Optimisation of Intermodal Transport Chain of Supermarkets on Isle of Wight, UK

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***Abstract*—**This work investigates an intermodal transportation system for delivering goods from a Regional Distribution Centre to supermarkets on the Isle of Wight (IOW) via the port of Southampton or Portsmouth in the UK. We consider this integrated logistics chain as a 3-echelon transportation system. In such a system, there are two types of transport methods used to deliver goods across the Solent Channel: one is accompanied transport, which is used by most supermarkets on the IOW, such as Spar, Lidl and Co-operative food; the other is unaccompanied transport, which is used by Aldi. Five transport scenarios are studied based on different transport modes and ferry routes. The aim is to determine an optimal delivery plan for supermarkets of different business scales on IOW, in order to minimise the total running cost, fuel consumptions and carbon emissions. The problem is modelled as a vehicle routing problem with time windows and solved by genetic algorithm. The computing results suggested that accompanied transport is more cost efficient for small and medium business-scale supermarket chains on IOW, while unaccompanied transport has the potential to improve the efficiency and effectiveness of large business scale supermarket chains.

***Keywords*—**Genetic algorithm, intermodal transport system, Isle of Wight, optimization, supermarket.

I. Introduction

THE United Kingdom of Great Britain and Northern Island is dominated by its main island (Great Britain) and has various small islands around its coast. The IOW is located in the English Channel and separated from the mainland by the Solent. The IOW is the largest island of England with an area of 147 square miles and is an island that possesses the second largest population (approximately 141,000). Furthermore, the IOW has been a popular tourist destination [1].

Presently, there are 43 supermarkets under 11 major grocery retailers on the IOW. Co-operative Food owns the largest number of both large and small scale supermarkets on the IOW. Aldi, Bookers, Lidl, M&S and Waitrose do not have small supermarkets whereas Nisa and Spar only have small supermarkets on the IOW. Daily freight movements of each supermarket brand are estimated based on the data provided by Steve Porter Transport. Most of food and grocery shopping transactions are performed in the four main stores: Tesco at Ryde, Sainsbury's at Newport, Morrisons at Newport and Morrisons at Sandown. Although Co-operative Food owns the highest number of stores on the IOW, Tesco has the largest number of transport movements, followed by Morrisons and Sainsbury's. Yet, the estimation of transport movements for each supermarket brand on IOW may not be accurate but should be reasonable. Moreover, although Tesco, Morrisons and Sainsbury's all own less than five stores each on the IOW, this indicates that the location of a store is a part of its competitive advantage. These four brands are all located at the most populous regions, especially Newport which is the dominant shopping centre.

Not surprisingly, most firms on the IOW have to rely on suppliers not located on the island. Every day, large volumes of both chilled and ambient products are dispatched from the supermarkets' Regional Distribution Centre (RDC) on the mainland. The RDC is used as a result of Just-In-Time principles which were wildly applied in the early 1990s and which created a market for Third-Party Logistics (3PL) service providers [2], like Steve Porter Transport Co. The two main ferry routes usually used in goods shipping are Southampton to East Cowes (operated by the Red Funnel Ltd.) and Portsmouth to Fishbourne (operated by Wightlink Ltd.). The distance from Southampton to East Cowes is 11.9 miles and one journey usually takes one hour (Red Funnel, n.d.). The distance from Portsmouth to Fishbourne is 9.7 miles and it takes 0.67 hour for a single journey [3]. These are the two ferry routes that are available for the transport of goods for supermarkets from mainland England to the IOW.

Every day, goods are sent from the RDC for IOW under its supermarket brand to either the port in Southampton or Portsmouth. Presently, most supermarkets in the IOW employ Ro-Ro transport to cross the Solent channel, where a tractor with its semi-trailer or a rigid vehicle is driven directly onto a ferry and the driver travels as a passenger [4]. After arriving at the port on the IOW, the vehicle is driven off from the ferry and visits the supermarkets on the island. López-Navarro et al. [4] defined this kind of transport mode as Short Sea Shipping (SSS) which is a form of accompanied transport.

Compared to this transport mode, Aldi applies the "drop trailer" service provided by Steve Porter Transport Co. Based on business connection with Red Funnel Distribution Ltd., Steve Porter Transport Co. has designed this intermodal transport plan specifically for customers who require regular, multiple deliveries to the IOW (Steve Porter Transport, n.d.). Once arrived at the port of Southampton, only the semi-trailer is shipped across the Solent towards the IOW. The driver can then drive the tractor back to RDC or start another job. After the semi-trailer has arrived at the island, the new tractor is re-instated to continue the delivery tasks. This is known as unaccompanied transport [4].

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After the introduction, this paper is organised as follows: Section II reviews the related works in the literature; Section III describes the problem and gives the mathematical formulation of the considered problem, Section IV presents the experimental results. At last, Section V summarises this work and suggests future research areas.

II. Literature Review

This section will review all the relevant works on supply chain management and logistics problems. Supply Chain Management (SCM) has become a "hot topic" in manufacturing, distribution, marketing, customer management or transportation [5]. In the area of SCM logistics in UK grocery retail, the United Kingdom is considered to have the most efficient supply chain in the world, particularly in the retail industry [2]. The RDC was used as a result of JIT principles being wildly applied in the early 1990s [6] which created a market for 3PL service providers. After that, the concept of supply chain integration was implemented when Efficient Consumer Response (ECR) was introduced [7].

For a better understanding of the trends and challenges of UK grocery logistics, literature encompassing varying views has been reviewed. Burch and Lawrence [8] studied the shift of power in relationships in agri-food supply chains of UK's supermarkets. Research by Towill [7] focused on the hidden financial pressure imposed by UK supermarkets. He found that UK supermarkets compete for market share through price wars and pass these cost savings to their suppliers; the author argued that the trend of supermarkets in the UK is an emphasis on price competition rather than service provision. Under this trend, the greater a supermarket's market share, the larger the pressure on price it will exert on its suppliers. Moore [9] compared the social and financial performance of UK supermarkets and found that they have a strong, positive relationship. Ge et al. [10] studied on the bullwhip effect with a system dynamic approach and suggested that a better structured information flow can improve the efficiency of UK supermarket supply chain. Fernie and McKinnon [6] studied logistic networks and focused on transport operations of UK's grocery supply chain. This research discusses how the supply chain of UK grocery trends has changed in recent years. The work by the above authors found the KPI for grocery transport and pointed out that reducing the "transport – intensity" could improve the efficiency of the grocery supply chain.

Regarding the intermodal transportation, Lowe [11] and Mattfeld [12] define the SSS as the costal or cross-channel sailing. The former author has summarised that in both short-sea and costal shipping the scale of transportation and the freighters are much smaller than deep-sea shipping. Additionally, the latter one pointed out that other differences are "direct shipment and hub feedering" compared with deep-sea shipping. Similar with intermodal transport, short-sea and coastal shipping are modes of transport that has existed for a long time [11]. In fact, SSS is competing with road and rail transport in Europe's transport system [12]. The demand for more operationally efficient, effective and environmentally sustainable alternatives gives motivation for further research in this field [11]. Although there are increasing interests in SSS, López-Navarro et al. [4] hold the belief that the recognition and market share of SSS is insufficient which inhibits the development of SSS. In the above research, the definition of SSS is deemed to be freight transport by sea between European countries and non-European countries in coastwise area.

Regarding the transportation methods, both the accompanied transport and unaccompanied transport in the research by López-Navarro et al. [4] is based on the employing of a so-called articulated vehicle. The tractor is hitched with the front-end of the semi-trailer, the attractive unite. Cheng et al. [13] defined the transport mode using this tractor and semi-trailer combination as semi-trailer swap transport. Their work has proposed this transport mode as Vehicle Routing Problem with Simultaneous Pick-up and Delivery (VRPSPD) mode in large-scale of manufacturing enterprises. Their research has captured the feature of semitrailer swap transport in inland transportation which can effectively reduce the waiting time for loading and unloading as well as the number of vehicles and drivers used. The objective is to minimise the total distance and the volume of deliveries in order to optimise costs. Although the problem in this research is quite different, since this mode is not applied in waterway transport, their model proved a helpful framework in modelling the transport mode. Research by López-Navarro et al. [4] has compared accompanied transport and unaccompanied transport in SSS transport operation. In addition, this research studied a similar issue to this paper which is to investigate the elements that affect a certain company to choose between accompanied transport and unaccompanied transport although theirs is based on a survey, rather than the empirical approach adopted in this paper. The above study found that cooperation and trust is very important in multimodal transportation operations, and unaccompanied transport has a higher level of information sharing than accompanied transport. The research by López-Navarro et al. [4] is a rare supplement to literature and is of great practicality to this paper. The heart of this transport mode is that the tractor unit can be swapped off at the destination and a new tractive unit can be re-instated with the autonomous part, leaving for the next destination.

III. Problem Description and Formulation

A. Background

Generally, supermarkets on the IOW employ two types of vehicle: the rigid vehicle and articulated vehicle. The total time consuming, total running cost and the production rate for these two types of vehicles are explained in this subsection. Rigid vehicles have smaller capacity than articulated but are advantageous for small delivery amounts and can access almost any location. This is one of the main reasons why truck and trailer routing problems are studied.

The main difference between deploying the rigid vehicle and articulated vehicle is that, firstly, the former allows larger volume to be transported. Secondly, the loading and unloading times can be reduced since these processes can be continued when the semi-trailer ends its task and the tractor carries out another task. Nevertheless, this feature is not very obvious since swapping off the semi-trailer mainly occurs in waterway transport, not at supermarkets.

There are three brands in the 'small' category. This includes Spar, Nisa and Iceland that have daily movements as are less than two articulated-trailer units. Although Nisa and Spar have more than four stores on the IOW, all of these three brands only have convenience stores. Next, Aldi, Lidl, Waitrose, M&S, Brookers are classified as 'small-medium'. These supermarkets need two to four articulated movements per day and they all have less than two large stores but no small stores on the IOW. Morrisons and Sainsbury's are classified into the 'medium' group since they have at least eight but less than 10 articulated-trailer-units demand per day. Finally, the large group consists of Tesco and Co-operative Food. Although Tesco has less stores than Co-operative Food, it has a superstore on the IOW and their daily demand exceed 10 articulated-trailer units daily.

Thus, the logistics chain from RDC to supermarkets on the IOW can be modelled for four transport scenarios. Based on total running cost, fuel consumption and carbon emission, these transport modes are evaluated and the optimal delivery plan is proposed for supermarkets on the IOW for each different business scale. Four supermarkets are selected to represent each size category to be tested in the model. These have been selected to be Spar, Lidl, Morrisons and Co-operative Food, representing small, small-medium, medium and large respectively. The most effective delivery method of each business scale will be investigated and the application of unaccompanied transport in coastwise transport in practice will be interpreted and discussed.

B. Problem Description

This paper considers the problem of multimodal transport chain optimisation as not only the choice of suitable transport modes, but also the nodes and paths. There are a number of customers on one side and an origin on the other side. Several nodes lie in the middle. Alternative modes of transport exist between every node. Operational cost and time consuming vary with different transport modes. Moreover, the capacity of each transport mode is different. Now the requirement for an intermodal transport operator is to choose the appropriate nodes and suitable transport mode and organize an available route, which can achieve the delivery task within the specified time with minimum operational cost and time. A mixed integer programming (MIP) model is designed for this problem.

We have the following assumptions for the model:

- It is assumed that there are enough articulated tractors, articulated trailers and rigid vehicles.
- It is assumed that all the operators in this logistics system collaborate together.
- The route is assumed that symmetrical and the transport distances are fixed.
- According to UK's legislation, after certain hours continuous driving, drivers must rest for a certain period. We assumed that this is ignored in this model.
- It is presumed that a driver is tied with his/her vehicle. Driver and vehicle are viewed as a combination.
- The distance from Steve Porter Transport, where articulated tractor is sent out in reality, to port of East Cowes is ignored, since the route is not very long.
- It is assumed that the destination of a vehicle is the same as its origin, but vehicles cannot go directly from its origin to its destination. Only two nodes are able to send out articulated tractors and they are RDC and Port of East Cowes. Port of East Cowes only sends out articulated tractors when there is an articulated tractor to send out from RDC and unaccompanied transport is applied, which is scenario 3.
- It is assumed that the volume of a full load trailer is 1 unit and the capacity of a rigid truck is 0.6.
- It is assumed that articulated tractor (4×2) and 18 tonne rigid truck are used here.
- It is assumed that all vehicles travel at the average speed 65 mile/h in mainland England and 50 mile/h on IOW. The difference in fuel consumption under different loads, weather conditions and road conditions are ignored here, and only considers the transport distance.
- The time windows of the whole transport system are assumed the same as the start and end of the timetable of the ferry. It is assumed that all ferries routing between Southampton and East Cowes are able to carry both unaccompanied and accompanied transport. RDCs are assumed to be operating 24 hours.
- Transport movements of each supermarket and its brand are estimated based on the information provided by Steve Porter Transport. Changes on delivery demand due to seasonal etc. are ignored.

C. The Model

The decision variables are as:

$$\rho_{ij}^{hm} = \begin{cases} 1 \text{ Vehicle m is taking charge of the transportation between vertex i and j in task h} \\ 0 \text{ Otherwise} \end{cases}$$

$$\tau_{ijmn}^{h} = x_{ij}^{\beta h} = \begin{cases} 1 \text{ In task h path i to j is used for empty travel of vehicle k after transporting m to vertex i and before taking team n from vertex j} \\ 0 \text{ Otherwise} \end{cases}$$

The empty travel happens and only happens when the ferry only ships the unaccompanied trailer.

$$x_{ij}^{kh} = \begin{cases} 1 \text{ In task h, transportation mode k is used at path i to j} \\ 0 \text{ Otherwise} \end{cases}$$

$$y_{i\,h}^{kl} = \begin{cases} 1 \text{ In task h, transportation mode k transfer to mode l at vertex i} \\ 0 \text{ Otherwise} \end{cases}$$

$$z_{im}^{h} = \begin{cases} 1 \text{ Vehicle m is selected for customer i in task h} \\ 0 \text{ Otherwise} \end{cases}$$

$$u_{i}^{h} = \begin{cases} 1 \text{ Supermarket i is delivered in task h. } i \in C \\ 0 \text{ Otherwise} \end{cases}$$

In the model, the following indices are used:

$$\text{N} = \begin{cases} O\ RDC \\ Pm = \{Pm_1, Pm_2, \dots, Pm_n\}\ Port\ on\ mainland \\ Pi = \{Pi_1, Pi_2, \dots, Pi_n\}\ Port\ on\ Island \\ C = \{C_1, C_2, \dots, C_n\}\ Customer(Supermarket) \end{cases}$$

l_{ij}: distance between vertex i and vertex j. $i \neq j, l_{ij} = l_{ji}, l_{ii} = 0$ $ij \in E$, d_i Demand of vertex i. $i \in C$, v^k Average speed of the transportation mode k. $k \in K$, c_{ij}^k Cost of the transportation mode k per hour between vertex i and vertex j. $ij \in E, k \in K$, Ct_i^{kl} Cost of transferring from transport mode k and mode l at vertex i. $i \in Pm \cup Pi$, Cu_i Unloading cost at vertex. $i \in C$, Cf Fixed cost each task, C_h Total cost of task h, including the transportation cost associated with time, transfer cost associated with intermodal transfer and unloading cost associated with the unloading volume and time.

$$C_h = \sum_i \sum_j \sum_k \sum_m c_{ij}^k \times \rho_{ij}^{hm} \times x_{ij}^{kh} \times t_{ij}^k + \sum_i \sum_j \sum_m \sum_n \sum_k c_{ij}^k \times \tau_{ijmn}^h \times t_{ij}^k + \sum_i \sum_k \sum_l \sum_m Ct_i^{kl} \times z_{im}^h \times y_{i\,h}^{kl} \times (Av_{im}^h - D_i) + \sum_i Cu_i \times z_{im}^h \times u_i^h \times Tu_i \times q_i^h + Cf$$

q_i^h Volume delivered at vertex i in task h. $i \in C$, Q_{ij}^{hk} Volume of transportation between vertex i and vertex j with transportation mode k. $ij \in E, k \in K$, $[LT_i, ET_i]$ Time windows of vertex i. $i \in N$, Av_{im}^h Arrival time of vehicle m, conducting task h at vertex i. $i \in N, m \in M$, Dv_{im}^h Departure time of vehicle m, conducting task h at vertex i. $i \in N, m \in M$, Tp_{im}^h Process time of task h at vertex i, including waiting time and unloading time. $i \in N, m \in M$, t_{ij}^k Average transport time with transportation mode k between vertex i and vertex j. $ij \in E$, $i \neq j, t_{ij}^k = t_{ji}^k, t_{ii}^k = 0$, $t_{ij}^k = \frac{l_{ij}}{v^k}$, Tu_i Unloading time at vertex i. $i \in C$, D_i The fixed departure time of vertex i. If there is no fixed departure time of vertex i, $D_i = 0$, in this cast, goods can departure at any time. Otherwise, $Tp_{im}^h = Av_{im}^h - D_i + Tu_i$. $i \in N$, $m \in M$, Tv_m^h Total transportation time of vehicle m when it is conducting task h, including the transporting time and the process time at each node it has visited. $m \in M$

$$Tv_m^h = \sum_i \sum_j \sum_k \rho_{ij}^{hm} \times x_{ij}^{kh} \times t_{ij}^k + \sum_i z_{im}^h \times Tp_{im}^h$$

T_h Total transportation time of task h, including the maximum time of vehicle teams and the time for empty travel (if unaccompanied transport is applied).

$$T_h = max(Tv_m^h) + \sum_i \sum_j \sum_m \sum_n \sum_k \tau_{ijmn}^h \times t_{ij}^k$$

There is a difference of the time consuming between drop-and-swap mode and traditional transport mode on vehicles departing from RDC. With the traditional transport mode of full load and direct drive, the total time is the travel time is the sum up of the time from the driver leaving to RDC and delivering goods on IOW to the driver going back to IOW, since the driver accompanies his vehicle all the time. With the drop-and-swap mode, the total time consuming actually is as the previous one. However, the next task can start earlier because the driver does not need to travel to IOW with ferry and the rest delivery task is conducted by the tractor re-instated on IOW.

W_k^h Total CO2 emission of task h. $k \in K$, EM_k CO2 emission per unit of task h. $k \in K$, $W_k^h = EM_k \times l_{ij} \times x_{ij}^{kh} \times Q_{ij}^{hk}$, $Qmax^k$ The maximum volume of transportation mode k. $k \in K$, T Total time for delivering all stores of the same brand on IOW per day.

$$T = \sum_m \sum_h Tv_m^h$$

Z Total cost running cost of delivering all stores of the same brand on IOW per day.

Our MIP model is as follows: The objective function of the MIP is to minimize the total travel cost including the transportation cost associated with time, transfer cost associated with times of transport mode transfer and unloading cost associated with the unloading volume and time. Other objective function can be easily modelled, such as minimize the total travel time of vehicles departure from RDC or minimize the total CO_2 emissions.

$$\text{Min } Z = \sum_h \left[\sum_i \sum_j \sum_k \sum_m c_{ij}^k \times \rho_{ij}^{hm} \times x_{ij}^{kh} \times t_{ij}^k + \sum_i \sum_k \sum_l \sum_m Ct_i^{kl} \times z_{im}^h \times y_{i\,h}^{kl} \times (Av_{im}^h - D_i) + \sum_i Cu_i \times z_{im}^h \times u_i^h \times Tu_i \times q_i^h + Cf \right]$$

Subject to: Constraints of transport mode and path:

$$\sum_k x_{ij}^{kh} = 1 \ \forall k \in K, \forall ij \in E \quad (1)$$

$$\sum_k \sum_l y_{ih}^{kl} \leq 1 \ \forall k, l \in K, \forall i \in N \quad (2)$$

$$x_{i-1\,i}^{kh} + x_{i\,i+1}^{lh} \geq 2y_{ih}^{kl} \ \forall k, l \in K, \forall i \in N \quad (3)$$

$$l_{i \in O j \in Pi \cup C} = \infty, l_{i \in Pi \cup C j \in O} = \infty \quad (4)$$

$$l_{i \in Pm j \in O \cup C} = \infty, l_{i \in O \cup C j \in Pm} = \infty \quad (5)$$

$$y_{ih}^{\alpha\beta} = y_{ih}^{\gamma\delta} = 0 \quad (6)$$

$$y_{i \in O \cup C\, h}^{\gamma l} = y_{i \in O \cup C\, h}^{\delta l} = 0, \quad (7)$$

$$x_{ij \in Pm \cup C}^{\gamma h} = x_{ij \in Pm \cup C}^{\delta h} = 0 \quad (8)$$

$$y_{Pm_1\, h}^{\alpha\delta} + y_{Pm_1\, h}^{\alpha\gamma} + y_{Pm_1\, h}^{\beta\delta} = 1, \quad (9)$$

$$y_{Pi_1\, h}^{\delta\alpha} + y_{Pi_1\, h}^{\gamma\alpha} + y_{Pi_1\, h}^{\delta\beta} = 1, \quad (10)$$

$$x_{Pm_2 Pi_2}^{\gamma h} = 0, \quad (11)$$

$$y_{Pi_2\, h}^{\gamma\alpha} = 0 \quad (12)$$

$$l_{Pm_1 Pi_2} = \infty \quad (13)$$

$$l_{Pm_2 Pi_1} = \infty \quad (14)$$

$$x_{Pm_1 Pi_2}^{kh} = x_{Pi_1 Pm_2}^{kh} = 0 \quad (15)$$

$$x_{Pm_1 Pi_1}^{kh} \times x_{Pm_2 Pi_2}^{kh} = 1 \quad (16)$$

$$x_{O j \in Pm}^{kh} \cdot x_{i \in Pm\, j \in Pi}^{kh} \cdot x_{i \in Pi\, j \in C}^{kh} = 1 \quad (17)$$

Constraints (1) assures that each path ij is visited exactly once in each task. Constraints (2) assures that at each vertex, the transfer between different transport modes is no more than once. Constraints (3) is the correspondence of transportation mode, which assures when the transport mode transfer from mode k to mode l at note i, the transport mode adopted from i-1 to i is mode k and mode l is taken from i+1 to i. Since vehicles from the RDC must pass through the Solent channel to the corresponding port on IOW to carry on its delivery tasks, we have Constraints (4), (5). Constraints (6) assures that there is no transfer between two road transport modes or between two waterway transport modes at a vertex i. Set $= \{Pm_1, Pm_2\}$, let $Pm_1 =$ Southampton Port; $Pm_2 =$ Portsmouth Port. Set $Pi = \{Pi_1, Pi_2\}$, And let $Pi_1 = East\ Cowes\ Port$; $Pi_2 = Fishbourne\ Port$ Leaving from Southampton, the only corresponding port on IOW is East Cowes. And both the drop-trailer service and traditional shipment service are available on this route. Departing from Portsmouth, the only corresponding port on IOW is Fishbourne. But on this route, only the complete vehicle is shipped. Constraints (7), (8) assure that only the road transportation mode is available on the route from RDC to port on the mainland. Constraints (9), (10) assure that there must have transfer between different transportation modes from road transfer to waterway transfer at ports. Constraints (11), (12) assure that the route from Portsmouth to Fishbourne is not available on the drop-trailer service. Constraints (13)-(16) assure that the only corresponding port on IOW leaving from Southampton is East Cowes and both the drop-trailer service and traditional shipment service are available on this route. Departing from Portsmouth, the only corresponding port on IOW is Fishbourne. Constraints (17) is used to describe the order of echelons to be going through. To visit the supermarkets on IOW, the vehicle must leave from RDC to port on mainland and go across the Solent channel and arrive at the port on IOW.

Constraints on transport volume:

$$0 \leq \left\lceil \frac{d_j}{min\{Qmax^k\}} \right\rceil \leq \sum_h \sum_k x_{ij}^{kh} \quad \forall k \in K, \forall i, j \in C \quad (18)$$

$$\sum_{i \in C} q_i^h \times u_i^h \leq min\{Qmax^k\}, \forall k \in K \quad (19)$$

$$\sum_k Q_{i\,i+1}^{hk} = q_i^h - q_{i+1}^h \ \forall i, j \in N \quad (20)$$

$$0 \leq q_i^h \leq \sum_k x_{ij}^{kh} Q_{ij}^{hk} \leq Qmax^k \ \forall k \in K, \forall ij \in E \quad (21)$$

Constraints (18) assures that the visit times of each supermarket are equal to the rounding up of demand for that supermarket divided by the maximum capacity of the transport mode used. Constraints (19) ensures that no vehicle is loaded with more than its capacity allows it to. Constraints (20) is the flow balance constraint, which assure that the volumes transported between two vertex is the difference between the volume delivered at vertex i and vertex j in one task. Constraints (21) is the capacity constraint, which is to assure that the delivered volume at a vertex i in a certain task shall not exceed the capacity of road transport, which cannot exceed the maximum capacity of a transport mode adopted allowed.

Constraints on vehicles team:

$$\sum_{j \in Pm \cup Pi \cup C} \sum_h \rho_{Oj}^{hm} = 1, \sum_{i \in Pm \cup Pi \cup C} \sum_h \rho_{iO}^{hm} = 1, m \in m \quad (22)$$

$$\sum_{j \in C} \sum_h \rho_{Pi_1\,j}^{hm} = 1, \sum_{i \in C} \sum_h \rho_{i\,Pi_1}^{hm} = 1, m \in n \quad (23)$$

$$\sum_{i \in N} \sum_h \rho_{ij}^{hm} = z_{im}^h, \ \forall j \in N, m \in m \quad (24)$$

$$\sum_{i \in Pi \cup C} \sum_h \rho_{ij}^{hm} = z_{im}^h, \forall j \in N, m \in n \quad (25)$$

$$\sum_{j \in N} \sum_h \rho_{ij}^{hm} = z_{im}^h, \forall i \in N, m \in m \quad (26)$$

$$\sum_{j \in Pi \cup C} \sum_h \rho_{ij}^{hm} = z_{im}^h, \forall j \in N, m \in n \quad (27)$$

Constraints (22), (23) assure that vehicle from team m departs from RDC (O) and must come back to RDC (O), as well as, vehicle from team and leave from Pi_1, Port of East Cowes and must come back to Pi_1, East Cowes. Constraints (24), (25) assure that a vehicle, no matter which team it belongs to, must visit all vertexes it set to drop by in its task. Constraints (26), (27) are constraints on the numbers of vehicles to leave from a vertex to be visited in a task.

Constraints on time windows:

$$Dv_{im}^{h\prime} \geq Av_{im}^h + Tv_m^h \quad (28)$$

$$Av_{jm}^h + M\ (1 - \rho_{ij}^{hm}) \geq Dv_{im}^h + \sum_k x_{ij}^{kh} t_{ij}^k \quad (29)$$

$$Dv_{jn}^h + M\ (2 - \rho_{ij}^{hm} - \tau_{ijmn}^h) \geq Av_{im}^h + \sum_k x_{ij}^{kh} t_{ij}^k + z_{im}^h \times (Av_{im}^h - D_i) + z_{jn}^h \times (Av_{jn}^h - D_j) \quad (30)$$

$$LT_i \leq Av_{im}^h \leq Dv_{im}^h \leq ET_i \ \forall i \in N \quad (31)$$

Constraints (28) assures that the start time of the next task for the same vehicle shall not be earlier than the completion time of its last task. Constraints (29) assures that the time vehicle m arrives at its next destination j should not be earlier than the sum of the travel time and its departure time in a task. Constraints (30) assures that when is an empty travel exist at edge ij, the departure for vehicle from team n leave from vertex j should not earlier than time of when vehicle from team m leave from vertex i plus the travel time of this edge ij and the transfer time at both the transfer point. Constraints (31) assures that the departure time for leaving the vertex i should not be earlier than the time arriving at the previous vertex.

IV. Model Implementation and Results

MATLAB is an advanced technique for data analysis, function optimizing and algorithm developing [14]. GA solver provides methods for solving mixed-integer optimisation [15]. GA toolbox is applied to search for the solution to the problem proposed in this paper. The model is implemented in four supermarket brands on IOW: Spar as small scale business, Aldi as small-medium scale, Lidl as medium scale and Co-operative Food as large scale business.

A. Small Business Scale-Spar

Only one articulated trailer is employed and the delivery tasks from six supermarkets are divided into two times to be delivered. The total running costs per day are estimated as £1,062.55 and it takes about 17 hours to finish all delivery tasks. The CO_2 emission is estimated to be 54.95 kg. It takes about 108 seconds to obtain the result and the approximate result is obtained at the 55th generation. The suggested deliver route for all Spar stores on IOW (and the departure time of each node) are as in Table I.

B. Small-Medium Business Scale-Lidl

The computing time for the case of Lidl is 193 seconds and at the 61st generation, the approximate optimal solution is achieved. The most cost effective solution for Lidl is that three articulated vehicles are used and all of them employs scenario 5. The total running costs for supplying the two stores on IOW is £1,626.20 and the total time consuming is approximately 20.28 hours. There is 61.63 kg CO2 emitted. The route (and the departure time) for each vehicle is as in Table II.

TABLE I
COMPUTING RESULTS OF SMALL BUSINESS SCALE-SPAR

NO.1 articulated vehicle								
2.91	5.75	7.02	7.12	7.97	8.78	9.5	10.17	13.70
RDC	Portsmouth	Fishbourne Port	E. Cowes	Wroxall	Wootton	Fishbourne Port	Portsmouth	RDC
13.70	17.00	18.27	18.39	19.03	19.67	21	21.67	25.20
RDC	Portsmouth	Fishbourne	Newport James	Newport Gunville	Newport	Fishbourne Port	Portsmouth	RDC

TABLE II
COMPUTING RESULTS OF SMALL-MEDIUM BUSINESS SCALE-LIDL

NO.1 articulated vehicle						
3.70	5.75	7.02	7.13	8.5	9.17	10.92
RDC	Portsmouth	Fishbourne Port	Newport	Fishbourne Port	Portsmouth	RDC
NO. 2 articulated vehicle						
3.70	5.75	7.02	7.13	8.5	9.17	10.92
RDC	Portsmouth	Fishbourne Port	Newport	Fishbourne Port	Portsmouth	RDC
10.92	14.00	15.27	15.50	16.5	17.17	18.92
RDC	Portsmouth	Fishbourne Port	Shanklin	Fishbourneb Port	Portsmouth	RDC
NO. 3 articulated vehicle						
3.70	5.75	7.02	7.25	8.5	9.17	10.92
RDC	Portsmouth	Fishbourne	Shanklin	Fishbourne Port	Portsmouth	RDC

TABLE III
COMPUTING RESULTS OF MEDIUM BUSINESS SCALE-MORRISONS

NO. 1 articulated vehicle						
3.70	5.75	7.02	7.13	8.5	9.17	10.91
RDC	Portsmouth	Fishbourne Port	Newport	Fishbourne Port	Portsmouth	RDC
NO. 2 rigid vehicle						
3.24	5.75	7.02	7.13	7.25	7.92	9.66
RDC	Portsmouth	Fishbourne Port	Newport	Fishbourne Port	Portsmouth	RDC
10.92	14.00	15.27	15.50	16.50	17.17	18.92
RDC	Portsmouth	Fishbourne Port	Shanklin	Fishbourne	Portsmouth	RDC
NO. 3 articulated vehicle						
3.70	5.75	7.02	7.23	8.50	9.17	10.91
RDC	Portsmouth	Fishbourne Port	Lake	Fishbourne Port	Portsmouth	RDC
NO. 4 articulated vehicle						
3.70	5.75	7.02	7.23	8.50	9.17	10.91
RDC	Portsmouth	Fishbourne Port	Lake	Fishbourne Port	Portsmouth	RDC
NO.5 articulated vehicle						
3.70	5.75	7.02	7.23	8.50	9.17	10.91
RDC	Portsmouth	Fishbourne Port	Lake	Fishbourne Port	Portsmouth	RDC
NO. 6 articulated vehicle						
3.70	5.75	7.02	7.23	8.50	9.17	10.91
RDC	Portsmouth	Fishbourne Port	Lake	Fishbourne Port	Portsmouth	RDC
NO.7 articulated vehicle						
3.70	5.75	7.02	7.23	8.50	9.17	10.91
RDC	Portsmouth	Fishbourne Port	Lake	Fishbourne Port	Portsmouth	RDC
10.91	14.00	15.27	15.48	16.50	17.17	18.91
RDC	Portsmouth	Fishbourne Port	Lake	Fishbourne Port	Portsmouth	RDC

C. Medium Business Scale-Morrisons

Morrisons also has two stores on IOW but each store has larger demand than Lidl. The computing time is 726 seconds and the approximate optimal solution is obtained in the 142nd generation. It is suggested that to satisfied the demand of these two stores, six articulated vehicles and one rigid vehicle are needed. Scenario 4 is applied for the rigid vehicle and all 5 articulated vehicles take scenario 5. The running costs are £3,296.89 per day in total and the sum of transport time for these seven vehicles is 39.24 hours. This suggested deliver plan is estimated to emit 119.53 kg CO2. The suggested transport solution is as in Table III.

D. Large Business Scale-Co-Operative Food

Co-operative Food has four large-scale stores and six small-scale stores on IOW. The computing time for finding an approximate optimal solution is 1,238 seconds and the result is obtained at the 124th generation. According to the result, there are four articulated vehicles dispatched from RDC and three of them apply scenario 3, one applies scenario 5. Two articulated vehicles on IOW are needed to continue the delivery task when articulated vehicle No.1, No.3 and No.4 take unaccompanied transport. The total running costs for the whole system are £4,437.76 and the sum of transport time is 69.98 hours. The CO2 emission is estimated as 106.97 kg. Unaccompanied transport is applied as one part of the delivery arrangement for all the three vehicles employing this method. See Table IV.

TABLE IV
COMPUTING RESULTS OF LARGE BUSINESS SCALE-CO-OPERATIVE FOOD

No.1 Articulated Vehicle (RDC)				No.1 Articulated Vehicle (East Cowes)			
5.25	5.75	6.42	8.33	9.50			
RDC	Southampton	East Cowes Port	Freshwater	East Cowes Port			
5.75	..	8.00	9.27	9.98	11.50	12.25	
Southampton	RDC	Southampton	East Cowes Port	Freshwater	East Cowes Port	RDC	
12.25	16.00	17.27	17.73	18.50	19.25		
RDC	Southampton	East Cowes Port	Newport	East Cowes Port	RDC		
NO.2 Articulated Vehicle							
5.00	5.75	7.02	7.09	8.50	9.17	9.67	
RDC	Portsmouth	Fishbourne Port	Ryde	Fishbourne Port	Portsmouth	RDC	
9.67	12.00	13.27	13.34	14.50	15.17	15.67	
RDC	Portsmouth	Fishbourne Port	Ryde	Fishbourne Port	Portsmouth	RDC	
15.67	18.00	19.27	19.51	21.00	21.67	22.17	
RDC	Portsmouth	Fishbourne Port	Shanklin	Fishbourne Port	Portsmouth	RDC	
NO.3 Articulated Vehicle							
5.25	5.75	7.02	7.52	8.31	9.22	10.50	11.25
RDC	Southampton	East Cowes Port	Ryde	Shanklin	Cowes Terminus Rd	East Cowes Port	RDC
NO.3 Articulated Vehicle				No.1 Articulated Vehicle (East Cowes)			
11.25	15.00	15.67	17.22	17.97	18.69	19.50	
RDC	Southampton	East Cowes Port	Cowes Terminus Rd	Newport	Cowes	East Cowes Port	
15.00	…	15.00	19.27	19.62	20.51	22.50	23.25
Southampton	RDC	Southampton	East Cowes Port	Cowes	Shanklin Green Ln	East Cowes Port	RDC
No.4 Articulated Vehicle (RDC)				No.2 Articulated Vehicle (East Cowes)			
5.25	5.75	6.42	8.33	9.18	9.90	11.50	
RDC	Southampton	East Cowes Port	Freshwater	Newport (low)	E. Cowes	East Cowes Port	
8.00	9.27	9.60	10.40	11.18	11.89	13.50	14.25
Southampton	East Cowes Port	E. Cowes	Ventnor	Sandown	Ryde Somerset Rd	East Cowes Port	RDC
14.25	18.00	19.27	19.79	20.51	21.36	22.5	23.25
RDC	Southampton	East Cowes Port	Ryde Somerset Rd	Bembridge	Ventnor Pier St	East Cowes Port	RDC

V. CONCLUSION

The model results are similar with the how the transport scenario applied in this logistics chain presently. Employing articulated trailer and applying accompanied transport through the waterway are the most effective and efficient delivery methods to most supermarkets on IOW.

Although unaccompanied transport is necessary to demonstrate the capability of a better utilization of vehicle and driver resources; since the objective of this paper is recognised as satisfying the daily demand of supermarkets with the minimum cost in the whole transport chain within the time windows, the unaccompanied transport scenario is not the most effective one to be employed. The main reasons lie in that as long as there is an articulated vehicle dispatched from RDC and unaccompanied transport is applied. Another articulated vehicle and driver are dispatched to take over this delivery task, this leads to more dispatch costs. Moreover, both fixed cost and capitals are increased under the unaccompanied transport scenario if the transport chain is viewed as an integrated system. As a result, the more competitive delivery methods are choosing the ferry route between Portsmouth and Fishbourne and applying accompanied transport for Spar, Aldi and Morrisons. It can be inferred that accompanied transport is more cost efficient for small and medium business scale supermarket chains on IOW.

In fact, not all ferry routing between Southampton and East Cowes is able to offer unaccompanied transport service and both RDCs and supermarkets have their own working timetable. Moreover, the timetable for ferries varies with seasons and both RDCs and supermarkets have different timetable on weekends and holidays. All these can be considered as the future work.

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