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DISTANCE OPTIMISATION OF MILK TRANSPORTATION FROM DAIRY FARMS TO A PROCESSOR OVER A NATIONAL ROAD NETWORK

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Abstract

This paper presents an innovative desktop milk collection route simulation model. The simulation focuses on the development of an optimal routing plan for a designated fleet of articulated lorries (trucks) and purpose-built tankers used in the collection, transportation and varying seasonal delivery patterns of milk from farms to processors over a national road network vis-à-vis, the Irish road network. A brief background of the significant role that ever-evolving technology has had on the dairy industry is presented. Followed by an outline of the multi constituents that form the complex milk assembly process. We move on to describe a model which has been designed to robustly cater for the specific characteristics that uniquely occur within the Irish dairy industry. The research presented suggests the formulation of a paradigm to accommodate the dynamic nature of the Irish milk collection process. A modified adaptation of a more ubiquitous solution, that was devised to encompass a broad-spectrum approach tasked with the efficient solving of numerous variations of the well-known Vehicle Routing Problem (VRP) across multiple environments, is implemented. Employing the widely used heuristic technique known as the large neighbourhood search (LNS) algorithm, a new model has been conceived and tested that allows for the formation of scheduled collection and delivery routes that can efficiently resolve routing problems that are distinctive to the dairy industry and principally those of the Irish industry. With issues such as Brexit now facing the Irish dairy industry this paper aims to put forward an efficient model to support those involved at various levels within the milk transportation sector of the industry. Furthermore, the model has been designed with the intention that future research can use this base model as a cornerstone for more in-depth research in the ever-evolving area of milk assembly.

Key words: *Milk transportation, milk assembly, Vehicle Routing Problem, Simulation, Large Neighborhood Search*

1. INTRODUCTION

In this paper, the efficiencies of the bulk collection of freshly produced milk from farms to processors are investigated. This process is also known as milk assembly (O'Dwyer and Keane, 1971). Although in this paper particular focus centres on the Irish dairy industry, it is the authors' hope that methodologies and findings employed in this research will be of use to an international dairy related audience and may also be of interest to the wider supply chain management logistics communities.

Post milk quota regime, Irish milk production has increased dramatically. Since the beginning of 2015 nationally, there has been an increase in production in excess of one and a half billion litres of milk annually (see Table 2.1). Taking an average tanker capacity of 29,000 litres and further assuming that all tankers are fully loaded when returning to the processor after each collection route, this equates to at least 55,000 extra journeys per annum. Indeed, as a consequence of this expansion, it has been estimated that there would be upwards of 30,000 extra milk tanker journeys undertaken annually in the Cork County area alone (O'Connor and Keane, 2014). Furthermore, due to these increased transport requirements, it is expected that the average capacity of the specially designed milk tankers that are required will increase capacity to support the transportation of the increased volume. These larger tankers can carry loads weighing between 35 and 45 tonnes relative to a current typical load of circa 29 tonnes. With this combination of forecasted increases in road usage, vehicle size and milk volumes, there is clearly an urgent need for research to analyse the economic and environmental impacts of these dramatic changes facing the dairy industry in Ireland. More recently, due the challenges which may arise as a result of the United Kingdom's vote to leave the EU (Brexit) production costs will possibly become more critical and any possible savings in the area of transportation more welcome.

The main focus of this research is to create a highly efficient and dynamic routing solution that can be employed to produce cost-efficient route collection schedules for milk assembly in a fast changing environment. Milk assembly, comprises a myriad of input variables that are often unique to the activity. Therefore, any solution proposed must be designed so that it is flexible enough to accommodate what is a highly sophisticated and complex process, that can be described as being uniquely dependent on a exceptionally distinctive set of input variables. For example, there is need at the design stage to take into account the fluctuations of certain input elements such as herd size, seasonality and the unpredictability of Irish weather patterns, all must be considered as part of any proposed output solution.

Currently, as previously stated, dramatic changes are taking place within the dairy industry. On the farm supply side, factors such as a general trend to lower dairy farm numbers, combined with a parallel increase in dairy cow numbers has led to a dramatic increase in the average population size of the typical Irish dairy herd, overall dairy herd yields, increased quality of the product being produced (Donnellan et al., 2015) and ultimately resulting in the long range effects on the sustainability of supply (Dillon et al., 2010; McElroy, 2015). While on the processing side there has been major investment in and modernization of the industry (Quinlan, 2013).

As computing technologies in general have matured to the extent that previously prohibitive costs and specialized labor skill requirements created barriers, which had effectively prevented the widespread use of technology in the highly cost sensitive area of agriculture (Borchers, 2015) no longer apply. Historically, much of the research carried out in this area was confined to mainly the bastions of scholarly research and were therefore of very little practical value for real life modelling of the problems such as that of milk assembley (Mwangi and Kariuki, 2015). Recently, as general computing power has become relatively less expensive, it now feasible to carry out research that serves a dual role to the research community and also a more practical function of supporting the increasing efficiency of various commercial aspects of the industry. Based on such a dramatic background, research that previously was impractical can now be conducted to consider the effects on transportation models required to best maximize the benefits that can be gained due to changes occurring across the Irish dairy industry.

The research undertaken in this paper highlights that the solution arrived at, must provide a very flexible working model that can be efficiently tested with simulated data. Moreover, it must be constructed with the potential to be a useful modelling tool with the capabilities to support the milk collection route scheduling needs of the Irish dairy industry. Based on the research in the area of logistical optimization, the model must further be able to provide practical routes that can be used by schedulers to service their load building needs. Initially, the model needs to be able to recommend realistic routes for milk collection that take into account the unique factors encountered by the Irish dairy sector.

In order to achieve this the Vehicle Routing model (Erdoğan, 2017a) is further adapted to the almost unique milk production pattern which exists in Ireland. Using simulated farm data based on current Irish milk production patterns three alternative scenarios were considered. These scenarios were each run seven times to validate the accuracy of the model in an Irish context. Following this, one of the simulations is presented in detail with load numbers, volumes and efficiencies.

In the next sections the milk assembly problem is defined. This is followed by a description of the recent evolution of the Irish dairy farm sector and a brief review of the milk transportation problem. The methodology employed and the chosen simulation are then described. The results of the simulation are then presented, a discussion on the findings is given, before finally a number of conclusions are drawn.

2. MATERIALS AND METHODS

2.1. Milk assembly

For the purposes of this paper, milk assembly can be described as the umbrella term that encompasses the start-to-finish processes required to move milk from the dairy farm to the processor (O'Dwyer & Keane 1971). Through their analysis, the authors were specifically able to identify three main component areas where distinct costs are incurred. Firstly, at the farm level where costs depend on items such as farm and herd size, type of milk cooling and quantity of storage in place, other items such as costs that are incurred by the farmer as part of any transport process that they might directly be involved in must also be incorporated. Secondly, the milk transport element which covers the transport of the milk between producer and processor, this would include items such as driver labor cost, vehicle capital and fuel costs. Thirdly, creamery level costs, these would include costs such as testing, intake and washing facilities.

A more recent definition of milk Assembly (Quinlan, 2013), describes six distinct activities that occur during the milk assembly process (1) transport driving, (2) assembly driving, (3) on farm routine activities, (4) on farm pumping, (5) plant non-pumping activities and (6) plant pumping (Quinlan, 2013). Furthermore, the paper points to two areas of focus that are of particular importance to this research. These are firstly the transport driving, which covers the costs involved with the initial drive from the processor to the first farm on the scheduled route and the drive from the last farm collection back to the processor for delivery. Secondly, assembly driving which the author describes as the costs involved with driving between the individual farms that have been included in that particular route schedule. The following figure (Fig 2.1) illustrates these activities and how the transport driving and assembly driving components integrate into the overall milk assembly process.

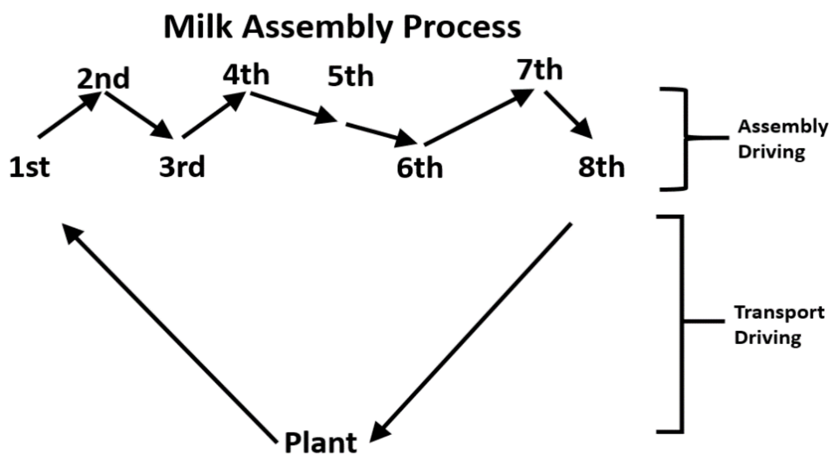

Fig 2.1. Assembly process for one collection route

Source: Own (Based on Quinlan, 2013)

In broad terms, the main characteristics of the Irish dairy industry are of an efficient grass based, spring calving process (Smyth et al., 2009) combined with a mild, but changeable climate has led to a peak to trough (also known as head and shoulders) seasonal milk production system (Heinschink et al., 2013). For the most part the industry produces milk through a family unit based farming system but recent trends are towards increased herd size (Micha et al., 2017).

The Central Statistics Office (CSO) farm structure survey of 2013 reports 18,150 specialised dairy farms in Ireland (CSO, 2017, p. Table 3.1). A more recent farm structure survey conducted by Teagasc, the Irish Agriculture and Food Development Agency, report an increase in the total number of dairy farms to 18,351 (Kelly et al., 2017). Of note in this latter survey was that there was an increase in the number of dairy herds categorized as having a herd size greater than 100 dairy cows. This report shows that there was an increase from the previous survey in 2010 of 2,740 to 4,262 in the number of herds with a population of greater than 100 cows. From these figures, it is significant to point out that over the three-year period from 2013 to 2016 there has been a relatively marginal addition of approximately 200 herds to the national herd total figure, whereas there was a 56% increase in the national number of herds that have an average dairy cow population which is in excess of 100 active milk producing cows per dairy farm (Kelly et al., 2017)

As can be seen from Table 2.1, there are now approximately 1.3 million dairy cows in Ireland. Significantly, over the last 10 years there has been an increase of over 30% in the size of the national dairy cow herd with the greater part of this expansion occurring since quota removal in 2015.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Total Dairy cows	1,017.30	1,024.10	1,022.40	1,006.90	1,035.60	1,060.30	1,082.50	1,127.70	1,239.90	1,295.20	1,343.30
Domestic Milk production	5,074.10	4,943.20	4,785.40	5,173.40	5,377.00	5,232.40	5,422.70	5,648.50	6,395.20	6,653.80	7,262.50

Table 2.1. Total Dairy Cow (000’s) and Domestic Milk (million liters) production per year

Source: CSO 2018

As previously stated the national number of dairy farms is 18,351 (Kelly et al., 2017) combining this data with data from Table 2.1 it can be calculated that the national average size of herds in Ireland consist of approximately 73 dairy cows. It should be further noted that due to soil types and farming methods there are significant regional variations. Notwithstanding, these regional variations it worth pointing out that the average herd size has increased from 54 cows in 2005 (Kelly et al., 2017) to current figures that point to a significant increase of over 35% in the average national dairy herd size over a relatively short period of time.

Teagasc, within its role as the Irish state agency that has the primary responsibility for nationally undertaking research and development, training and advisory services in the agri-food sector, has been conducting the National Farm Survey (NFS) on an annual basis since 1972. Results from the 2015 NFS (Teagasc, 2015) suggest that approximately 50% of the national dairy herds are now achieving an annual production per dairy cow of over 5,400 liters. Production levels in Ireland are less intensive relative to those achieved across the top 6 production countries in the EU (Skarżyńska and Abramczuk, 2017).

As Ireland is an island situated in the North Atlantic, located off the coast of Western Europe, with a mild and temperate oceanic climate, forage from grass pastures is the primary source of feed for dairy cows. However, grass growth is very seasonal, where the most efficient management of grass is focused on the period from mid-March to late-October, depending on specific weather conditions that can vary considerably from year to year. The financial advantage of grass based milk production can be clearly understood from Teagasc’s estimation that on average the total cost of producing one kilogram of milk solids, the dried powder left after all the water is removed from liquid milk, from a dairy cow being feed fresh pastoral based grass is approximately in the region of 80% to 85% less than the cost of producing milk solids under a more intensive concentrate-based regime (Teagasc and PastureBase, 2017). However, this may not always be the case as the cost of a concentrate-based regime will vary over time depending on the cost of animal feed, but it is indicative of the margin of competitive advantage that is naturally attainable by the Irish milk producer. Under normal conditions the peak for daily grass growth, in Ireland, usually occurs between mid-May and the first half in June each year (Teagasc, 2017).

Due to this seasonal nature of grass growth, Irish dairy farmers plan their main calving cycle to occur in a short spring time frame so that their dairy herd’s optimum milk production time window can coincide and take full advantage of the dramatic rise in the grass growth over the May to June period.

Taking monthly data from the CSO, from the beginning of January 2014 to end of March 2018 (Fig 2.2), clearly shows the very cyclical and highly seasonal nature of the annual domestic Irish milk production system forming of a series of peaks and troughs over the four-year period 2014 - 2017.

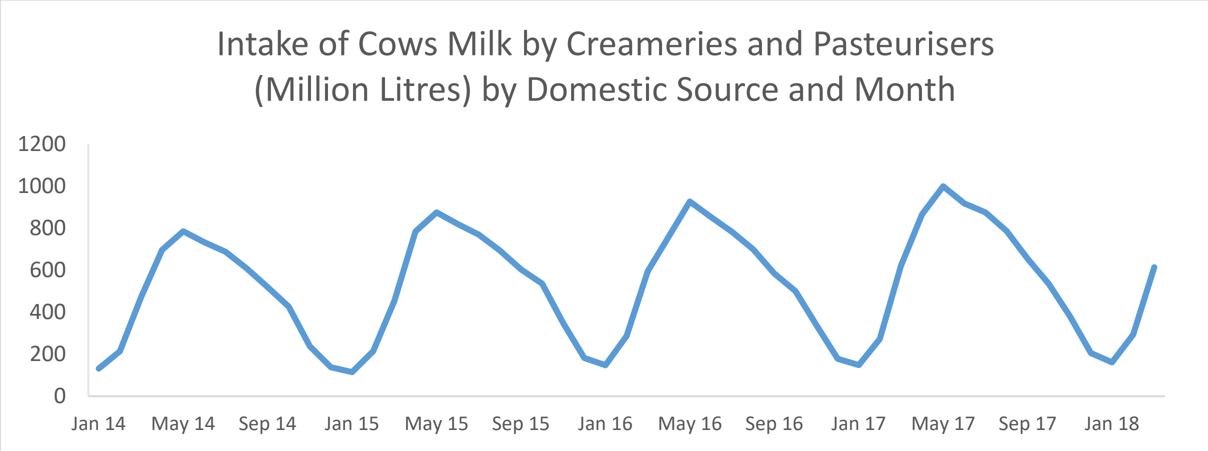

Fig 2.2. Monthly pattern of milk intake from Domestic Supply Sources 2014 – 2018

Source: CSO 2018

The pattern of peaks and troughs in the annual production of milk are often referred to as the "head and shoulders" of Irish milk production. Furthermore, Fig 2.2 highlights graphically several interesting points about the pattern of milk production in Ireland: (1) Annual peak to trough pattern (2) highest level of production occurs in May each year, (3) least amount of milk is produced in January and (4) there is an underlying general upward trend in milk production (see also Table 2.1).

Ireland's dairy industry has the highest level of seasonality in relation to the production of milk within the European Union. Seasonality, is much less of a concern for the majority of the other EU states where the peak to trough ratio ranges from little or no seasonality affect at 1.1:1 to 1.3:1 (European Commission, 2018). Whereas, for example in 2009, Irish domestic milk production recorded a ratio of 4.9:1 between the peak and trough periods of the year (Heinschink et al., 2012).

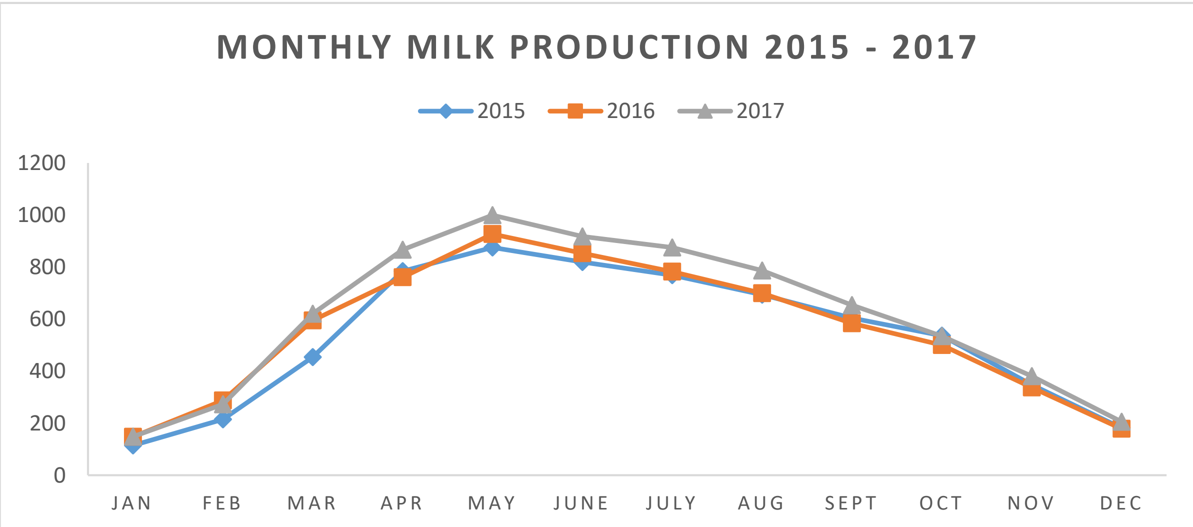

Fig 2.3. Intake of Cows Milk from Creameries and Pasteurizers (Million Liters) by Domestic Source by Month (years 2015 to 2017)

Source: CSO 2018

Figure 2.3 shows a comparison of the recorded total volumes of milk that was delivered to milk processors of domestically produced milk over the 36-month period Jan 2015 to Dec 2017. The 2017 production curve that is shown in Fig 2.3, reflects a net increase of over 614.3 million liters of milk supplied for the year 2017 over the previous year this equates to an overall annual production increase of approximately 9%. Furthermore, over the last number of years the production has become increasingly more seasonal (Fig 2.2), with the ratio for peak (May) to trough (Jan) for Irish domestic milk production increasing dramatically from 4.9:1 in 2009 (Quinlan et al., 2012) to 7.6:1 in 2017 (CSO 2018). In addition, Fig 2.3 demonstrates the monthly variation in production, with for example March production in 2015 significantly different to March 2017.

The significant seasonality factor that occurs in Ireland has unique ramifications for Irish milk production support services such as those of milk collection and transportation. Somewhat surprisingly, when studied, it was found that the net effect on transport cost was considered to be little different when various models were investigated, taking different levels of seasonality into account (Quinlan et al., 2012). However, the authors point out that more research would need to be undertaken, to investigate the effects of seasonality on production and assembly costs before any conclusive finding could be made in relation to identifying the most advantageous supply model for the Irish dairy industry. In addition, this study predates quota removal and the rapid expansion which has followed.

2.2. Milk assembly literature

Due to the nature of the problem, researchers have had a continual interest in milk assembly and similar collection processes (Les Foulds et al., 1996; Laporte, 2009; Lahrichi et al., 2012) as the area creates challenging real world logistical problems. Often farm locations are dispersed over a wide rural area. Thus, processor based milk collection schedulers face challenges when deciding on the routes that truck drivers should take when collecting milk. The type of problems that face the schedulers when designing routes include the fact that rural road network may not be adequately designed for the large tankers required to transport the freshly produced milk to processing depots, the need to reroute because of traffic or road works for example. In Ireland, the seasonality of supply demands particular attention of the schedulers to ensure that when creating collection routes that they are efficient over the annual collection period.

Data generated from dairy activity, further analysis and the presentation of this data has been greatly improved by the use of advanced techniques now available because of enhancements in the realms of information technology and operations research. Moreover, as a direct result of these advances it has been possible to build complex decision support systems (DSS), which in turn aid milk collection schedulers in their daily route building processes, (Keenan, 1998; Butler et al., 2005). Butler et al considered the benefits to a scheduler when a geographical information system (GIS) is used in conjunction with a DSS, allowing them the opportunity to take advantage of optimization algorithms, such as optimizing routing algorithms, to efficiently plan milk collections, (Tlili et al., 2013).

The Irish milk assembly process has previously been modelled using a variant of the well-known Travelling Salesman Problem (TSP) (Butler et al., 1997). The Systematic Travelling Salesman Problem (STSP) (Freisleben and Merz, 1996) was presented as a method to solve a problem consisting of 42 nodes (41 dairy farms and 1 depot) with varied collection periods of between a one and two period collection schedule. The authors have implemented several Integer Programming formulations to solve their model. Notwithstanding the success of the approach, the paper is now over 20 years old and the technology and research that underline the paper has moved on considerably. In conclusion the authors refer to future work that they identified would involve considering the use of heuristic methods to solve the problem and further including vehicle capacity constraints to their model. Furthermore, the paper deals with the problem of the distances between the nodes in a Euclidean fashion drawing straight lines between the various nodes. While this approach is useful from a research point of view, lack of traversable route information limits the papers use for the practical solving of this real-world problem. Also, it should be noted that the distances used were accurate to 1/10th of a mile (Butler et al., 1997). From a practical point of view this would be of little real-world use.

Some of the challenges that the commercial milk assembly process in Ireland face are not unique to the Irish situation. More recently, related work on the milk collection process has been studied in other countries such as Canada, Chile and Kenya, where logistics modelling researchers have focused on variants of the Vehicle Routing Problem (VRP) (Lahrichi et al., 2012; Paredes-Belmar et al., 2016; Murimi Ngigi and Wangai, 2015). Due to the fact, that the milk collection vehicles that are used in the actual collection process have a fixed maximum capacity, the problem can be further described as Capacitated Vehicle Routing Problem (CVRP). The principle objective of the CVRP is to minimize the number of vehicles or travel time required. Furthermore, the CVRP must consider that the total supply of milk for each route cannot exceed the capacity of the vehicle which serves that designated route.

2.3. Vehicle Routing Problem (VRP)

There has been a significant corpus of research (Eksioglu et al., 2009; Laporte, 2009) with regard to the subject of the well-known combinatorial optimization and integer programing problem known as the Vehicle Routing Problem (VRP). Where milk assembly is a specialized instance of the vehicle routing problem (Masson et al., 2016). The general VRP consists of a set of homogeneous vehicles that serves customers. The main objective of a solution to a VRP is to minimize one or more objective functions such as fleet size, total routing cost etc. Each route starts and ends at a depot. For the Capacitated VRP (CVRP) to be applicable the vehicles each must be of a predefined capacity. Furthermore, capacity may not be exceeded. The VRP is considered to be non-deterministic polynomial-time hard (NP hard) and therefore, is usually solved by (Meta) heuristics. Metaheuristics are known as higher level heuristics that are designed to search for good but may not be exact solutions to specific optimization problems. When applied, metaheuristic solutions are high level strategies that can be used to guide heuristic algorithms that can then be applied to problems that are thought to be NP-Hard or NP-Complete. Examples of metaheuristic algorithms would include tabu search, simulated annealing, genetic algorithms and memetic algorithms.

The VRP is seen as a generalization of the Traveling Salesman problem (TSP), (Laporte, 2009; Pillac et al., 2013). The Traveling Salesman Problem is often described as a Hamiltonian circuit. Like the Travelling Salesman Problem (TSP) research has shown that it is very difficult to solve large VRP problems optimally. Bearing in mind that the VRP is believed to be in the category of NP-Hard problems, exact solutions are often not available to solve problems of this nature, for this reason researchers of the VRP have looked towards other methods for workable solutions. Heuristic approaches have been devised to quickly find approximate solutions that provide reasonably accurate (near optimum) solutions to the problems that are posed in the VRP arena (Vidal et al., 2014).

Since it was first described the Vehicle Routing Problem (VRP) has been a rich research space within the field of operation research and combinatorial optimization. In their seminal paper, entitled "The Truck Dispatching Problem" (Dantzig and Ramser, 1959) were concerned with investigating the optimization of routing of a fleet of gasoline delivery trucks between a storage terminal and a number of service stations (seven in total). Using a linear programming approach, the researchers were able to establish a near optimal solution for the supply of gasoline to the various service stations in their study. As is the case with the pioneering research undertaken (Dantzig and Ramser, 1959), an attractive aspect of research in this area is that solutions to VRPs can find direct application in real world systems that plan and schedule the distribution and collection of a wide range of goods and the provision of services. For example, areas such as the optimum routing for a wide range of industries such as those of milk and rubbish collection. Owing to the rich nature of the problems that can be solved using the VRP many variants have emerged. These variants include specific constraints that embrace factors such as multiple time windows, vehicle capacity constraints, homogeneous and heterogeneous vehicle fleets, multiple depots and plants, pickup and delivery route scheduling (Eksioglu et al., 2009).

The concept of the Large Neighborhood Search (LNS) was first introduced by (Shaw, 1997). He suggested that a technique that continually reworks a solution by focusing on transforming the local neighborhoods created in the original solution. Later solutions use the previous solution as a basis for future searches with the goal of finding the optimal solution to the problem. The transformation is accomplished through the use of destroy and repair algorithms that try to improve on the previous solutions. The basic principle of the LNS was further developed by (Pisinger and Ropke, 2010). In their paper, they describe the destroy and repair function of the LNS and show a visual demonstration of how the algorithm would work in practice see Fig 2.4 and Fig 2.5

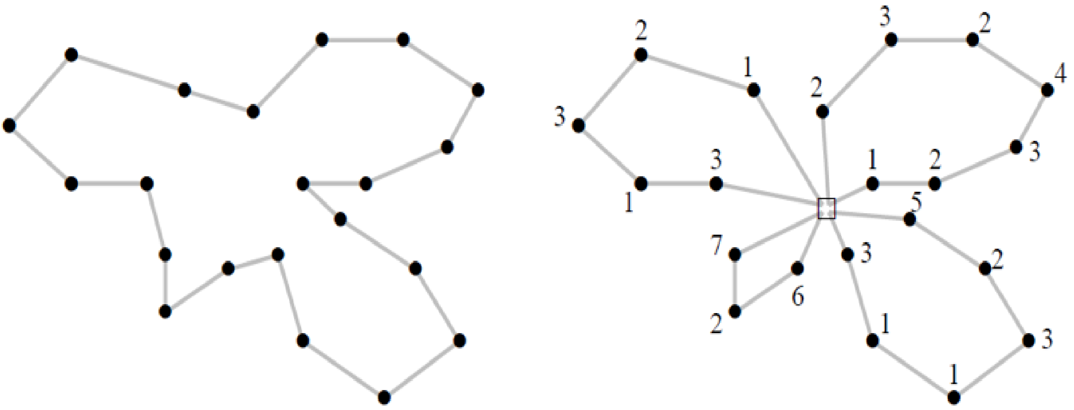

Fig 2.4. Travelling Salesman Problem TSP (left) Vehicle Routing Problem VRP (right)

Source: Pisinger and Ropke, 2010

An example of a Traveling Salesman Problem solution to the problem is simply joining all of the nodes in an efficient manner, see route on the left-hand side of Fig 2.4. As would be expected the routing solution that is devised consists of a single continuous route connecting all of the available nodes together by the most efficient path between them. Next a depot is introduced and in this case located in the center of the nodes. Furthermore, additional constraint of quantity demand, or supply depending on the problem to be solved and the vehicles have limited carrying capacity, the problem now becomes a Capacitated Vehicle Routing Problem (CVRP). Looking for a fast and efficient solution that implements LNS, Pisinger and Ropke (2010) based on Shaw (1997) found that heuristic searches could be every effective in determining good solutions to problems with large populations sets. The researchers point out that since the destroy method can destruct a large part of the solution, the neighborhood contains many possible solutions. They make the point through an example of a CVRP instance with 100 customers. If the degree of destruction of the solution is 15%, there would be a total of C (100,15) =100!/(15!×85!) =2.53338E+17 ways to select the customers to be removed as part of the destruction phase of the process

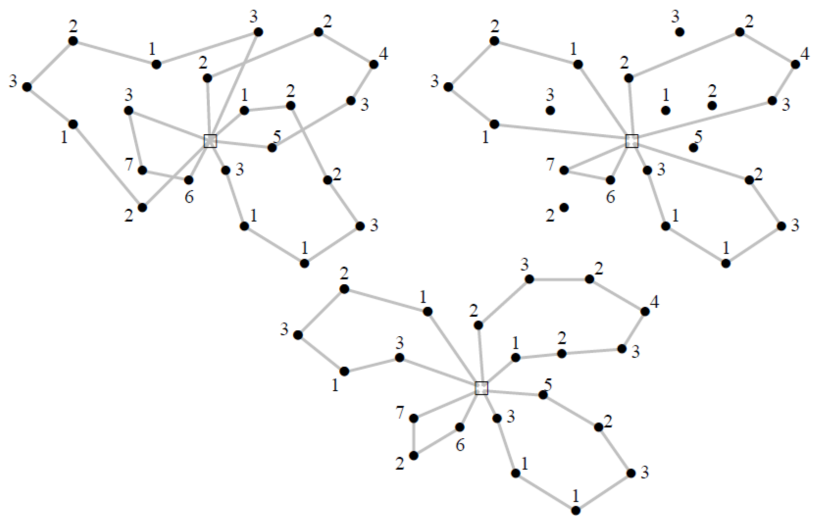

Fig 2.5. Destroy and repair process

Source: Pisinger and Ropke, 2010

Figure 2.5 visually demonstrates the “destroy and repair” process. An example of a CVRP solution before the destroy algorithm is applied, can be seen in the top left corner. The initial suggested route contains several crossover points for the routes and would be inefficient in practice as vehicles would be crossing each other’s paths. Post destroy stage, six customer nodes have been removed and the routes redrawn creating routes that will allow a vehicle to efficiently travel to all of the other nodes that have been specified. In the final stage of repair, as represented in the final route solution located at the bottom of Fig 2.5, the six previously removed nodes are efficiently reintroduced to the routes. As can clearly be seen from the process the final solution is a much more efficient route schedule compared the original route schedule.

Furthermore, Pisinger and Røpke (2010) found that various destroy and repair methods were not consistent in how efficiently they performed throughout the solution finding process. Some methods were more effective when the solution process was initiating whereas others performed increasingly more effectively later in the process. To solve this problem, they devised a dynamic weighting system for the various destroy and repair methods that continually updated. As each method is requested their individual weightings would be judged and the currently most efficient destroy or repair method would be applied.

2.4. VRP solver

The Microsoft Excel workbook "VRP Spreadsheet Solver" is an open source unified platform for representing, solving, and visualizing solutions for various variants of VRP (Erdoğan, 2017a). The platform unifies Microsoft Excel, public GIS and metaheuristics designed to search for efficient routing solutions. The spreadsheet based solver is driven by VBA code to run an algorithm which is based on the implementation of a modified version of the LNS algorithm. Using benchmark instances created to test the efficiency of implementations of various VRP algorithms, (Uchoa et al.,2003), the solver was shown to run efficiently in finding solution values relative to the best solutions found for a set of well-known research benchmark instances. For validation purposes a set of well-known instances created by (Christofides et al., 1981) was used. Of the 14 instances that were tested all of the solutions found by the VRP Spreadsheet Solver has a small array of “best gap” values ranging from zero percent or at worst in one instance a best gap value of just 2.46%. Indeed, 2 instances with 50 customers, vrpnc1 and vrpnc6 were able to calculate the best solution known for these problems within a 15-minute period see (Erdoğan, 2017a). Furthermore, the author puts forward and describes at length a mathematical formulation implemented by the VRP Excel Solver and has been used in the solving of multiple variations of VRP including the CVRP.

2.5. Data Simulation

In this section we show how the data was collected. For the design of this simulation model, a collection depot was located in a large town situated in the province of Munster which is situated in the south of Ireland. The town is well serviced by the national road network – for testing reasoning only one depot was used. If necessary the simulation model used has the flexibility that it can accommodate multiple depots for any future more in-depth analysis that maybe undertaken. Also, variations such as the ability to include varying sized capacity of collection vehicles can be used.

To make the simulation as realistic as possible an initial dairy farm population was identified. The preliminary process used to locate the individual farms was based on using satellite view from Google maps. It was decided to use an area located adjacent to the plant depot location as the farms in the hinterland of the town chosen chiefly operate as dairy enterprises.

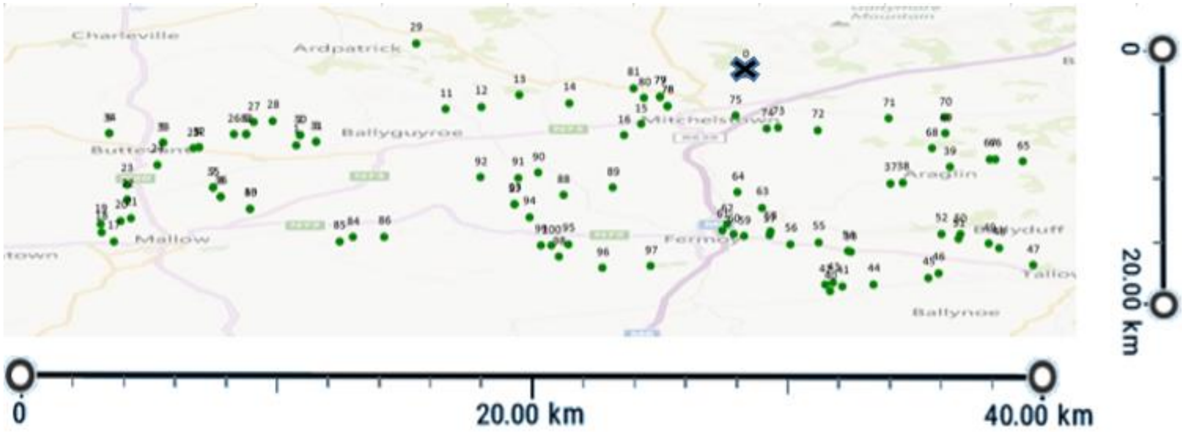

Fig 2.6. Farm distribution

Source: Google maps

The delivery processor depot for the suppliers within the sample population is marked by the symbol X (located in the top right-hand side of the map). The total area covered in the sample consists of an area of approximately 800km^2. By using a reasonably wide spread of locations realistic road distances can be analyzed. Additionally, at a later stage it will be possible to run further analysis that compares these simulations to those of real world collection schedules. The map locations used were kept at a low resolution to ensure the nonspecific identification of the sample farm locations that were chosen for the population sample.

The exact farm locations utilized were chosen at random using Google maps and their relevant latitude and longitude details were recorded to allow for route building to and from the initial depot location and collection from specific producers based on the dynamic routes created by the simulation model. Even though the selection of the farm locations included in the sampling population was random, identification of possible locations is based on the style of related buildings in place at each location from the satellite image of the farm. One of the major advantages of using mapping GIS services software such as Google Maps or alternatively Microsoft Bing is that relatively accurate distances can be calculated from producer locations back to the processor's depot or to neighboring dairy farms. Frequently, rural roads in Ireland will follow the contours of the landscape making the roads seem to "twist" through the countryside. Milk truck drivers sometimes are required to travel longer routes to avoid obstacles such as narrow roads or can be required to travel significant distances to access a bridge to allow traversal over a river, whereas on paper the Euclidean distance between locations may indicate that the travel time between locations is minimal. Also, the actual farm locations are not always located directly at the side of a public road. Often farms will have private access roads that will need to be included in the overall distance calculations that are created as part of the overall journey distances that need to be travelled between suppliers.

A master data table of simulated farms was created. Using the data from this master table, varying herd sizes were generated. Using published data from the CSO as a basis, the farms created ranged in herd sizes from 37 milking cows to approximately herd size of 500 milking cows. Furthermore, using the CSO average herd sizes as a basis, annual milk production for each dairy cow was created using annual production level of 5,000 liters (note this figure can be varied as required). Total annual production of milk was calculated by simply multiplying herd size by average production per cow. Again, this can be further modified to adjust for the simulation to reflect more realistic values.

To implement a level of seasonality for each farm's production quantities, the quantity totals were divided over 12 months period and further weighted according to a monthly seasonal adjustment for each month to reflect the head and shoulders shape of Irish milk production see Table 3.1. For this simulation it is assumed that milk collection will occur once every two days (on average 15 times per month there will be a slight variant from month to month) and that all herds are milked twice daily.

3. RESULTS

Simulations were run on a homogeneous computer lab of 21, Dell PCs each configured with an Intel i5 CPU and 8GB of Ram, the machines have the latest version of Microsoft Windows 7 operating system and Microsoft Office version 2013 installed on each. Excel VRP solver was downloaded from the web (Erdoğan, 2017b), version 3.1 of the solver was used. Using the built-in console interface, the solver was configured as required. A CPU time limit of 1 hour was imposed on each scenario that was run.

A number of different scenario samples were identified from the master sample of 100 farm locations which were selected from the Munster area - see Fig 2.6. Scenario one (S1) was created by including the 50 farm locations in closest proximity (by road distance) to the processor depot. Scenario two (S2) took a random sample of 50 farm locations from across the master sample. For the third scenario (S3) it was decided to divide the master sample in half, creating an East West divide of the sample farm locations, testing was carried out on the most westerly 50 producer locations.

Using CSO figures for domestic milk collection data for the years 2015–2017 - see Table 3.1, the following average monthly national production percentage figures were calculated.

Years	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
15-17	2.02	3.82	8.22	11.87	13.80	12.75	11.94	10.73	9.07	7.73	5.29	2.77	100

Table 3.1. Milk production percent per month,

Source: CSO 2018

Table 3.1 represents the breakdown of average milk production per month by percent and was used to calculate an annual peak to trough seasonality ratio, which is currently applicable to Irish milk production (see Fig 2.3). The ratio 7:1 (rounded up) was derived by comparing the monthly level of milk production at the peak month of Irish milk production (May – 13.80%) to the levels produced during the lowest annual month of milk production (January – 2.02%). It should be further noted that most of the milk production is carried out between the months of March – 8.22% and October -7.73% each year.

Month	**V1 Distance**	**V2 Distance**	**V3 Distance**	**V4 Distance**	**V5 Distance**	**V6 Distance**	**V7 Distance**	**V8 Distance**	**V9 Distance**	**# of Vehicles**	**Total Distance**
Jan	99.7	97.4	31.7							3	228.75
Feb	107.4	97.4	31.7							3	236.46
Mar	64.6	70.6	47.0	57.7	49.7					5	289.67
Apr	64.8	53.8	48.4	43.5	45.7	52.0	36.8			7	345.05
May	47.2	10.7	54.8	9.3	58.0	41.4	43.7	65.4	40.5	9	371.02
Jun	64.8	10.7	45.7	40.8	45.1	59.4	52.3	42.4		8	361.27
Jul	36.8	52.0	58.0	10.7	48.4	43.5	45.7	54.8		8	349.91
Aug	60.8	60.6	62.8	36.8	49.4	55.0				6	325.41
Sept	49.0	49.7	66.0	57.7	70.6					5	292.94
Oct	80.4	45.3	46.3	64.6	50.4					5	287.01
Nov	82.3	101.1	55.1							3	238.47
Dec	99.7	97.4	31.7							3	228.75
Total distance travelled (km) per collection over 12-month period											**3555.00**

Table 3.2. Total Distances (km) instance 1 under S1 for a single collection per month (Jan – Dec)

Table 3.2 represents the distance that would need to be travelled to complete one single collection per month from all 50 sample farms generated for instance 1 under the scenario S1.

It can be clearly observed from the results of Table 3.2, as would be expected, there is a dramatic increase in the number of loads required to successfully collect the total milk produced, in a two-day time period, during the peak production months of May to the end of August. For the month of May, 9 vehicle loads are required to cover a total distance of 371.02 km. alternatively, during the month of January only 3 vehicle loads would be required to cover all collections necessary with a total distance travelled of 228.75 km. It should be further pointed out, that for a real-world solution, it may be impractical to collect milk from over 20 locations in one load but for the simulations that have been run this factor will be ignored as a limiting characteristic.

A follow-on point from Table 3.2 is that in some collection schedules such as those for January and February time period, even though the number of vehicles used are the same, there is a difference in the total distance that is travelled for the different time periods Jan – 228.75 km and Feb – 236.46 km. From Table 3.3 it can be seen that there is approximately a 30,000 liter increase in supply for the month of May. Therefore, while the same farms must be visited the routes used must be varied to allow efficient milk assembly.

Month	V1 Qty. (Eff)	V2 Qty. (Eff)	V3 Qty. (Eff)	V4 Qty. (Eff)	V5 Qty. (Eff)	V6 Qty. (Eff)	V7 Qty. (Eff)	V8 Qty. (Eff)	V9 Qty. (Eff)	# of Loads	Total Quantity
Jan	12684 (0.42)	17873 (0.6)	2436 (0.08)							3	32,993
Feb	27874 (0.93)	29911 (1)	4607 (0.15)							3	62,392
Mar	29824 (0.99)	27269 (0.91)	23881 (0.8)	26158 (0.87)	27131 (0.9)					5	134,263
April	27708 (0.92)	28350 (0.95)	28150 (0.94)	28911 (0.96)	28511 (0.95)	22536 (0.75)	29713 (0.99)			7	193,879
May	29813 (0.99)	8060 (0.27)	29440 (0.98)	14021 (0.47)	27626 (0.92)	29955 (1)	29023 (0.97)	29908 (1)	27391 (0.91)	9	225,237
June	29762 (0.99)	7451 (0.25)	26748 (0.89)	29159 (0.97)	28254 (0.94)	28599 (0.95)	28643 (0.95)	29633 (0.99)		8	208,249
July	29914 (1)	22687 (0.76)	23939 (0.8)	6984 (0.23)	28340 (0.94)	29107 (0.97)	28701 (0.96)	25513 (0.85)		8	195,185
Aug	29469 (0.98)	27766 (0.93)	29398 (0.98)	29976 (1)	29287 (0.98)	29362 (0.98)				6	175,258
Sept	29690 (0.99)	29937 (1)	29566 (0.99)	29995 (1)	28954 (0.97)					5	148,142
Oct	29612 (0.99)	20628 (0.69)	18279 (0.61)	28045 (0.93)	29691 (0.99)					5	126,255
Nov	29219 (0.97)	29862 (1)	27324 (0.91)							3	86,405
Dec	17396 (0.58)	24508 (0.82)	3340 (0.11)							3	45,244

Table 3.3. Total Quantity (liters) per vehicle (S1) compared to efficiency of each load (Jan – Dec)

Using a single 2-day collection period for each month, Table 3.3 (based on scenario S1 instance 1) displays the volume of milk collected for that time period. For each month, the table outlines the number of loads that would be necessary to collect the total quantity of milk produced that requires collection during each time period (two-day collection cycle) as specified in column entitled "Total Quantity". Also, included in the table is the efficiency for each load, this is calculated by dividing the load volume by the capacity of the collection tanker which has been set for the simulation at 30,000 liters.

It should be noted, that there are a number of vehicles returning to the depot which are not fully loaded. For example, in January, to collect 32,993 liters of milk, three vehicle loads are required, resulting in an average load capacity of less than 40%, indeed one load is less than 10% full on return to the depot (see Table 3.3 cell Jan-V3). However, as would be expected for a simulation to optimize distance, when the distance travelled by this vehicle is considered, it is 31.68km (see Table 3.2 cell Jan V3) which is less that then 14% of the total distance traveled to collect the total amount of milk for this period. Furthermore, for the month of May as the peak month, the majority of loads (7 out of the 9), all have a capacity of over 90 percent, indeed 4 of the loads have over a 98% load capacity. The two remaining loads (see Table 3.3 May V2 and May V4) have a combined load efficiency of less than 37%, but have combined distance travelled of slightly less than 20km which accounts of less than 6% of the total distance travelled for this time period.

Scenario	**Instance 1**	**Instance 2**	**Instance 3**	**Instance 4**	**Instance 5**	**Instance 6**	**Instance 7**	**Average distance**
S1	53,325	53,355	53,445	53,490	53,370	53,295	53,265	53,370
S2	72,225	72,135	71,595	72,030	72,240	72,255	72,330	72,120
S3	67,275	67,275	67,365	67,305	67,275	67,185	67,425	67,305

Table 3.4. Total annual distances (km) travelled for each instance under scenario S1, S2 and S3

Taking an annual view of the 3 scenarios (S1, S2 and S3) which were run concurrently using 7 PCs to create 7 instances per scenarios as outlined previously. The total annual distance for each instance is presented in Table 3.4, these represent the summation of the total calculated distance that must be travelled on an annual basis, to collect the total supply of the milk produced by the appropriate cohort of milk producers identified for that scenario.

Description	**S1**	**S2**	**S3**
Mean	53,364	72,116	67,301
Standard Dev	80.25	248.85	76.35
Coefficient of variation	0.0015	0.0035	0.0011
Range as % of mean	0.0042	0.0102	0.0036

Table 3.5. Total mean annual distance (km) travelled for all instances under scenarios S1, S2 and S3 (incl. Standard Deviation & Coefficient of variation and range as a percent of mean for each scenario)

Leading on from Table 3.4, Table 3.5 offers, for each scenario (S1, S2 and S3), a further analysis of the total distances for each instance calculated during the simulation process. Based on the instances presented in Table 3.4, the mean, standard deviation, coefficient of variation and the range as a percentage of the mean has been calculated for each scenario and compared in Table 3.5. Overall for each scenario, it should be noted the similarity of the total distances travelled for each instance, which is reflected in the low standard deviation for each scenario. Taking the minimum and maximum values for each instance the range as a percentage of the mean for each scenario was calculated again highlighting the low variation on the distances that were generated for each scenario see Table 3.5. The very low coefficient of variation that was calculated for each scenario, demonstrates how similar the results from each instance are. There is a slight variation in the standard deviation to be seen between the various instances generated under scenarios S2 and S3. However, it should be pointed out, that the coefficient of variations for these scenarios is negligible see Table 3.5.

4. DISCUSSION

This research should be of value to both the academic and practitioner communities in the field. With the Irish dairy sector in a state of rapid growth, we the authors have put forward the argument that research is urgently required in respect of the central topic of milk assembly within an Irish context for several reasons. Firstly, the Irish dairy industry is in a state of major transition. In recent years the industry has seen a continual significant increase in the total number of dairy cows in the national herd, this has led to the average herd size increasing dramatically. Secondly, the substantial increase in the average herd size combined with increases in the level of milk production per cow, has led to a substantial annual increase in the total amount of milk produced nationally. Furthermore, the study is required as the cost of transport for milk assembly is significant, some estimates would put at it being in the region of 50 -60 million Euro per year for the industry (Quinlan, 2013). The environmental costs associated with the distances travelled, the $C0_2$ emissions and the costs associated with the upkeep of the road networks are factors that the authors would argue strengthen the requirement of this study. In relation to the processing side of the industry, there has been major investment and modernization of plants used in the processing of fresh milk. The industry is now in a post milk quotas era and with Brexit looming, these factors alone, have added more uncertainty which furthers the need to re-examine the optimization of areas such as the transportation to lend support to an efficient, low emissions, high quality and dynamic milk assembly operations that are now required by the modern Irish dairy industry. Many of dairy farms in Ireland are run as family unit businesses that are based on a grass feed seasonal production cycle that leads to a peak to trough production system. Indeed, the authors point out that Ireland has the most seasonally based farming system within the European Union. All of these factors strengthen the need for further research in the area to the benefit of the overall industry.

Previous research in relation to Irish milk assembly has modelled a feasible solution for a small number of farms using a method devised to solve the Systematic Travelling Salesman Problem, however, much of the research in the area and technologies used have moved on since this previous study was conducted. Current research in the field would suggest that a more appropriate method to solving the problem could be found through the use of metaheuristics employed in the finding of feasible solutions in the area of capacitive vehicle routing problems (CVRP). Where the main considerations are the optimization of the distances and number of vehicles required to allow the efficient transportation of milk from producers to processors. As pointed out by the authors the large neighborhood search technique is often employed in the search for highly efficient solutions to the problem.

The solver blends the strengths of a unique combination of Microsoft Excel, GIS services and metaheuristic algorithms to solve the problems posed by the various variants of the Vehicle Routing problem. It is further argued that by building a simulation model based on farm production data the solver can be employed to find highly efficient routes between farms and processor. Raw data is generated such as farm locations, using a GIS service. It is pointed out the advantage of using actual road distance data as opposed to Euclidean distances.

For the simulation, 3 scenarios were described (S1, S2 and S3) and run. Overall, it is felt by the authors that the results obtained validate the accuracy of the simulation by using 7 individual instances that were run for each of the scenarios that have been proposed see Table 3.5. Furthermore, from the analysis of the data offered in Tables 3.4 and 3.5 it can be clearly seen how closely aligned the results of each scenario are to one another. As pointed out by the paper's authors certain data was calculated before the simulations were run, this action was undertaken to give a more realistic basis for the simulation. For example, weighted monthly production figures for the years 2015 to 2017 were employed, in turn these were used to calculate distance values for S1, the values were derived from CSO supplied data see Table 3.1. Under the various scenarios the optimum total annual driving distances that would need to be travelled to complete the full collection of milk for the 50 sample farms is given in Table 3.4. As a two-day collection window has been assumed for the simulation the total optimized travel distance was further broken down see table 3.2. Furthermore, the table represents the summation of the total distances travelled in a single two-day time window for each of the 12 months. The results highlight the negligible variation in the distances obtained for all instances across the various scenarios see Table 3.4. Additionally, taking a detailed look at instance 1 as seen in Table 3.2, we see a monthly breakdown in the actual number of loads and distances that are required to fully collect all milk quantities that is produced across the sample farms. Leading on from this analysis, Table 3.3 highlights the total quantities and levels of efficiency that is reached by each vehicle load. By the further step of combining the data collected and further analysis displayed in Tables 3.4 and 3.5, we can give a coherent overview of how the outputted data from the simulation is able to build an efficient schedule of the routes and the distances that would be required to complete a full milk assembly process of the 50 farms under analysis.

As a previously stated, for simulation purposes the collection time window has been set to 2 days which represents the period of time between the transporter's last and next visit to the same farm. In practice, for example during the winter months this time window may increase or halt completely based on the lower amount of milk produced at this time in the year and cases where certain producers halt production fully. However, for the spring, summer and autumn months and often into the winter months a two-day time period would be appropriate for much of the milk assembly undertaken in the Munster region.

5. CONCLUSIONS

In this paper we have proposed and demonstrated a novel approach to the simulation of milk assembly based on the Irish road network. One of the major findings of the research presented, is that because of the seasonal supply of milk the monthly variation in truck load numbers and routes is striking, suggesting that at a minimum, routes should be revised monthly rather than what anecdotal evidence suggests of peak and shoulder, where for example 9 trucks could be replaced by 3 or 4 see Table 3.5.

Another significant conclusion that can be drawn from the results of the simulations is that when farms are located near a processing plant it may make sense to employ short trips collecting a small number of farms near the plant.

Future research in this area using the simulation model that has been suggested will be undertaken to look at larger catchment areas that cover a much greater cohort of producers. Multiple depots will also be considered for further investigation. Other avenues of interest such as the overall environmental costs associated with fuel usage can be investigated. One of the main strengths of this simulation approach is the fact that multiple realistic constraints can be included in the model to ensure a more credible modelling of the real-world problems posed by milk assembly. Some of these problems that could be further considered would include roads that have one-way systems in place, farms that can only be accessed from one direction. We have also argued that variations in milk assembly time windows for example going from a 2-day to 3-day collection window can easily be added and included in further research in this the area of milk assembly.

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