MODELLING RAW-MILK TRANSPORTATION IN IRELAND: FASTEST OR SHORTEST ROUTE FROM FARM TO FACTORY.

Sean O'Callaghan[1, 2], Declan O'Connor[1], David Goulding[1, 3]

[1]Mathematics Department, Cork Institute of Technology, Cork, Rep. of Ireland.

[2]ITServices Department, Cork Institute of Technology, Cork, Rep. of Ireland.

[3]Centre for Advanced Photonics & Process Analysis, Cork Institute of Technology, Cork, Rep. of Ireland.

Email: Sean.OCallaghan@cit.ie

ABSTRACT: Post milk quota removal across the European Union, the Irish dairy industry has seen a significant increase in overall milk production. This has had a knock-on effect on the transportation requirements of the industry. Schedulers face multiple challenges when planning collection routes. One of these is should the schedule minimise distance or time when planning collection routes? This study employs a simulation that incorporates GIS road data, individual farm locations, and two separately located depot sites in order to calculate the trade-off between time and distance in the transportation of raw milk to the processor site. A testbed of 50 simulated farms was created to simulate the seasonal milk production pattern, with various scenarios examined. The findings suggest that the seasonal milk production pattern requires dynamic scheduling of milk routes. Also, relatively small changes in site location can lead to large increases in transportation distances. Finally, a focus on minimising distances may be short-sighted, in particular, where farms are located at even a modest distance from the processing site.

KEYWORDS: *Seasonal, Transportation, Raw Milk; Capacitated Vehicle Routing Problem (CVRP); Fastest Route; Shortest Route; Simulation; Large Neighborhood Search (LNS); Optimization.*

INTRODUCTION AND BACKGROUND

In 2019 almost 8.7 billion litres of milk was transported to the 19 main milk processing sites distributed throughout the Republic of Ireland. Almost 8 billion litres of this milk was produced south of the border by approximately 17,500 dairy farmers, with the remaining 710 million litres originating North of the border (CSO, 2019). A previous industry survey estimated that the overall cost of raw milk collection in 2004 to be in the region of €57 million per year, which equated to 1.15 cents per litre (Quinlan, 2013). Extrapolating this to the 2019 processing of over 8.7 billion litres represents a cost in excess of €100 million. Added to this financial cost is the environmental cost of milk collection such as greenhouse gas emissions, road degradation, and traffic congestion for example. Taking a typical milk tanker with a capacity of 29,000 litres this represents almost 316,000 loads in 2019, should these tankers achieve an average of 95% capacity or 333,300 at 90% capacity.

The milk collection problem is typically considered a Capacitated Vehicle Routing Problem (CVRP), which in turn can be seen as a generalization of the Travelling Salesman Problem (TSP). While TSP's can now be solved for large numbers of customers (Laporte, 2009; Pillac et al., 2013) it has been difficult to consistently solve instances of the CVRP, even with comparatively small numbers of customers, by means of exact algorithms (Baldacci et al., 2012; Toth and Vigo, 2014; Vidal et al., 2014). As a result, much of the research efforts have turned to the development of powerful metaheuristics. Recently, researchers have shown how efficient metaheuristics for VRPs have found solutions within one percent of the optimum for problems where a large number of customers are considered such as those involved in milk collection (Lahrichi et al., 2012; Vidal et al., 2014). A highly successful approach to solving large VRPs has been the introduction of the Large Neighborhood Search (LNS) technique which employs greedy search methods to solve VRPs (Shaw, 1997). Through the use of this technique, researchers were able to demonstrate that the approach could be reliably used and developed to produce highly accurate solutions to VRPs which contain large numbers of customers that needed to be visited (Lusby et al., 2016; Lutz et al., 2014; Kytöjoki et al., 2007). The LNS method was further developed to incorporate an efficient adaptive destroy and repair algorithm. The Adaptive LNS (ALNS) extending the ability of this approach to solve various real-world transportation and scheduling problems (Pisinger and Ropke, 2010). For example, this approach was successfully used by researchers to model sugarcane harvesting and transportation scheduling (Pitakaso and Sethanan, 2019).

Internationally, researchers have investigated the costs directly associated with various aspects of the raw milk collection supply chain. Within the dairy industry in New Zealand, researchers considered the use of a decision support system (DSS) to reduce the overall costs of milk collection (Foulds et al., 1996). They presented a DSS tool that was designed to find efficient routes for collection schedules which also allowed schedulers to manually fine-tune their routing schedules when required. The research suggests that at busy times the arrival of full tankers to the processor plant could be more carefully managed by the schedulers. More recently, researchers have described a similar two stage spatial decision support system of milk collection in Spain (Amiama et al., 2015). Stage one solves the overall routing problem using VRP algorithms. In stage two, the route manager, where necessary has the flexibility to relax some constraints in order to achieve optimum solutions. In Thailand, researchers employed a differential evolution metaheuristic approach to determine routes for raw milk collection from collection centers to dairy factories with the objective of minimizing the total costs (Sethanan and Pitakaso, 2016). Canadian researchers considered a variant of the VRP, the Dairy Transportation Problem (DTP) (Lahrichi et al., 2012). They studied the routing problem which occurred when there are multiple hauliers and depots involved. Through the application of their model, they found improvements in distances travelled by hauliers ranged from 0.5% to 4%. Furthermore, the research found that the use of an ALNS approach for multi-period vehicle routing problem was able to produce high-quality solutions for milk collection in Canada (Dayarian et al., 2016). More recently, researchers considered the transport requirements of a sample case involving a large number of farms in a rural region of Chile (Paredes-Belmar et al., 2016, 2017). The researchers investigated the trade-off between lower costs of transportation and segregated collection of different blends of milk. Using blending, the authors were able to increase overall payload capacity which in turn increased the feasibility, profitability, and efficiency of the vehicles used in the collection process.

Unlike the international dairy industry experience, research in the area of milk transportation in Ireland is relatively sparse. Now significantly dated, a previous study compared the effect of farm size and the levels of milk production in Ireland on collection costs using a Lockset analysis of raw milk collection (O'Dwyer and Keane, 1971). While (Butler et al., 1997) applied a variant of the TSP to model the collection process of dairy farms located in north county Dublin, Republic of Ireland. They modelled distances between the farms which were only accurate to 1/10th of a mile (0.16 of a kilometre). More recently, based on the smallest legally defined administrative areas in the Irish republic, District Electoral Divisions (DED's) researchers created an estimate of road distance from a central or appropriate point from each of the administrative areas (Quinlan, 2013).

Irish milk production relies on an efficient grass-based spring calving system (Smyth et al., 2009). However, grass growth in Ireland is highly seasonal leading to variable milk production pattern which is described later. Due to volatile production levels, milk hauliers face the dilemma of having to decide between keeping routes static or potentially changing routes to fully optimise the collection process as volume patterns continually change on individual farms throughout the year. Any savings in financial costs, improved CO_2 emissions and other environmental factors that can be gained during the planning of collection schedules, through the application of modern technology must be continually examined, and thus provide the motivation for this study.

In order to model Irish milk production and transportation from farm to factory, a testbed of 50 representative farms was created, and a number of simulations considered. An open-source VRP Spreadsheet Solver (Erdoğan, 2017a) was adapted to create milk collection routes and estimate the associated travel distances based on these routes. As the solver requires mapping data on the location of farms and milk processing sites Microsoft Bing maps were used to estimate both the shortest route and the fastest route between locations. A comparison of these options is presented in detail in this paper. Erdoğan, 2017 conducted case studies within the tourist and health care industries demonstrating the flexibility of the solver. This analysis will help inform milk collection schedulers address one of the many decisions they need to make, such as which farmers to add to a particular schedule, which sequence to collect the milk how often to collect from each farm for example.

The remainder of the paper is organised as follows. In Section 2, the methods and materials used in the creation of the simulation model are described, Section 3, the results obtained from the running of a number of relevant simulations are presented. Section 4 discusses the findings of the research and draws conclusions with some suggestions for future research.

MATERIALS AND METHODS

The Irish dairy sector is highly dependent on the effect that seasonal meteorological conditions have on grass growth (Hurtado-Uria et al., 2013). Figure 1 compares the monthly national volumes of domestic milk collected in 2014, the last year that milk quotas applied, and 2019. Peak production occurs between mid-May and early June, tailing off during the winter months each year, giving a peak to trough ratio of approximately 6:1. The overall increase in annual production of circa 41.4% is not uniform across the months. While November volumes have increased by 76% and May by 36%, the actual deliveries increased by 180 million litres and 286 million litres respectively. This explains why a dynamic milk collection schedule rather than a static model is desirable in Ireland. A schedule based on May volumes would be highly inefficient in the spring, autumn, and winter months.

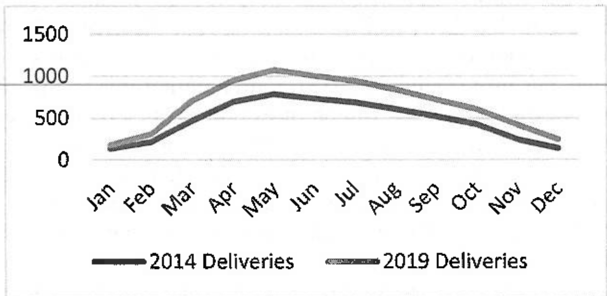


Figure 1 **Monthly domestic milk intake by creameries and pasteurisers 2014 and 2019 (Million litres) Source CSO 2019**

There are two distinct components related to the collection and transportation of raw milk, transport driving, and assembly driving. Transport driving, also referred to as trucking, can be described as the driving-related to travelling between the milk collection depot and the initial farm and the return journey from the final farm visited on each route back to the collection depot. While assembly driving is the driving from farm to farm (Quinlan, 2013). Due to the highly seasonal nature of Irish milk production patterns, the balance between these two categories of driving can vary significantly over the year. Figure 2 shows an example of the significant variation of route schedules for the efficient collection of milk from a cluster of farms at peak through to trough times during the year.

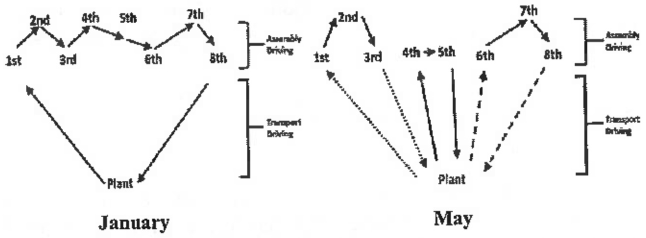


Figure 2 **Seasonal variation in Transport and Assembly driving patterns.**

The simulation model used here is formulated to investigate the optimum routing schedule to collect raw milk from producers and deliver to a milk collection depot. A simulation testbed which incorporates a milk catchment area made up of fifty sample farm locations is created. Using web-based mapping services, for each of the randomly selected sample farm locations, within the catchment area, a GPS location is recorded (O'Callaghan et al., 2018). For this simulation, the sample catchment area covering the cluster of farm locations is approximately 800 km^2 in size. Each farm within the catchment area is assigned a random number of lactating cows. Individual herds ranged in size from 37 to 330 cows with an overall average herd size of 91 cows per herd. Overall, the testbed has a total population of 4,571 cows. Each herd's yield per cow is set at 5,000 litres per year which is close to the national average of 5,100 litres per year. Seasonal production levels are imposed that follow the national pattern as shown in Figure 1. The seasonal volumes produced during an average two-day cycle for each month over a peak to trough cycle are calculated. In relation to milk collection depots, two depots are considered. Depot A, adjacent to the milk catchment area with Depot B located approximately 40 Km from Depot A.

Several factors were considered in the selection of depot locations. Including several practical characteristics, such as having a relatively good road network which would allow for high-quality access to and from the initial depot location. Moreover, in the event of any road issues arising on the primary route to be used by the haulers, there must be alternative but similar routes available that can be taken by the driver to allow the collection vehicle access to the designated milk processing depot location.

The mathematical formulation for the model presented in this paper is based on the unified formulation as presented in (Erdoğan, 2017a). Define $G = (V, A)$ to be a directed graph where $V = (0, 1, 2, 3, 4, \ldots, n)$ is defined as a set of vertices and $A = \{(i, j): i, j \in V: i \neq j\}$ is the set of arcs between each vertex. The collection depot, d, is a single vertex, for simplicity is defined as follows

$$d = \{0\} \quad (1)$$

S is defined as the set of all dairy farms producing raw milk that are to be visited and each supplier (farm) is denoted as $S = \{1, \ldots, n\}$ where

$$S = V/d \quad (2)$$

The amount of raw milk produced on each farm over a given two-day collection period is given by $\{q_1, q_2, q_3, \ldots, q_n\}$. Let Q, the total volume of milk to be collected be defined as follows

$$Q = \sum_{i=1}^{n} q_i \quad (3)$$

The number of vehicles required for a given collection window is defined as k. It is assumed that all vehicles are homogeneous and have a maximum capacity of C. The minimum value of k can be estimated as the ceiling of the total volume collected divided by vehicle capacity.

$$\min\{k\} = \left\lceil \frac{Q}{C} \right\rceil \quad (4)$$

It should be noted here that in practice this is not always reflective of how many trucks are used in an effort to minimize overall distances, more trucks maybe required. Let S_t be the set of farms visited by a single collection vehicle.

$$S_t \subseteq S : t = \{1, \ldots, k\} \quad (5)$$

The following decision variable X_{ij} is defined with a value of 0 or 1. Where the value 1 denotes edges that are traversed and a value of 0 is assigned to those edges that are not utilized as part of a route.

$$X_{ij} \in \{0, 1\} \quad (6)$$

Where, the decision variable is defined such that only one vehicle can enter a farm

$$\sum_{i \in S_t \cup d} X_{ij} = 1, \qquad \forall j \in S_t \cup d, i \neq j \quad (7)$$

Only one vehicle can exit a farm

$$\sum_{j \in S_t \cup d} X_{ij} = 1, \qquad \forall i \in S_t \cup d, i \neq j \quad (8)$$

The following distance variables are defined

Y_{ij} = Distance between individual nodes (i, j) $: i, j \in S_t : i \neq j$

$Y_{d\alpha_t}$= Distance from depot to first farm α of route S_t (9)

$Y_{\omega_t d}$= Distance from the last farm ω of S_t back to the depot

Equation (9) describes three distinct distance variables for each route. The assembly distance between each farm, the transport distance from the depot to the first farm and the return distance to the depot from the last farm visited.

$$Y_t = \sum_{i,j \in S_t} X_{ij} Y_{ij} + Y_{d\alpha_t} + Y_{\omega_t d} \quad (10)$$

The function Y_t yields the total distance travelled for each defined route. The following function is to be minimized

$$\sum_{t=1}^{k} Y_t \tag{11}$$

Subject to the following conditions:

$$C \leq 30{,}000 \tag{12}$$

$$\left\lceil \frac{Q}{C} \right\rceil \leq k \leq n \tag{13}$$

$$Y_t \leq 400 \text{ km} \tag{14}$$

It should be noted that a number of conditions were imposed. A maximum tanker capacity for each vehicle was set at 30,000 litres (12). The number of vehicles to be used must be greater than or equal to the total capacity of raw milk to be collected divided by the capacity of the tanker used (13). Furthermore, a distance limit of 400 km was set for each trip, as it would be considered impractical for a milk tanker to travel longer distances in an Irish context (14).

To solve the various scenarios, simulations were deployed to a set of standard Dell desktop computers. Each device is configured with an Intel i5 CPU and 8GB of RAM. Microsoft Office version 2013 and Windows 7 operating system was installed on all of the machines used. Version 2.2 of the VRP Spreadsheet solver was employed (Erdoğan, 2017b). There is a built-in console interface which is used to configure the solver for the simulations - Solver Console. Using this interface, a number of required criteria and data values were entered for the solver. Additionally, the number and locations of the sample farms which were obtained from Microsoft Bing Maps, the capacity and number of the collection vehicles to be used were also recorded. Two approaches were taken for the simulations. The shortest route and the fastest route were obtained from Microsoft Bing maps for each edge for all nodes used in the simulations. Varying levels of CPU running time limits were considered for the simulations. It was decided to run each simulation for one hour, to ensure that feasible solutions were found.

RESULTS

Table 1 presents a summary of the combined total shortest distances travelled over a single two-day collection period for the months of January and May. These represent the months of the least and highest levels of production, respectively. Taking Depot A, for example, the shortest combined route distances required to be travelled in May is approximately 64% greater than the shortest distance that is necessary to be completed in January. Whereas, when Depot B is considered, there is almost three times the difference in the total distance travelled between the trough and peak months.

Furthermore, it can be seen that there is a significant increase in the combined route distances required as the site of the target depot is relocated from Depot A to B. The relative distance travelled index for January increases from 100 for Depot A to 214 for Depot B (an overall increase of 114%). Similarly, for May there is an increase in the index from 100 to 379 (an overall increase of 279%).

Table 1. **Comparison of total distances (km) and percentage differences for January and May using shortest routes**

Depot	Trip Distance Jan (km)	Relative Distance (Jan) Index	Trip Distance May (km)	Relative Distance (May) Index	(%) Distance Travelled Jan to May
A	300.6	100	491.8	100	64
B	642.6	214	1864.7	379	190

Source Own Calculations

As discussed earlier milk collection comprises of two distinct elements, transport driving and assembly driving. **Error! Reference source not found.** displays the shortest transport driving distances and the percentage that it contributes to the overall collection journey for each route. From this table, we see that the number of vehicles required (V) increased from 2 to 8 for both depots as we move from January to May.

Table 2 **Transport driving distances and (%) of the overall distance (km) travelled per collection**

Depot A	V1	V2	V3	V4	V5	V6	V7	V8
Jan	12.4 4%	8.6 49%						
May	34.4 83%	31.6 37%	34.4 64%	7.8 17%	44.0 48%	15.3 22%	41.8 46%	10.1 84%
Depot B	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**
Jan	187 49%	175 67%						
May	205 83%	209 87%	182 80%	191 97%	197 74%	218 92%	203 87%	184 84%

Source Own Calculations

When production increases, as would be expected, there are more deliveries to the individual milk collection depots. As fewer farms are visited there is an increase in the proportion of trucking that is required as part of the overall journey time that must be undertaken for each collection. Likewise, as the collection depot site is located at further distances from the milk pool catchment area, or where the catchment moves, the trucking element becomes a more significant component for each of the routes. Of the distances covered by drivers transporting to Depot B in May more than 75% is spent driving between the depot and first farm or last farm and depot.

Table 3 **Combinations of shortest (S) and fastest (F) distances (km) and duration (hh: mm) of assembly (a) and transport (t) components for May collection window for Depot A and Depot B**

Depot A	S_aS_t	F_aS_t	S_aF_t	F_aF_t
V1	41.57	45.48	45.48	45.55
V2	85.95	67.11	70.84	71.65
V3	54.04	29.38	29.38	11.96
V4	45.48	42.69	57.29	43.65
V5	92.36	106.87	109.89	102.59
V6	69.27	84.76	83.12	95.92
V7	91.19	57.50	44.53	62.67
V8	11.96	68.71	74.14	90.84
Total	491.82	502.50	514.68	524.82
Duration	10:40	10:35	10:07	9:56

Table 3 continued

Depot B	S_aS_t	F_aS_t	S_aF_t	F_aF_t
V1	246.4	252.11	271.09	268.82
V2	240.36	238.84	259.55	259.92
V3	226.91	225.1	233.29	243.13
V4	196.93	196.93	211.24	211.24
V5	266.92	279.35	288.37	290.24
V6	236.51	233.88	253.24	253.14
V7	233.34	230.58	248.00	249.64
V8	217.28	217.28	227.42	227.44
Total	1864.65	1874.06	1992.19	2003.56
Duration	36:00:00	35:30:00	26:09:00	25 h 45 m

(Source Own Calculations)

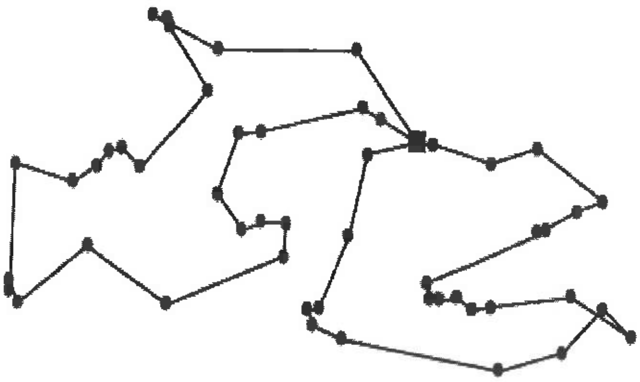
In Table 3 the effect on the total distance of using combinations of the fastest route times with the shortest route times is estimated. This analysis focus on May collections for both depots and four combinations are considered based on assembly and transport driving. In the first instance, the shortest transport and shortest assembly driving are considered (S_aS_t). This is directly analogous with the May data in **Error! Reference source not found.**. Next, the fastest assembly times are combined with the shortest transport times (F_aS_t). This is followed by the shortest assembly times and fasted transport driving times (S_aF_t). Finally, the fastest assembly time is combined with the fastest transportation times (F_aF_t). In addition, the overall times required for these different route combinations are presented.

The routes that would provide the shortest and the fastest node-to-node distances between the individual farms and from farms to both collection depots were obtained from Bing maps online mapping service. The duration time for any given route is calculated by the mapping service using the average speed limits along the route that would apply to a small vehicle. It should be further noted that these are estimated values which do not consider payloads, vehicle types, size, etc. The results of the duration time can only be considered as indicative values. In real-world situations, actual journey times recorded by vehicles would be used in place of these indicative duration times. In the Irish republic the standard speed limits that apply for a small vehicle range from 30 km/h to 120 km/h. Additionally, trucks with a gross weight of more than 3,500 kg have an upper-speed limit on motorways of 90 km/h and a maximum of 80 km/h on all other roads types.

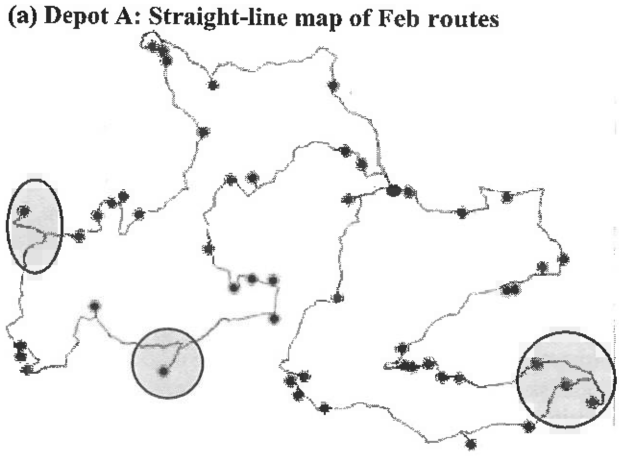
The results for Depot A show that even though there is only 33 km of a difference between combinations S_aS_t and F_aF_t there is a time difference of 44 minutes between the two combinations of routes. For Depot B a total distance of 1874 km was identified for F_aS_t, whereas, a slightly shorter distance of 1,865 km was found by S_aS_t. More interesting, for this particular scenario the findings show that the shortest route distance S_aS_t, (1,865) is just 139 km shorter than the longest F_aF_t (2,004) a difference of less than 7%. However, there is a 40% increase in the estimated time required to complete the collection, giving an actual difference of 10 hrs and 15 min in the estimated time duration for these combinations is considered.

A question this approach poses is, why are certain individual F_aS_t truck routes shorter than those found for S_aS_t, even though the overall combined distance is longer? For instance, Depot B, F_aS_t V3 has an aggregate distance of 225 km, whereas, for S_aS_t for V3 has a larger calculated distance of 227 km. In short, the objective of any CVPR optimiser is to search for an optimised aggregate set of feasible routes that will meet the conditions set by the problem. Solutions consider a combination of different length routes where some routes are longer, and others used in the solution are shorter than those used in a solution that has an overall shorter distance value for all routes when combined together.

The results in Table 3 suggest that as transport driving becomes a greater proportion of the overall journey distances there is a greater difference in the overall journey times required for various combinations of routes. Access to this high-level data gives the scheduler the flexibility to choose alternative approaches that maybe, depending on circumstances, more closely align with the company's overall transport objectives.



(a) Depot A: Straight-line map of Feb routes



(b) Depot A: Road map of Feb routes

Figure 3 **Comparison of the straight-line distance map and the actual road routing map**

Finally, as can be seen from Figure 3 straight-line mapping of the routes can often underestimate the actual journey path that is required by the driver to complete the schedule. There can be significant variations on the actual routes (see Fig 3 (b)) that need to be driven by drivers to optimally complete the collection sequence that the vehicle drivers would have originally been issued with by the scheduler. For example, Figure 3 (b) has a number of instances circled where a driver is required to double back on part of their route to efficiently reach the next location.

DISCUSSION AND CONCLUSIONS

Against a background of highly variable seasonal milk production GIS data is integrated with an ALNS metaheuristic-based approach to solve the CVRP that arises from the collection of milk from a simulated set of fifty milk-producing farm locations. For this research, the objective was to minimize the overall distance required to complete the collection routes for the seasonal production period and then make comparisons with the fastest routes.

The results of the model suggest that milk collection schedules should frequently change as production increases in line with national norms in Ireland. Considering Depot A, which is located nearest the milk catchment area, the overall distance increases from the January to May period from 300.58 km to 491.82 km which for this scenario represents a 64% overall increase. Only two vehicles are required in January, which increases to eight vehicle loads during the peak production month of May. In addition, it was found that the transport driving element increases substantially as production levels increase over the trough to peak cycle. It is also evident that when the designated delivery depot is located at further distances to the milk pool catchment area the transport element of the milk collection process increases in relative importance. The model can also be extended to consider multiple combinations of fastest and shortest routes that could be used for milk collection while noting it can only produce indicative travel duration times. The results suggest that the trade-off between driver time and distance is not linear and as the depot/catchment areas are more separated the more consideration should be given to using faster rather than shorter routes.

It is clear from our snapshot findings that the Irish dairy industry needs to maintain a highly dynamic milk collection infrastructure. There is a need for an increasing number of vehicles as routes change from month to month (for these scenarios from two to eight per route). In addition, the requirement for a fleet of varying capacity tankers and the use of three-day collection windows for a number of trough months merits further consideration. From an industry perspective, the model also gives an indication of the greatly increased transportation requirement which would be associated with any rationalisation of the industry at the processing level. The acquisition of milk pools at even relatively close proximity to an existing milk intake point can see transportation distances increase dramatically and in particular for peak months. Along with the increased financial costs the environmental impact would also need to be considered. Likewise, any decision to share facilities such as milk intake at trough months should carefully consider the transportation implications before any agreements are finalised.

Future research should consider the extension of the base model presented. For example, factors such as multiple delivery depots during peak production months, the inclusion of multiple milk pool catchment areas, and variations in the frequency of milk collection at each location could be further investigated. Furthermore, the implications of fuel consumption based on the conflict of speed and distance are future avenues for research that can be explored using the model presented in this paper. This then needs to be balanced with the driver costs associated with spending additional (less) time on the road.

REFERENCES

[1] Amiama, C., Pereira, J.M., Carpente, L., Salgado, J., 2015. Spatial decision support system for the route management for milk collection from dairy farms. Transportation Letters 7, 279–288. https://doi.org/10.1179/1942787515Y.0000000001

[2] Baldacci, R., Mingozzi, A., Roberti, R., 2012. Recent exact algorithms for solving the vehicle routing problem under capacity and time window constraints. European Journal of Operational Research 218, 1–6. https://doi.org/10.1016/j.ejor.2011.07.037

[3] Butler, M., Williams, H.P., Yarrow, L.A., 1997. The two-period travelling salesman problem applied to milk collection in Ireland. Computational Optimization and Applications 7, 291–306.

[4] CSO, 2019. Intake of Cows Milk by Creameries and Pasteurisers by Domestic or Import Source, Year and Statistic - StatBank - data and statistics [WWW Document]. CSO.ie. URL https://www.cso.ie/px/pxeirestat/Statire/SelectVarVal/saveselections.asp (accessed 8.18.19).

[5] Dayarian, I., Crainic, T.G., Gendreau, M., Rei, W., 2016. An adaptive large-neighborhood search heuristic for a multi-period vehicle routing problem. Transportation Research Part E: Logistics and Transportation Review 95, 95–123. https://doi.org/10.1016/j.tre.2016.09.004

[6] Erdoğan, G., 2017a. An open source Spreadsheet Solver for Vehicle Routing Problems. Computers & Operations Research 84, 62–72. https://doi.org/10.1016/j.cor.2017.02.022

[7] Erdoğan, G., 2017b. VRP Spreadsheet Solver – Version 2.2 [WWW Document]. Excel Vrp Solver, Bath University. URL http://people.bath.ac.uk/ge277/index.php/vrp-spreadsheet-solver/ (accessed 4.16.18).

[8] Foulds, L., Igbaria, M., Basnet, C., 1996. FleetManager: A Microcomputer-Based Decision Support System for Vehicle Routing. Decision Support Systems 16, 195–207. https://doi.org/10.1016/0167-9236(95)00010-0

[9] Hurtado-Uria, C., Hennessy, D., Shalloo, L., O'Connor, D., Delaby, L., 2013. Relationships between meteorological data and grass growth over time in the south of Ireland. Irish Geography 46, 175–201. https://doi.org/10.1080/00750778.2013.865364

[10] Kytöjoki, J., Nuortio, T., Bräysy, O., Gendreau, M., 2007. An efficient variable neighborhood search heuristic for very large-scale vehicle routing problems. Computers & Operations Research 34, 2743–2757. https://doi.org/10.1016/j.cor.2005.10.010

[11] Lahrichi, N., Crainic, T.G., Gendreau, M., Rei, W., Rousseau, L.-M., 2012. Strategic Analysis of the Dairy Transportation Problem. Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation.

[12] Laporte, G., 2009. Fifty Years of Vehicle Routing. Transportation Science 43, 408–416. https://doi.org/10.1287/trsc.1090.0301

[13] Lusby, R.M., Schwierz, M., Range, T.M., Larsen, J., 2016. An adaptive large neighborhood search procedure applied to the dynamic patient admission scheduling problem. Artificial Intelligence in Medicine 74, 21–31. https://doi.org/10.1016/j.artmed.2016.10.002

[14] Lutz, R., Schöning, U., Völkel, D.-I.G., 2014. Adaptive Large Neighborhood Search. Ulm, Universität Ulm, Bachelorarbeit, 2014.

[15] O'Callaghan, S., O'Connor, D., Goulding, D., 2018. Distance Optimisation of Milk Transportation from Dairy Farms to a Processor over a National Road Network. Journal of International Scientific Publications 6, 18.

[16] O'Dwyer, T., Keane, M.J., 1971. Increasing efficiency in milk assembly. Irish Journal of Agricultural Economics and Rural Sociology 125–143.

[17] Paredes-Belmar, G., Lüer-Villagra, A., Marianov, V., Cortés, C.E., Bronfman, A., 2017. The milk collection problem with blending and collection points. Computers and Electronics in Agriculture 134, 109–123. https://doi.org/10.1016/j.compag.2017.01.015

[18] Paredes-Belmar, G., Marianov, V., Bronfman, A., Obreque, C., Lüer-Villagra, A., 2016. A milk collection problem with blending. Transportation Research Part E: Logistics and Transportation Review 94, 26–43. https://doi.org/10.1016/j.tre.2016.07.006

[19] Pillac, V., Gendreau, M., Guéret, C., Medaglia, A.L., 2013. A review of dynamic vehicle routing problems. European Journal of Operational Research 225, 1–11. https://doi.org/10.1016/j.ejor.2012.08.015

[20] Pisinger, D., Ropke, S., 2010. Large neighborhood search, in: Handbook of Metaheuristics. Springer, pp. 399–419.
[21] Pitakaso, R., Sethanan, K., 2019. Adaptive large neighborhood search for scheduling sugarcane inbound logistics equipment and machinery under a sharing infield resource system. Computers and Electronics in Agriculture 158, 313–325. https://doi.org/10.1016/j.compag.2019.02.001
[22] Quinlan, C.B., 2013. Optimisation of the food dairy coop supply chain (Doctoral thesis). University College Cork, Cork, Ireland.
[23] Sethanan, K., Pitakaso, R., 2016. Differential evolution algorithms for scheduling raw milk transportation. Computers and Electronics in Agriculture 121, 245–259. https://doi.org/10.1016/j.compag.2015.12.021
[24] Shaw, P., 1997. A new local search algorithm providing high quality solutions to vehicle routing problems. APES Group, Dept of Computer Science, University of Strathclyde, Glasgow, Scotland, UK.
[25] Smyth, P., Laurence, H., Hennessy, T., 2009. Seasonality and Costs of Production on Irish dairy farms from 2000-2007 [WWW Document]. The 83rd Annual Conference of the Agricultural Economics Society. URL http://www.aesi.ie/aes2009/s2i.pdf (accessed 11.11.14).
[26] Toth, P., Vigo, D., 2014. Vehicle Routing: Problems, Methods, and Applications, 2nd ed. SIAM.
[27] Vidal, T., Crainic, T.G., Gendreau, M., Prins, C., 2014. A unified solution framework for multi-attribute vehicle routing problems. European Journal of Operational Research 234, 658–673. https://doi.org/10.1016/j.ejor.2013.09.045