Optimizing Vehicle Routing in the Food Cross-Docking System

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Abstract. The continuous rise in food quality awareness has been a key reminder for food enterprises. The intrinsic characteristic of food product quality along with adapting sustainable control measures have led to the necessity for innovation in supply chain management with the flexibility such that it can integrate the economic considerations of food cold logistics along with the environmental issues and the food quality preservation. In this paper, we address the Vehicle Routing Problem (VRP) in the cross-docking system along with food supply chains. This study considers multiple objectives to optimize vehicle routing in the cross-docking system. The first objective is to minimize the total cost consisting of logistic cost, operational costs and material handling costs considering mixed fleet of electric and conventional vehicles. The second objective is to minimize the total degradation in quality. Depending on the welfare of human resource utilization, this study recognizes the third objective to minimize the variability of the travel time of each driver. Due to the complexity of formulated model, this paper applies Non-dominated Sorting Genetic Algorithm II (NSGA-II) to obtain the optimal solution.

Keywords: food supply chain, cross-docking, vehicle routing problem, NSGA-II

1. INTRODUCTION

Customers have become more stringent on product selection and demanded more environmental-friendly goods and products (Byrne *et al*., 2013). As the pressure for taking responsibility of social and environment factors faced by the stakeholders, government, consumers and profit and non-profit organizations is continuously growing, companies have to integrate more and more sustainable processes in their policies (Seuring *et al*., 2008; Ageron *et al*., 2012). It has been reported in Kewill (2008) that logistics is the only sector where an enterprise can do the most in implementing sustainable strategies.

Cross-docking is an effective way of logistics used by many industries as it eliminates the cost of storing, which has been proved to be substantially expensive and time consuming (Hanchuan *et al*., 2013; Buijs *et al*., 2014; Ladier and Alpan, 2015). Particularly, for the supply chain of perishable foods, cross-docking has been proved to be effective by reducing quality degradation due to shortened time cycle (Validi *et al*., 2014). At the same time, cross-docking leads us to the added advantage of having full truck load (FTL) rather than wasting space in having less than truck load (LTL) using the capacity available to its fullest (Apte and Viswanathan, 2000). An optimal operating route with proper fleet of mixed types of vehicles would lead to less transportation cost and less environmental damage, which is sustainable in nature with reduced transportation time leading to reduction in food degradation.

Very recently, cross-docking was introduced for the distribution of perishable products especially in food supply chains as it proved to be time saving in a supply chain (Agustina *et al*., 2014). However, the research of cross-docking goes back to 1995, when Rohrer (1995) discussed cross-docking as a concept of material handling and distribution, even though the first literature on VRP was published in 1959. Apte and Vishwanathan (2000) demonstrated that the cross-docking improves the effective responsiveness and flexibility of distribution. Yu and Egbelu (2008) developed a scheduling model for inbound and outbound vehicles to minimize the operational time in the cross-dock using a temporary storage area located at the shipping dock.

Although, there has been an extensive research independently in the fields of vehicle routing and cross-docking, a few of researchers dealt with vehicle routing together with cross-docking. Lee *et al*. (2006) addressed the single cross-dock problem with pickup and delivery where a fixed time window was taken into account, and it was solved by using a Tabu search algorithm. Liao *et al*. (2010) solved the same problem by using a new Tabu search algorithm. Wen *et al*. (2009) used the similar pickup and delivery process and allowed an exchange of goods between the vehicles, and they solved it by using Tabu search with an adaptive memory procedure. Santos *et al*. (2011) proposed a branch and cut algorithm for a similar kind of problem. Very recently, Mousavi *et al*. (2014) considered the duality of location and VRP in a cross-docking distribution and applied a hybrid fuzzy probabilistic-stochastic programming under uncertainty to resolve the problem. Madani-Isfahani *et al*. (2014) dealt with the scheduling problem in a multiple-cross-dock system where the capacity was restricted. They also compared the solutions obtained by two meta-heuristics, simulated annealing and firefly algorithm.

This paper attempts to address the VRP of multiple cross-docks in case of a sustainable and perishable food supply chain. Inspired by the previous work (Validi *et al*., 2014), this paper considers the following multiple objectives, minimization of total cost consisting of operational and logistic cost, cross-docking product exchanging cost under constrained carbon emission due to vehicle routing, minimization of workload balance of drivers, and minimization of quality degradation during the operations. With the ideology of this paper, operation managers can introduce some ECVs without completely discarding the existing ICCVs, and at the same time, consider the cost of operations and quality of foods supplied to customers.

2. PROBLEM DESCRIPTION

This paper investigates the multiple-objective VRP for distribution center with multiple cross-docks in a food supply chain. In the cross-docking system, pickup/inbound vehicles transport the food products from suppliers to the distribution center. After receiving the food products, they are sorted according to the demands ordered by customers, and then delivery/outbound vehicles drops them at the specific demand points. The distribution center works on a system with multiple cross-docks where no inventory is held, and the numbers of gates both for pickup and delivery are equal.

Each cross-docking gate is allotted with certain numbers of pickup vehicles and delivery vehicles. A vehicle operates only if it is allocated to a cross-dock, otherwise it remains idle. Similarly, a cross-docking gate remains idle if no vehicle is allocated to it. Each operating vehicle visits certain number of supply nodes (suppliers) or delivery nodes (customers or customer zones), where the perishable foods are loaded or unloaded. The system handles perishable food products suffering deterioration in quality. In this paper, it is assumed that the food products suffer no further deterioration in the time spent in the distribution center because the cross-docking time is relatively short. In addition, the initial quality levels of all food products are assumed to be same. The deterioration rates differ by the type of vehicles used to transport the food products. Each supply node houses a single kind of product that to one of its own kind. However, the demand nodes may have a stipulated demand of various kinds of products in various quantities.

After visiting all of the supply nodes in a pickup route, the pickup vehicle returns back to the distribution center where the food products are unloaded and sorted, and may be moved through a material handling system. The material handling system is responsible to move goods loaded to outbound gates based on the delivery vehicles allotted to the particular gates, which are further governed based on the delivery nodes visited by the delivery vehicles. In this paper, two types of vehicles, ICCV and ECV, are used to transport products. Each vehicle individually can be either of the two types making the logistics system to have a heterogeneous fleet of vehicles. Each driver working in the cross-dock operates as per a schedule allotted to them in advance. As per the human resource policy of firms, the workload is equalized among all the workers.

3. MODEL

3.1 Notation

Parameters:

N_p Number of pickup nodes.

N_d Number of delivery nodes.

NV_p Number of pickup vehicles available for use.

NV_d Number of delivery vehicles available for use.

v Type of vehicle; $v=1$ represents vehicle is ICCV, $v=2$ represents vehicle is ECV.

N_{cd} Number of cross-docks available in the distribution center.

C_d Cost of operating a cross-dock based on number of pickup and delivery vehicles used.

C_h Cost of handling product exchange at cross-docks based on per unit of product.

C_{OP}^m Operating cost of pickup vehicle m.

C_{OD}^l Operating cost of delivery vehicle l.

DS_{ab}^{pick} Distance between pickup nodes a and b, where $a/b=0$ denotes the distribution center.

DS_{ab}^{delv} Distance between delivery nodes a and b, where $a/b=0$ denotes the distribution center.

CP_{ab}^s Transportation cost of pickup vehicle type s from pickup node a to node b.

CD_{ab}^s Transportation cost of delivery vehicle type s from delivery node a to node b.

rp_p^s Deterioration rate for product *p* for pickup vehicle type s based on per minute of travel.

rd_p^s Deterioration rate for product *i* for delivery vehicle type s based on per minute of travel.

CEP_{ab}^s Carbon emission from pickup node a to node b for pickup vehicle type s.

CED_{ab}^s Carbon emission from delivery node a to node b for delivery vehicle type s.

QL_i Quantity of food product i loaded at pickup node i.

QU_i^p Quantity of food product p to be unloaded at delivery node i.

QP_{ab} Quantity of food product transported from pickup node a to node b.

QD_{ab} Quantity of food products transported from delivery node a to node b.

$QP_{\max}$ Capacity of pickup vehicle.

$QD_{\max}$ Capacity of delivery vehicle.

$CE_{\max}$ Maximum carbon emission that is allowed.

TH_{pick} Time horizon for pickup.

TH_{delv} Time horizon for delivery.

TH_{total} Total time horizon.

CDK_d The d-th cross-dock.

$Tpick_{ab}^s$ Estimated travel time between pickup node a and node b for type s pickup vehicle including loading time and unloading time.

$Tdel_{ab}^r$ Estimated travel time between delivery node a and node b for type s delivery vehicle.

$\mathbf{S}_{pick}$ Set of pickup (supply) nodes.

$\mathbf{S}_{delv}$ Set of delivery (demand) nodes.

$\mathbf{S}_{CDK}$ Set of cross-docks in the distribution center.

Decision variables:

$$X_{ab}^m = \begin{cases} 1, & \text{if pickup vehicle } m \text{ goes from pickup node } a \text{ to node } b \\ 0, & \text{otherwise} \end{cases}$$

$$Y_{ab}^l = \begin{cases} 1, & \text{if delivery vehicle } l \text{ goes from pickup node } a \text{ to node } b \\ 0, & \text{otherwise} \end{cases}$$

$q_{d_a d_b}^p =$ Quantity of product p requires material handling from cross-dock d_a to d_b.

$$TP_m^s = \begin{cases} 1, & \text{if pickup vehicle } m \text{ is of type } s. \\ 0, & \text{otherwise} \end{cases}$$

$$TD_l^r = \begin{cases} 1, & \text{if delivery vehicle } l \text{ is of type } s. \\ 0, & \text{otherwise} \end{cases}$$

$$PC_{d_a}^m = \begin{cases} 1, & \text{if pickup vehicle } m \text{ is allocated to cross-dock } d_a. \\ 0, & \text{otherwise} \end{cases}$$

$$DC_{d_a}^l = \begin{cases} 1, & \text{if delivery vehicle } l \text{ is allocated to cross-dock } d_a. \\ 0, & \text{otherwise} \end{cases}$$

3.2 Objective functions

Total cost:

The total cost is minimized in this paper, and it is expressed in Eq. (1).

$$\sum_{a=0}^{N_p}\sum_{b\neq a,b=0}^{N_p}\sum_{m=1}^{NV_p}\sum_{s=1}^{v} Tp_m^s \times CP_{ab}^s \times X_{ab}^m + \sum_{a=0}^{N_d}\sum_{b\neq a,b=0}^{N_d}\sum_{l=1}^{NV_d}\sum_{r=1}^{v} Td_l^r \times CD_{ab}^s \times Y_{ab}^l + \sum_{a=1}^{N_p}\sum_{m=1}^{NV_p} C_{OP}^m \times X_{0a}^m + \sum_{a=1}^{N_d}\sum_{l=1}^{NV_d} C_{OD}^l \times Y_{0a}^l + C_h \sum_{d_a=1}^{N_{cd}}\sum_{d_b\neq d_a,d_b=1}^{N_{cd}}\sum_{p=1}^{N_p} q_{d_a d_b}^p + C_d \sum_{d_a=1}^{N_{cd}}\sum_{m=1}^{NV_p} PC_{d_a}^m \sum_{a=1}^{N_p} X_{0a}^m + C_d \sum_{d_a=1}^{N_{cd}}\sum_{m=1}^{NV_d} DC_{d_a}^l \sum_{a=1}^{N_d} Y_{0a}^m \quad (1)$$

Load balance:

The second objective is to minimize the load balance for all of the drivers, and it is expressed as

$$\sum [std.dev(Tpick_{ab}^s \times TP_m^s \times X_{ab}^m) + std.dev(Tdel_{ab}^r \times TD_l^r \times Y_{ab}^l)] \quad (2)$$

Quality deterioration:

The third objective function is to minimize the quality deterioration of food products during the transportation in pickup and delivery. The objective function of quality deterioration takes the form as

$$\sum_{b\neq a,b=0}^{N_p}\sum_{a=0}^{N_p}\sum_{m=1}^{NV_p} rp_a^s \times TP_m^s \times Tpick_{ab}^s \times X_{ab}^m \times QL_a + \sum_{i=1}^{N_p}\sum_{a=0}^{N_d}\sum_{b\neq a,b=0}^{N_d}\sum_{l=1}^{NV_d} x_i^r \times TD_l^r \times Tdel_{ab}^r \times Y_{ab}^l \times QU_b^a \quad (3)$$

3.3 Constraints

$$\sum_{a=0,a\neq b}^{N_p}\sum_{m=1}^{NV_p} X_{ab}^m = 1 \quad \forall b \quad (4)$$

$$\sum_{b=0,b\neq a}^{N_p}\sum_{m=1}^{NV_p} X_{ab}^m = 1 \quad \forall a \quad (5)$$

$$\sum_{a=0,a\neq b}^{N_d}\sum_{l=1}^{NV_d} Y_{ab}^l = 1 \quad \forall b \quad (6)$$

$$\sum_{b=0,b\neq a}^{N_d}\sum_{l=1}^{NV_d} Y_{ab}^l = 1 \quad \forall a \quad (7)$$

$$\sum_{a=0}^{N_p} X_{ac}^m - \sum_{b=0}^{N_p} X_{cb}^m = 0 \quad \forall c,m \quad (8)$$

$$\sum_{a=0}^{N_d} Y_{ac}^l - \sum_{b=0}^{N_d} Y_{cb}^l = 0 \quad \forall c,l \quad (9)$$

$$\sum_{m=0}^{NV_p}\sum_{a=1}^{N_p} X_{0a}^m \leq NV_p \quad (10)$$

$$\sum_{l=0}^{NV_d}\sum_{a=1}^{N_d} Y_{0a}^l \leq NV_d \quad (11)$$

$$QL_p = \sum_{i=1}^{N_d} QU_i^p \quad \forall p \quad (12)$$

$$q_{d_a d_b}^p = \sum_{b=1}^{N_d}\sum_{l=1}^{NV_d} DC_{d_a}^l QU_b^p \sum_{a=0}^{N_d} Y_{ab}^l \quad \forall p, d_a, d_b \quad (13)$$

$$QP_{bc} - QP_{ab} = \begin{cases} QL_b & b \in S_P \\ -\sum_{a-1}^{N_p} QL_a & b \in S_T \end{cases} \quad (14)$$

$$QD_{ab} - QD_{bc} = \begin{cases} \sum_{a=1}^{N_p} QU_b^a & b \in S_D \\ \sum_{b=1}^{N_d}\sum_{a=1}^{N_p} QP_{ab} & b \in S_T \end{cases} \quad (15)$$

$$\sum_{s=1}^{v}\sum_{m=1}^{NV_p}\sum_{b=0}^{N_p}\sum_{a=0}^{N_p} TP_{ab}^s \times TP_m^s \times X_{ab}^m \leq TH_{pick} \quad (16)$$

$$\sum_{r=1}^{v}\sum_{l=1}^{NV_d}\sum_{b=0}^{N_d}\sum_{a=0}^{N_d} TD_{ab}^r TD_l^r Y_{ab}^l \leq TH_{delv} \quad (17)$$

$$\sum_{s=1}^{v}\sum_{m=1}^{NV_p}\sum_{b=0}^{N_p}\sum_{a=0}^{N_p} TP_{ab}^s \times TP_m^s \times X_{ab}^m + \sum_{r=1}^{v}\sum_{l=1}^{NV_d}\sum_{b=0}^{N_d}\sum_{a=0}^{N_d} TD_{ab}^r \times TD_l^r \times Y_{ab}^l \leq TH_{tot} \quad (18)$$

$$\sum_{s=1}^{v}\sum_{m=1}^{NV_p}\sum_{b=0}^{N_p}\sum_{a=0}^{N_p} CEP_{ab}^s \times TP_m^s \times X_{ab}^m + \sum_{r=1}^{v}\sum_{l=1}^{NV_d}\sum_{b=0}^{N_d}\sum_{a=0}^{N_d} CED_{ab}^r \times TD_l^r \times Y_{ab}^l \leq CE_{\max} \quad (19)$$

$$\sum_{a=1}^{N_{cd}} PC_{d_a}^m = 1 \quad \forall m \quad (20)$$

$$\sum_{a=1}^{N_{cd}} DC_{d_a}^l = 1 \quad \forall l \quad (21)$$

$$\sum_{a=1}^{N_p} X_{a0}^m \times QP_{a0} \leq QP_{\max} \quad \forall m \quad (22)$$

$$\sum_{a=1}^{N_d} Y_{a0}^l Q \times D_{a0} \leq QD_{\max} \quad \forall l \quad (23)$$

4. The NSGA-II Based Approach

For the methods dealing with multi-objective problems, NSGA-II (Deb *et al*., 2002) is one of the effective multi-objective genetic algorithms (GAs). The procedure of NSGA-II is briefly presented as follows (Deb *et al*., 2002).

Initialization: The population is initialized as usual based on the constraints and the given problem range.

Non-dominated sorting: The initialized solutions are sorted based on non-dominance into frontiers such that the solutions in the first frontier dominate all solutions in other frontiers, and the solutions in the second frontier are dominated by the first and they dominate the rest of frontiers and so on. The solutions based on their frontier are given a dominance rank.

Crowding distance: The crowding distance finds the Euclidian distance between individuals for all the objectives in the multi-dimensional space.

Selection: A one-to-one comparison is carried out for each individual with other individuals, where a preference of frontier rank is given first and for the same frontier rank the solution with higher crowding distance or as classified as more diverse is selected.

Crossover and mutation: The selected individuals are thereby put into crossover and mutation for generation of new solutions. The crossover and mutation are done depending on how the initial individuals are generated.

Recombination and selection: The new children generated are recombined with existing population, and selection is once again performed and the solution set is limited to the original size before moving on to the next generation.

Based on the above basic procedure of NSGA-II and the mathematical model presented in Section 3, the NSGA-II based optimization approach is developed to obtain the optimal solution.

5. Examples and Results

In this paper, we apply the modelling approach in a scenario discussed by Wen *et al*. (2009) and Agustina *et al*. (2014) to obtain the optimal solutions by using the optimization approach based on NSGA-II. We handled this problem in two test cases. The solution procedure is coded in MATLAB 2012b on a 2.33 GHz 3rd Generation Core i3 processor with 4GB RAM.

We consider for simplicity that conventional vehicles travel at 70km/hr. at an average speed throughout its entire journey with a transportation cost of $3/Km including the driver wages, whereas the electric vehicles an average speed of 40 Km/hr. throughout its journey with a transportation cost of $1/Km. The estimated time is thereafter calculated for each example. As per U.S. Environmental Protection Agency (2014), 255 grams of CO_2 emissions are released by a conventional diesel vehicle by travel of 1 Km, and for an electric vehicle inspite being plug in hybrid the amount of CO_2 emissions from tailpipe is too less to be considered in this particular scenario.

Table 1: Settings of examples.

Parameters	Example 1	Example 2
N_p	5	15
N_d	10	25
NV_p	3	5
NV_d	5	7
v	2	2
N_{cd}	3	5
C_d	350	350
C_h	5	5
C_{OP}^m	100	100
C_{OD}^l	50	50
DS_{ab}^{pick} (in kms)	Uniform (100,250)	Uniform (100,250)
DS_{ab}^{delv} (in kms)	Uniform (20,100)	Uniform (20,100)
rp_p^s	Uniform (0.1,0.5)	Uniform (0.1,0.5)
rd_p^s	Uniform (0.1,0.5)	Uniform (0.1,0.5)
QU_i^p	Uniform (10,75)	Uniform (10,75)
$QP_{\max}$	500	500
$QD_{\max}$	200	200
$CE_{\max}$	15kg	25kg
TH_{pick} (minutes)	75	75
TH_{delv} (minutes)	60	60

6. Conclusions

Integrating a wider consideration of economic factors, perishability and load balancing at the same time is an essential issue in the food supply chain. The cross-docking system can improve the efficiency of supply chain. Therefore, this paper addresses the VRP in the cross-docking system along with food supply chains. This paper considers multiple objectives to optimize vehicle routing in the cross-docking system, and developed a NSGA-II based optimization approach to resolve the multiple-objective mathematical model. While the model presented for the problem addressed in this paper still remains NP-hard, an extension of various computational experiments is required over a number of various scales of different sectors to provide model generality. In addition, the model does not consider any variability in demand and limits to a single period approach. It is suggested that future research which integrates multi-period stochastic dynamic programming with the existing modelling approach would be a valuable extension of this study. In addition, we consider no queue at the cross-dock gates. In further research, we can integrate queueing system to the model.

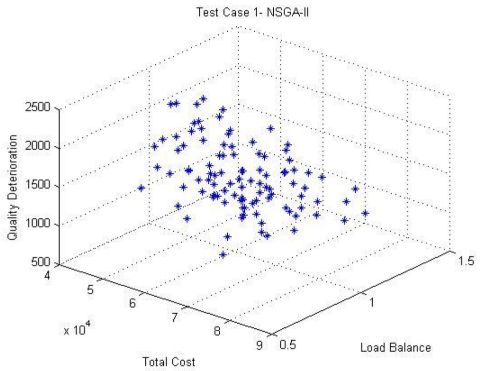

Figure 1: Pareto frontier for Example 1.

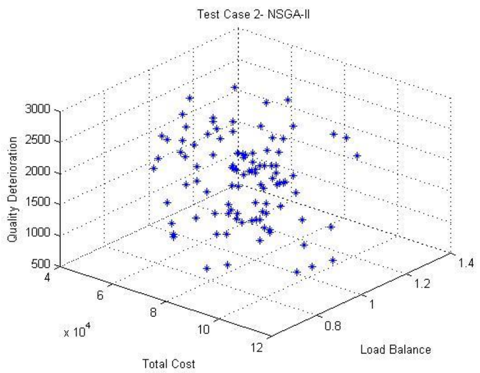

Figure 2: Pareto frontier for Example 2.

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