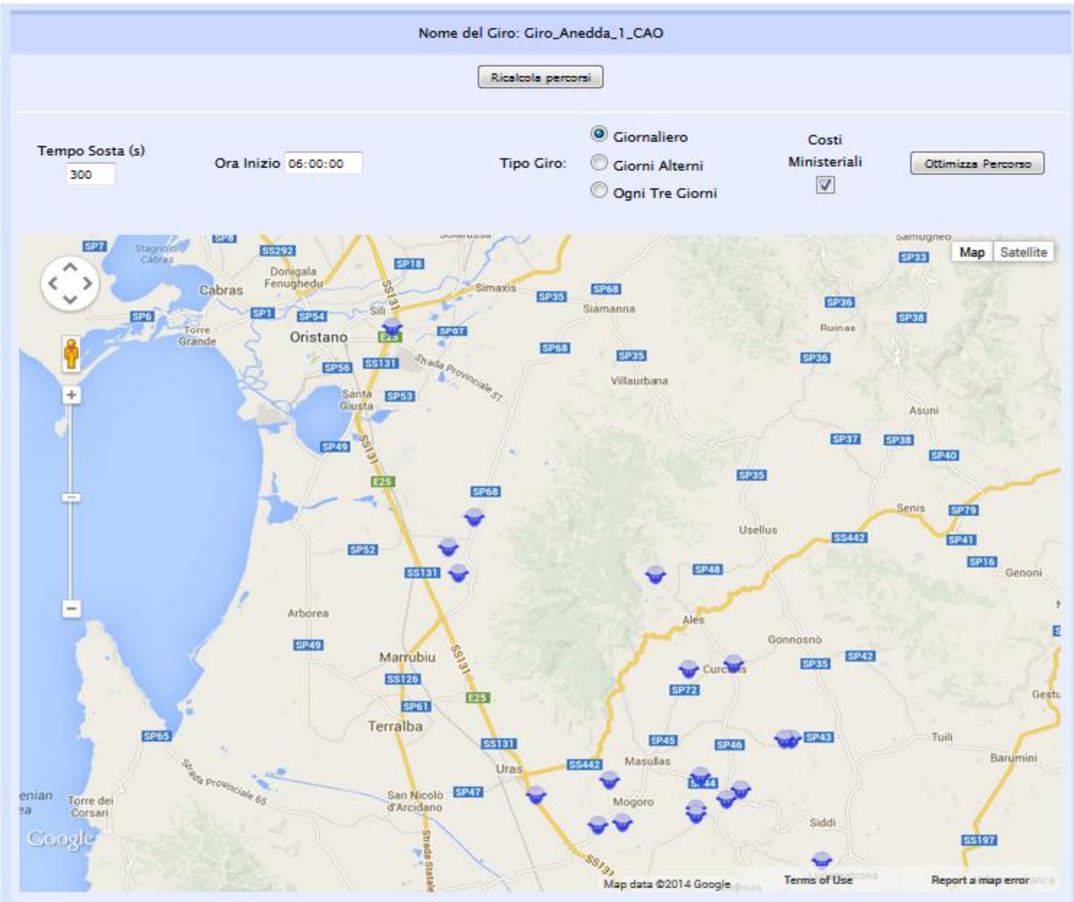

Figure 3. After the geographical location of the suppliers has been entered, the position of the collection points are shown on a Google map as small icons.

When the collection route has been defined, the operator may calculate the distance between the different points using the calculate distance command. Then, the user can optimise the milk route by choosing and inserting several parameters (time spent collecting milk, beginning time of the route, daily collection amount, capacity of the tankers) and the costs calculated by the cheese factory or the Italian Ministry of Infrastructure and Transport guidelines [36]. The ACO algorithm is used to optimise the collection route. This algorithm establishes the minimum distance that is needed to visit all the collection points. (Figures 4 and 5). The interface shows the original route and the good feasible solution based on the predefined sequence for visiting the suppliers, the time taken, the cost of the route, the density of collection (L/km), and the CO_2 emissions.

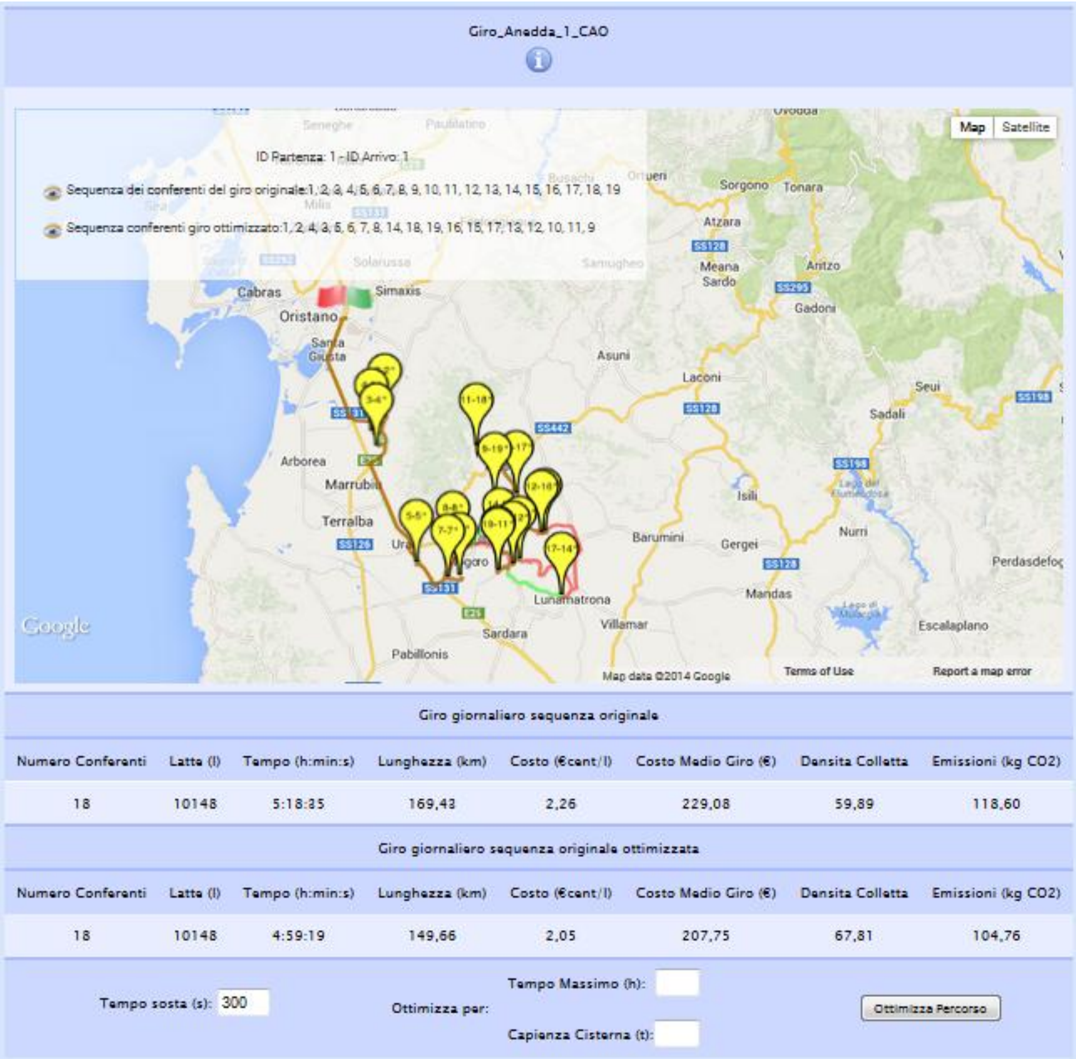

Figure 4. Optimisation of a route.

The suppliers positions are shown by coloured markers containing two numbers: the first is the position of the supplier in the original sequence, the second one is the position in the optimised sequence. The departure point (the cheese factory or the garage in the case of self-employed truck drivers) is shown by a green flag, while the arrival point has a red flag. All of the information concerning the optimisation can be copied in an HTML file. This will contain a dedicated map with the sequence of the suppliers visited and the partial and progressive distance of the route. The copy function can be found by clicking on the "*i*" button. This allows for the users to have a detailed and copyable record of every route that they have created.

Giro_Anedda_1_CAO
REPORT

Giro Giornaliero Originale

Giro	Numero Conferenti	Latte (l)	Tempo (H:M:S)	Lunghezza (km)	Costo per Litro (€cent/l)	Costo Medio Giro(€)	Densita Colletta	CO2 (kg)
1	18	10148	5:18:35	169,43	2,26	229,08	59,89	118,60

Ottimizzazione limite peso 10148 t

Dati Generali				Costo Giornaliero					Costo a Giorni Alterni					Risparmio	Aumento
Giro	Conferenti	Tempo (H:M:S)	Lunghezza (km)	Latte (l)	Costo per Litro (€cent/l)	Costo Medio Giro (€)	Densita Colletta (l/km)	CO2 (kg)	Latte (l)	Costo per Litro (€cent/l)	Costo Medio Giro (€)	Densita Colletta (l/km)	CO2 (kg)	% €	% CO2
1	18	4:59:19	149,66	10148	2,05	207,75	67,81	104,76	20296	1,17	118,37	135,62	104,76	43,02	0,00
	18	4:59:19	149,66	10148	-	-	207,75	-	20296	-	118,37	-	-	-	-

Figure 5. Detailed output of good feasible solution routes.

The server of the software used PHP language linked to the MySQL database. Once the set of suppliers has been established, then the server calculates the distance. The calculation is asynchronous, and uses a separate process that does not block the functions of the system while the calculations are being made. The optimisation algorithm writes the good feasible solutions for each route into the appropriate field of the database.

3.2. Analysis of the Milk Collection Routes for the Cheese Factories in the Sample

The data from the five cheese factories (37 collection routes) are shown in Table 1.

Table 1. The 37 collection routes in the sample.

Collection Route	Suppliers (No.)	Milk (L)	Time Taken for the Route (h:min:s)	Distance (km)			Cost (€ Cent/L)	Average Cost of the Route (€)	Density of Collection (L/km)	Emissions (kg CO_2)
				Total	Dead	Useful				
1	18	7559	06:57:22	243.7	174.8	68.2	3.97	299.85	31.0	143
2	18	5994	05:35:18	150.3	55.2	95.3	2.97	177.74	39.9	72
3	16	3432	06:48:32	240.6	88.0	152.2	6.57	225.48	14.3	90
4	18	7923	05:24:35	144.2	23.6	120.5	2.54	201.64	55.0	84
5	16	5291	03:58:34	135.7	23.7	112.1	3.10	164.22	39.0	65
6	20	6835	07:12:06	220.3	121.3	98.9	3.41	232.86	31.0	105
7	15	6848	06:08:11	194.4	131.7	62.7	3.13	214.33	35.2	93
8	22	4547	06:18:57	165.7	53.3	112.4	4.21	191.27	27.4	79
9	18	5874	06:00:50	143.8	39.6	104.2	2.92	171.76	40.9	68
10	15	6028	05:35:53	199.3	56.0	143.3	3.62	218.01	30.2	95
11	11	5614	04:31:53	122.0	53.1	68.9	2.69	150.76	46.0	58
12	18	10,148	06:18:35	169.4	60.5	108.9	2.26	229.08	59.9	99
13	14	8256	04:46:45	134.2	42.8	91.4	2.30	190.22	61.5	78
14	21	11,716	07:17:24	161.9	65.7	96.2	1.89	221.08	72.4	94
15	23	11,055	06:03:08	134.0	20.4	113.6	1.72	190.03	82.5	78
16	17	6497	05:57:28	125.5	23.4	102.1	2.37	154.25	51.8	60
17	21	11,985	08:00:03	238.3	46.6	191.7	2.46	295.16	50.3	139
18	19	11,247	07:37:01	246.1	22.8	223.3	2.68	301.88	45.7	144
19	11	7990	05:25:09	116.9	12.0	104.9	2.12	169.71	68.3	68
20	5	5187	04:11:27	118.2	39.5	78.6	2.83	146.92	43.9	57
21	26	12,757	05:50:33	107.7	20.8	86.9	1.24	158.35	118.4	63
22	25	11,046	05:58:52	118.3	19.9	98.4	1.55	171.33	93.4	69
23	26	10,939	07:12:48	149.0	22.0	127.0	1.89	206.97	73.4	87
24	27	11,531	06:45:07	129.7	23.7	106.0	1.60	185.00	88.9	76
25	24	8769	05:57:41	98.7	13.7	85.0	1.67	146.87	88.9	58
26	22	8913	07:30:08	113.9	7.6	106.3	1.86	165.99	78.3	67
27	13	5065	04:54:00	118.6	35.5	83.1	2.91	147.35	42.7	57
28	23	12,393	05:06:50	116.0	60.2	55.8	1.36	168.54	106.9	68
29	29	8698	08:57:58	234.4	80.2	154.2	3.35	291.67	37.1	137
30	18	11,904	04:32:58	110.8	28.2	82.5	1.36	162.12	107.5	65

Table 1. *Cont.*

Collection Route	Suppliers (No.)	Milk (L)	Time Taken for the Route (h:min:s)	Distance (km)			Cost (€ Cent/L)	Average Cost of the Route (€)	Density of Collection (L/km)	Emissions (kg CO_2)
				Total	Dead	Useful				
31	25	11,665	07:08:21	131.7	33.9	97.8	1.61	187.28	88.6	77
32	10	6557	05:53:27	245.7	87.6	158.1	3.80	249.13	26.7	118
33	18	6190	04:34:00	102.5	18.7	83.7	2.11	130.51	60.4	49
34	14	4346	04:15:05	141.5	17.4	124.1	3.90	169.64	30.7	68
35	25	5476	04:22:25	62.7	14.6	48.2	1.55	84.90	87.3	30
36	17	8400	03:30:35	70.3	31	39.3	1.30	108.85	119.5	41
37	13	5388	03:18:49	88.8	12.3	76.4	2.14	115.47	60.7	43
Average	18.7	8109.8	05:50:14	149.9	45.4	104.4	2.57	189.09	60.4	79.6
SD	5.38	2731.93	01:18:55	51.61	36.78	37.38	1.07	51.93	27.98	28.12

Five hours and fifty minutes are necessary for a typical trip of about 150 km, with on average 18.7 suppliers and 8109.8 litres of milk per collection route. The collection points are unfortunately quite far away from the cheese factories, and so the "dead distance" (45.4 km) makes up, on average, about 30% of the total distance covered. The average collection costs amounted to €189.09, including the running and maintenance costs of the vehicles. The CO_2 emissions correspond to 79.6 kg. The collection density is about 60.4 L/km, with a peak of 119.5 L/km. When the milk is collected from farms in a different province from that of the cheese factory (e.g., routes 1, 6, and 7), the dead distance is, indeed, greater than the useful distance, and the collection costs rise to €214–300 per trip.

3.3. Optimisation of the Milk Collection Routes for the Cheese Factories in the Sample

The information in the database for the suppliers and the five cheese factories was elaborated by a management tool that was created specifically for the collection of sheep milk in Sardinia. In this study, the optimisation for each of the 37 collection routes was done. The results are shown in Table 2. The software calculated the good feasible route and the sequence of visits that each tanker needed to take in order to collect milk from each supplier, while respecting the limitations set and minimising transport costs.

Table 2. Optimised collection routes for the 37 routes in the sample.

Collection Route	Suppliers (No.)	Milk (L)	Time Taken for the Route (h:min:s)	Distance (km)			Cost (€ Cent/L)	Average Cost of the Route (€)	Density of Collection (L/km)	Emissions (kg CO_2)
				Total	Dead	Useful				
1	18	7559	06:37:34	205.9	125.5	80.5	3.51	265.56	36.7	120
2	18	5994	05:29:20	147.0	61.1	86.0	2.92	174.77	40.8	70
3	16	3432	06:08:44	227.7	31.6	196.1	6.34	217.48	15.1	86
4	18	7923	05:24:35	144.2	23.6	120.5	2.54	201.64	55.0	84
5	16	5291	03:58:34	135.7	23.7	118.3	3.10	164.22	39.0	65
6	20	6835	05:36:05	190.6	66.3	75.1	3.09	211.37	35.9	91
7	15	6848	05:25:53	178.2	98.4	79.8	2.94	201.63	38.4	85
8	22	4547	05:18:03	137.7	54.6	83.2	3.65	166.13	33.0	66
9	18	5874	05:32:20	127.2	26.5	100.7	2.65	155.92	46.2	61
10	15	6028	05:31:20	196.1	15.7	180.4	3.58	215.61	30.7	94
11	11	5614	03:34:28	114.3	44.9	69.3	2.55	142.92	49.1	55
12	18	10148	05:35:19	149.7	24.0	86.2	2.05	207.75	67.8	87
13	14	8256	04:43:48	132.6	16.4	86.3	2.28	188.39	62.3	78
14	21	11,716	07:17:24	161.9	65.7	100.9	1.89	221.08	72.4	95
15	23	11,055	06:03:08	134.0	20.4	136.7	1.72	190.03	82.5	78
16	17	6497	05:43:36	119.7	23.5	91.6	2.28	148.43	54.3	57
17	21	11,985	07:49:40	233.1	18.3	179.6	2.42	290.51	51.4	136
18	19	11,247	07:17:51	235.3	25.3	201.3	2.60	292.49	47.8	138
19	11	7990	04:03:36	102.7	3.0	89.3	1.90	151.95	77.8	60
20	5	5187	03:10:21	115.5	20.2	92.8	2.78	144.25	44.9	55
21	26	12,757	05:34:05	90.9	15.4	65.9	1.07	136.72	140.4	53
22	25	11,046	05:45:18	103.5	17.7	76.2	1.39	153.01	106.7	60
23	26	10,939	06:49:58	139.3	18.5	110.3	1.79	196.13	78.5	81
24	27	11,531	06:32:49	121.3	26.4	85.6	1.52	175.02	95.1	71
25	24	8769	05:19:41	74.4	11.5	60.1	1.31	114.56	117.9	43
26	22	8913	05:22:50	102.5	12.0	101.5	1.70	151.82	86.9	60
27	13	5065	04:22:07	101.0	22.3	65.5	2.55	128.99	50.1	48
28	23	12,393	04:50:24	102.3	1.3	61.3	1.22	151.46	121.2	60

Table 2. *Cont.*

Collection Route	Suppliers (No.)	Milk (L)	Time Taken for the Route (h:min:s)	Distance (km)			Cost (€ Cent/L)	Average Cost of the Route (€)	Density of Collection (L/km)	Emissions (kg CO_2)
				Total	Dead	Useful				
29	29	8698	08:42:20	224.2	45.4	132.7	3.25	282.55	38.8	131
30	18	11,904	04:23:54	104.6	26.4	78.2	1.30	154.36	113.9	61
31	25	11,665	05:42:38	118.6	34.0	84.6	1.47	171.69	98.4	69
32	10	6557	05:02:21	232.5	69.3	215.7	3.67	240.92	28.2	111
33	18	6190	04:01:28	93.9	17.1	76.8	1.96	121.17	65.9	45
34	14	4346	04:13:38	141.2	15.6	141.2	3.90	169.37	30.8	68
35	25	5476	04:08:38	58.7	2.0	47.3	1.46	79.96	93.2	28
36	17	8400	03:13:13	69.0	17.7	46.6	1.27	106.99	121.8	40
37	13	5388	02:59:33	79.2	25.4	49.3	1.94	104.53	68.0	38
Average	18.7	8109.8	05:20:11	139.1	31.5	101.4	2.42	178.15	65.9	73.8
SD	5.38	2731.93	01:17:53	49.58	26.32	44.00	1.04	51.56	31.82	26.99

For the 37 routes in the analysis, in about 90% of cases optimisation reduced the time taken, the distance driven, the costs of collection and the CO_2 emissions, in which the density of collection increased about 8.5%.

Total results showed that the useful distance was 69.6% and 72.9% of the total distance for the original and optimised collection routes, respectively. Therefore, the optimisation of milk collection routes mainly affected the dead distance (9.3%) rather than the useful one (2.0%). The collection time of the optimised route decreased, as a consequence the productivity of the transportation fleet improved, obtaining an increase of 79 L/h per collection route.

The investigation showed a strong relationship between the density of collection (L/km) and the cost per litre of milk. Increasing the collection density reduced the cost per litre of the collected milk (R^2 = 0.98; Figure 6). Thus the collection density is a useful parameter when making a first evaluation of the efficiency of a collection route. The new good feasible routes could, also, improve the environmental impact associated with the transport operations and the traceability of milk. However, environmental emissions were not correlated to the number of suppliers.

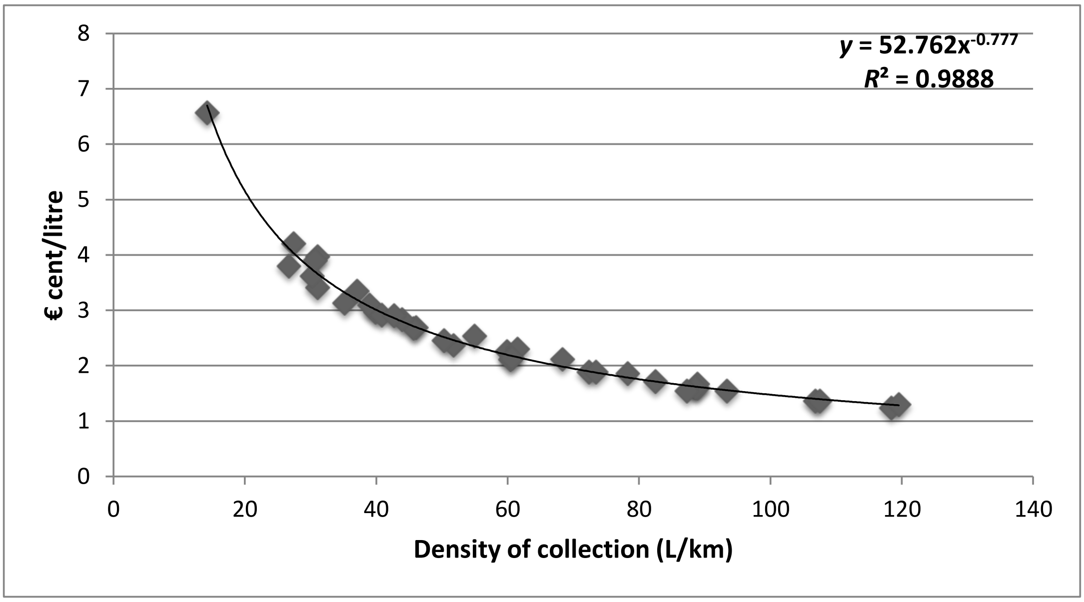

Figure 6. Relationship between costs of milk collection and collection density.

4. Conclusions

The simulation model to improve the logistics of sheep milk collection that is developed in this study is a significant contribution to solving the problems that are connected with scheduling of milk tankers and to assess the energy and carbon impact due to milk collection and delivery. The work aimed to find a decision support tool that could analyse the existing situation and obtain the new routes, which had the minimum costs. Furthermore, the developed tool allowed cheese factories to modify and rearrange milk collection routes based on the monthly variation of milk produced.

Results showed that optimisation of the routes reduced the collection costs by 6%, the distances driven by 7.4%, and the time taken for the trips by 8.6%. As a consequence, this reduced the number of man/hours employed, and CO_2 emissions by 7.5%.

In certain cases poor management of the collection routes was identified. Certain cheese factories collected small quantities of milk from farms in different provinces, with a consequent increase in "dead distance" when compared to "useful distance". This allowed a reduction of collection density, which seems to function in inverse proportion to the costs of transport.

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