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A stochastic dairy transportation problem considering collection and delivery phases

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ABSTRACT

Based on the dairy cooperatives in Indonesia, this study formulates a stochastic programming model to handle the milk collection and delivery process with the maximum route duration limitation, the external cooling facility option, and travel time uncertainty. Besides, the local practice of sharing the fleet for both collection and delivery further complicates the decision. A set covering-based solution approach is used, due to its flexibility in handling complicated operational requirements and alignment with the decision environment. According to the numerical experiment, the proposed solution algorithm can provide quality solutions with a reasonable computational time for the cooperative operators.

1. Introduction

It has been identified that transportation can be the most important decision among various logistics activities due to its high share of the overall logistics cost. For example, one estimate shows that the transportation cost can account for about 30% of the product price (Apte and Viswanathan, 2000). The concern over the cost of transportation is particularly serious in developing countries with relatively poor infrastructure and high operating costs.

This research was initiated by the decision problem in the dairy industry in Indonesia, where most of the dairy farmers belong to cooperatives, Gabungan Koperasi Susu Indonesia (GKSI), which manage the transportation, processing, and sales of the milk for their members. For example, one large GKSI, KPBS Pangalengan in Bandung, Java, operates one first-tier central treatment facility and a system of five external cooling units to serve its members associated with 33 milk collection points (Wardhani and Kusnadi, 2010). After being collected from the farmers, the milk is sent to the central treatment facility to be inspected, tested, pre-processed, and properly stored at a low temperature to maintain its quality. In order to collect the raw milk from the farmers and deliver the processed milk to the plants, the cooperatives normally maintain their own fleet of trucks. However, the milk trucks are usually not equipped with cooling instruments due to the cost concerns. Thus, the operators have to battle with time to finish the collection within a limited period of time to avoid a deterioration in quality caused by bacteria-related issues. One possible way to alleviate the problem is to utilize an external cooling facility (ECF) located near the dairy farmers, of which there may be in remote areas, to improve the efficiency. Otherwise, the truck capacity utilization needs to be sacrificed to meet the limitations imposed on the maximum route duration time.

As freshness is surely one of the main selling points of dairy products, the operators need to quickly deliver the raw milk collected to the next stage of the dairy supply chain, the plants of the dairy product companies to manufacture packaged milk, cheese, ice cream and related products. In particular, there may exist a cut-off time at the plants, given their pre-set production schedules for the various dairy products. Normally, the same fleet of trucks is used for both the milk collection and factory delivery phases to minimize

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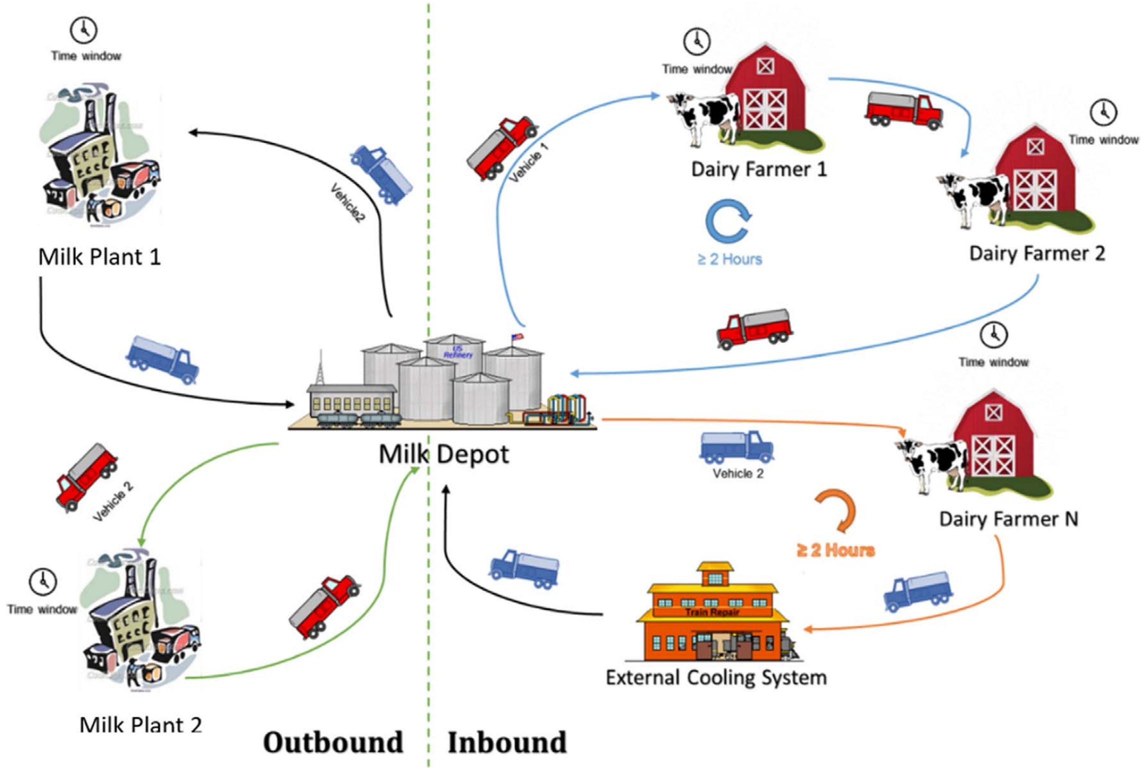

Fig. 1. Illustration of the collection and delivery activities of the dairy cooperatives.

the total asset investment and maintain full operational control. However, the operator then needs to plan the fleet usage in an integrated way so as to satisfy the operational requirements of both phases and to minimize the overall transportation cost. The collection and delivery phases for the dairy cooperatives in this study are illustrated in Fig. 1.

Given the perishable product nature and the concern over the milk quality, the route duration time must also be addressed from the aspect of transportation time uncertainty. Unpredictable factors, such as traffic congestion, road maintenance, and weather conditions, can extend the travel time, causing the whole vehicle load to risk spoilage. In order to resolve this issue, the stochastic feature of travel time is taken into account, and chance-based operational requirements are introduced into the model to prevent the tight milk collection schedule from becoming excessively vulnerable.

The decision problem in this study can be thought of as a variant of the Dairy Transportation Problem (DTP), first introduced by Lahrichi et al. (2015). Some similar features have been shared by the two studies, such as that both the collection and delivery of raw milk are considered. One fundamental difference is that the collection and delivery activities are integrated in one truck route in Lahrichi et al. (2015). However, in this study, collection and delivery are two distinct phases as the required cooling, testing, and processing at the central treatment facility prevent these two activities from being executed by one single truck. Due to sharing the same fleet, the two phases of collection and delivery are still highly interdependent.

In terms of the solution method, unlike most studies dealing with routing decisions, the study does not choose any meta-heuristic; instead, a set covering problem (SCP)-based approach is chosen, mainly due to its flexibility in handling complicated problem features, including the stochastic travel time. In addition, the SCP approach nicely fits the decision environment in the dairy industry, in which a cooperative serves its members with fixed locations; however, their production quantity varies due to the unexpected conditions, such as poor milk quality, farm breakdowns, livestock sickness, or even normal day-to-day variations (Lahrichi et al., 2015). If the historical route information is well stored in a database, the SCP-based solution approach can easily take it into account to improve the solution quality.

In summary, there are two potential contributions proposed in this study. First, we have extended the original DTP model by taking into account several important problem features, namely, the stochastic travel time, the external cooling facility, and the integration of truck usage planning for different phases to advance the research frontier of this specific type of problem. Second, we have developed an SCP-based heuristic algorithm that can tackle the complicated operational requirements and provide the decision support to the dairy cooperatives in Indonesia or in countries with a similar environment. The remainder of this paper is organized as follows. Section 2 presents a literature review of the dairy product delivery and routing as well as the scheduling research related to perishable products. The problem description, the novel deterministic integer programming (IP) model combining the collection and delivery phases, and SCP-based formulation are presented in Section 3. The heuristics-based approach for getting good results is described in Section 4. Section 5 contains a numerical experiment to validate the proposed solution algorithm, and is followed by the conclusions in Section 6.

2. Literature review

We first review several past research works related to the logistics management of dairy products as well as some that are related to perishable goods. Based on prior studies, transportation planning for dairy products can be broadly categorized into the production stage and the distribution stage. In this study, collecting raw material from natural sources and delivering it to the next-step facilities (such as plants) for further processing to make it ready for consumption belongs to the production stage. On the other hand, the distribution stage deals with distributing the final dairy products to the various retailing channels for the end consumers.

In the production stage, the transportation plan first has to deal with the picking up of raw milk from the suppliers. Given the perishable characteristic of such a product, a time limitation on the road can be the focus at this stage if the fleet used for collection is not equipped with the proper capability to prevent spoilage. Sankaran and Ubgade (1994) studied the case in India, in which the milk's life time on the road is considered. In particular, it is mentioned that the milk's life time tends to get longer in winter due to the lower temperatures. Basnet et al. (1997) studied the scheduling for a milk collection problem in New Zealand. They particularly emphasized the availability of a facility for pumping the milk from the tanker so as to address the waiting issue due to a facility shortage. Caramia and Guerriero (2010) studied a milk collection problem that included some small farms that were inaccessible to large vehicles. Moreover, they also addressed the issues caused by the different trucks with multiple compartments suitable for different kinds of milk. Based on the particular case of the province of Quebec, Lahrichi et al. (2015) introduced the dairy transportation problem (DTP), which sought to determine the best routes for collecting milk from farms and delivering it to processing plants. In particular, a high-level aspect was chosen to address strategic issues such as contract design. A generalized tabu search algorithm was developed to solve the problem. They also provided a scenario analysis to improve the overall solution. Their study was further extended by Masson et al. (2016), who considered a long planning horizon (up to a year) and proposed a two-stage method based on an adaptive large neighborhood search. Lastly, Sethanan and Pitakaso (2016) developed differential evolution metaheuristics to solve the milk collection problem with a heterogeneous fleet and different collection centers. Their research included the truck cleaning and sanitizing cost and truck traveling cost as components of the objective function.

In the distribution stage, finished dairy products are distributed to the retailers so as to be accessible to the end consumers. Adenso-Diaz et al. (1998) designed a hierarchical system for dairy product distribution in Spain. They modeled the distribution process as a traveling salesman problem with time windows and then applied a local search algorithm to solve the problem. Tarantilis and Kiranoudis (2001) studied the plan to distribute milk from the milk company to the consumers for a case in Greece. They proposed a fast and robust threshold accepting-based algorithm to solve the associated routing problem, in which the fleet is heterogeneous and fixed. Hsu et al. (2006) studied a routing problem for perishable food delivery, which was modeled by a random process, and the objective was to minimize cost, inventory, and energy. Segura et al. (2014) developed a maximum-coverage location model to expand the coverage of milk distribution in Mexico.

This study certainly belongs to the category of the production stage. However, in particular, there are two interrelated phases of collection and delivery operations, given the central treatment facility in the middle. Among all the prior studies, Lahrichi et al. (2015) and Masson et al. (2016) appear to be the only research works that consider both the raw milk collection routing from the depot to the dairy farmers and the milk delivery to the milk plants. However, in the so-called Dairy Transportation Problem (DTP) in their studies, these two transportation activities are performed by one single truck route, without any stopping for extra operations. Thus, the associated DTP can in general be thought of as a variant of the classic vehicle routing problem (VRP). On the other hand, the problem in this study has two clear phases of transportation activities, namely, collection and delivery (or later possibly referred to as inbound and outbound transportation from the aspect of the central treatment facility or the depot). Nonetheless, the interdependency of the two phases, due to sharing the same fleet, creates one of the challenges for solving the problem.

In addition to this major difference related to the multiple-phase operations, another important problem that arises is that the route duration time for the collection phase is limited to a certain upper limit to ensure the quality of the milk, given that the trucks do not come with cooling capability. In particular, this study further considers the option of using external cooling facility, a facility established relatively near the dairy farmers to extend the allowed route duration time. These features also make the problem in this study significantly different from typical VRPs.

Finally, in line with the concern regarding the milk's quality, travel time uncertainty must be viewed as a real-world experience that shows that travel time is subject to large fluctuations and can be difficult to control. This concern draws our attention to the literature on the stochastic SVRP, for which Gendreau et al. (1996) serves as an excellent survey. Recent studies that focus on the uncertainty of travel time can also be found in Kenyon and Morton (2003), Russell and Urban (2008), Li et al. (2010), and Tas et al. (2014).

To sum up, although sharing several important features with the DTP first introduced in Lahrichi et al. (2015), the research problem in this paper is significantly different from the decision problems in past works related to the logistics operations in the dairy industry. This unique research position in problem modeling as well as the development of the solution approach that is particularly suitable for the context should be able to justify the contributions of this study. The problem is formally defined in the next section by an IP formulation, which is followed by the section that presents the solution approach.

3. Problem definition and formulation

In this study, there are two phases of operations, namely, the collection and delivery of milk. The collection activity is about gathering the raw milk from farmers and getting it to the central treatment facility, and the delivery activity is about transporting the pre-processed milk from the treatment facility to the plants for the final dairy product production. The first sub-section describes the

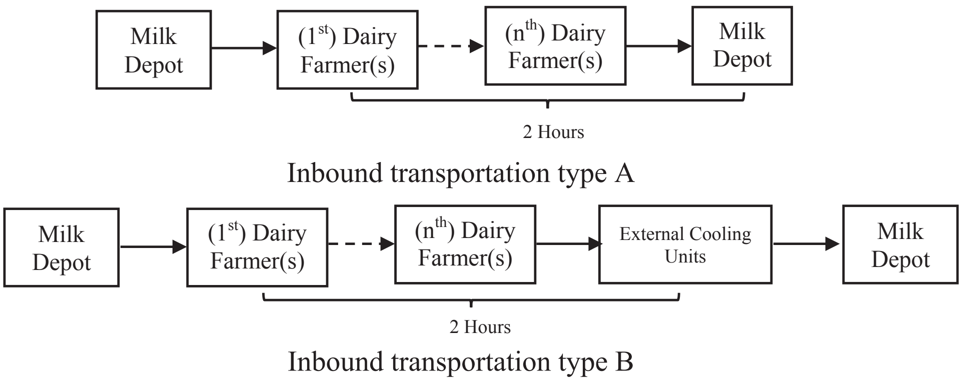

Fig. 2. Inbound transportation with and without external cooling units.

detailed activities of the two phases, and the second sub-section presents the associated deterministic version of the IP formulation. Finally, the SCP-based formulation for incorporating the stochastic features is provided in the third sub-section.

3.1. Operations of collection and delivery phases

The collection activity, or the inbound transportation, deals with the collection of raw milk from the dairy farmers by the trucks from the depot. There are certain time windows associated with the dairy farmers for collecting the milk. As the trucks are usually not equipped with cooling equipment, the pick-up operation must be accomplished within a limited time frame to ensure the milk's quality. Thus the trucks must come back to the depot within the time limit (*e.g.*, two hours) and have the milk inspected, tested, pre-processed, and properly stored at a low temperature before being sent on to a plant. Alternatively, the truck may go to an external cooling unit within the time limitation to obtain the temporary cooling treatment before it eventually returns to the depot for the required processes. For this option, the route travel time can be extended so as to cover more demand nodes and improve the utilization of the truck capacity. The two options of the inbound transportation are shown in Fig. 2.

Outbound transportation deals with the journey of the pre-processed milk to the milk plants. The travel time limitation and uncertainty is not imposed on the outbound transportation as the delivery is made by direct shipping (no milk-run type routing), and the distance is relatively short, leading to an extremely small chance of violating the time frame. However, the time windows of the plants are imposed. Thus, the operator still needs to deliver processed milk as quickly as possible to meet the requirement of the plants. The quantity required by a plant is relatively large when compared with the production quantity of a dairy farmer or the capacity of a truck. Thus, the outbound truck can be dispatched only if a sufficient amount of milk has been accumulated. This part of the operation is a little like the cross-docking at a distribution center. However, the same fleet of trucks is used for both inbound and outbound activities, and the interdependence between them must be carefully addressed.

3.2. Deterministic model formulation

For the dairy transportation described in the previous sections, we develop the following integer linear programming model, in which there are two major decision variables. The first is the standard VRP-type flow decision, x_{jk}^{v}, which indicates, using a value of 1, that the vehicle v moves from node j to node k for the inbound phase. The second decision variable concerns the milk transfer, s_{vw}^{i}, which defines the amount of milk transferred from vehicle v in the inbound phase to vehicle w in the outbound phase to satisfy the demand at milk plant i.

Sets and Indexes:

j,k,l	Indexes of inbound dairy farmer nodes
i	Indexes of outbound milk plant nodes
v	Indexes of inbound vehicles
w	Indexes of outbound vehicles
N	Set of dairy farmer nodes
N_C	Set of ECF nodes
N_O	Set of dairy farmer nodes and milk depot
N_B	Set of dairy farmers and ECF nodes
N_E	Set of ECF nodes and milk depot
N_A	Set of dairy farmer nodes, ECF nodes, and milk depot
N_I	Set of milk plant nodes
N_J	Set of milk plant nodes and milk depot
V	Set of vehicles

Variables:

x_{jk}^v	Binary variable indicating that vehicle v travels from j to k in the inbound activity
s_{vw}^i	Amount transferred from vehicle v in the inbound activity to vehicle w for milk plant i in the outbound operation
y_j^v	Accumulated load of inbound vehicle v at location j
a_j^v	Arrival time of inbound vehicle v at node j, a dairy farmer or an ECF
b_i^w	Arrival time of outbound vehicle w at plant node i
u^v	Accumulated route travel time of inbound vehicle v at the depot (the case without the ECF visiting) or the ECF (if visited)
p^v	Arrival time of vehicle v at the depot for the end of the inbound activity
o^v	Binary variable indicating whether inbound vehicle v visits an ECF
z_{wv}	Binary variable indicating whether a transfer has taken place from inbound vehicle v to outbound vehicle w
c_i^w	Binary variable indicating whether outbound vehicle w travels to plant i

Parameters:

G_j	Raw milk amount at inbound farmer node j
D_i	Demand size at outbound milk plant node i
Q^v	Capacity limit of vehicle v
T_{jk}	Travel time from j to k, including the loading time at j and the travel time
E_j	Earliest time of inbound node j
L_j	Latest time of inbound node j
E_i^o	Earliest time of outbound node i
L_i^o	Latest time of outbound node i
H	The maximum route time in a tour
M	A sufficient big number (*e.g.*, the length of the planning horizon)

Objective Function:

$$\min \sum_{j\in N_A}\sum_{k\in N_A}\sum_{v\in V} x_{jk}^v T_{jk} + \sum_{i\in N_I}\sum_{w\in V} c_i^w T_{0i} \tag{1}$$

Subject to

$$\sum_{j\in N_O}\sum_{v\in V} x_{jk}^v = 1 \quad \forall\, k\in N \tag{2}$$

$$\sum_{j\in N_A}\sum_{v\in V} x_{kj}^v = 1 \quad \forall\, k\in N \tag{3}$$

$$\sum_{k\in N_A} x_{jk}^v - \sum_{l\in N_O} x_{lj}^v = 0 \quad \forall\, j\in N, v\in V \tag{4}$$

$$\sum_{j\in N} x_{0j}^v \leqslant 1 \quad \forall\, v\in V \tag{5}$$

$$\sum_{i\in N_I} c_i^w \leqslant 1 \quad \forall\, w\in V \tag{6}$$

$$\left(\sum_{j\in N} x_{jk}^v\right) - x_{k0}^v = 0 \quad \forall\, k\in N_C, v\in V \tag{7}$$

$$y_j^v \geqslant y_k^v + G_j + (x_{kj}^v - 1)Q^v \quad \forall\, k\in N_A, j\in N_B, v\in V \tag{8}$$

$$y_j^v \leqslant Q^v \quad \forall\, j\in N_B, v\in V \tag{9}$$

$$y_j^v \leqslant \sum_{k\in N}\sum_{l\in N_O} x_{lk}^v G_k \quad \forall\, j\in N_B, v\in V \tag{10}$$

$$\sum_{w\in V}\sum_{i\in N_I} s_{vw}^i \leqslant \sum_{k\in N}\sum_{j\in N_O} x_{jk}^v G_k \quad \forall\, v\in V \tag{11}$$

$$\sum_{w\in V}\sum_{v\in V} s_{vw}^i - D_i \geqslant 0 \quad \forall\, i\in N_I \tag{12}$$

$$\sum_{i\in N_I}^{N_I} c_i^w \leqslant 1 \quad \forall\, w\in V \tag{13}$$

$$\sum_{v \in F} s_{vw}^{i} \leqslant c_i^{w} Q^{w} \quad \forall\ w \in V, i \in N_I \tag{14}$$

$$\sum_{i \in N_I} s_{vw}^{i} \leqslant z_{wv} Q^{v} \quad \forall\ v, w \in V \tag{15}$$

$$a_k^{v} \geqslant a_j^{v} + T_{jk} + (x_{jk}^{v} - 1)M \quad \forall\ k \in N_B, j \in N_A, v \in V \tag{16}$$

$$E_j \leqslant a_j^{v} \leqslant L_j \quad \forall\ j \in N, v \in V \tag{17}$$

$$E_i^{o} \leqslant b_i^{w} \leqslant L_i^{o} \quad \forall\ i \in N_I, w \in V \tag{18}$$

$$\sum_{j \in N_C} x_{j0}^{v} = o^{v} \quad \forall\ v \in V \tag{19}$$

$$u^{v} \geqslant (x_{j0}^{v} - 1)M + a_j^{v} + T_{j0}(1 - o^{v}) \quad \forall\ j \in N_B, v \in V \tag{20}$$

$$u^{v} - a_j^{v} + (x_{0j}^{v} - 1)M \leqslant H \quad \forall\ j \in N, v \in V \tag{21}$$

$$p^{v} \geqslant a_j^{v} + T_{j0} + (x_{j0}^{v} - 1)M \quad \forall\ j \in N_B, v \in V \tag{22}$$

$$b_i^{w} - T_{0i} \geqslant p^{v} + (z_{wv} - 1)M \quad \forall\ v, w \in V, i \in N_I \tag{23}$$

$$b_i^{w} - T_{0i} \geqslant p^{w} + (z_{wv} - 1)M \quad \forall\ v, w \in V, i \in N_I \tag{24}$$

$$x_{jk}^{v} \in \{0,1\} \quad \forall\ v \in V, j, k \in N_A \tag{25}$$

$$s_{vw}^{i} \geqslant 0 \quad \forall\ v, w \in V, i \in N_I \tag{26}$$

$$y_j^{v}, a_j^{v} \geqslant 0 \quad \forall\ j \in N, v \in V \tag{27}$$

$$b_i^{w} \geqslant 0 \quad \forall\ i \in N_I, w \in V \tag{28}$$

$$u^{v}, p^{v} \geqslant 0 \quad \forall\ v \in V \tag{29}$$

$$p^{w} \geqslant 0 \quad \forall\ w \in V \tag{30}$$

$$z_{wv} \in \{0,1\} \quad \forall\ v, w \in V \tag{31}$$

$$c_i^{w} \in \{0,1\} \quad \forall\ i \in N_I, w \in V \tag{32}$$

$$o^{v} \in \{0,1\} \quad \forall\ v \in V \tag{33}$$

The objective function (1) is to minimize the total time needed to perform inbound and outbound activities. Constraints (2) and (3) require that each inbound node (farmer) be visited by one entering vehicle and one leaving vehicle so as to ensure that its demand is served. Constraint (4) is the flow conservation constraint for the vehicles. Constraint (5) describes the requirement that a vehicle cannot be used twice for the inbound activity. Likewise, Constraint (6) is a similar constraint for the outbound activity. Given these constraints, it is impossible for any vehicle to complete multiple routes in one phase. However, if needed, a vehicle can be used for both the inbound and outbound phases. Constraint (7) shows that any vehicle needs to go back to the milk depot after visiting an ECF node.

Constraints (8)–(15) are the constraints related to capacity and load. Constraint (8) defines the accumulated load after serving a node (represented by j) for a vehicle (represented by v) for the inbound phase. Constraint (9) ensures that each vehicle v can only pick up milk for which it has the capacity, Q^v. Constraint (10) further requires that the accumulated load be exactly the same as what has been picked up, and not just less or equal to the capacity as specified by Constraint (9). Otherwise, if only Constraint (8) is applied, the value of the variable representing the accumulated load can be larger than the actual quantity picked up, resulting in the milk plants in the outbound phase being served with milk that does not exist. Constraint (11) ensures that for each inbound vehicle (represented by v), the total quantity of milk transferred to the milk plants (with the index i) via the outbound vehicles (with the index w) must not exceed the total amount of milk that it has picked up in the inbound activity. Constraint (12) ensures that each milk plant (with the index i) is served with a sufficient amount of milk (D_i), which is transferred from inbound vehicles to outbound vehicles. Constraint (13) is related to the milk plant assignment decision of the outbound vehicles. Constraint (14) is the capacity constraint of the outbound vehicle, in terms of the total quantity transferred. Constraint (15) defines the binary variable, z_{wv}, which indicates whether or not there is a transfer between one pair of inbound and outbound vehicles (represented by v and w) and links it to the transfer quantity variable.

Constraints (16)–(24) are the time-related constraints. Constraint (16) determines the accumulated travel time after arriving at an inbound supply node (represented by k), including link travel time, node processing time and idle time. Constraints (17) and (18) describe the time window restriction for the inbound and outbound phases, respectively. Constraints (19)–(21) ensure that the travel time on one route should be less than the time limitation specified in relation to the concern over the deterioration in milk quality in

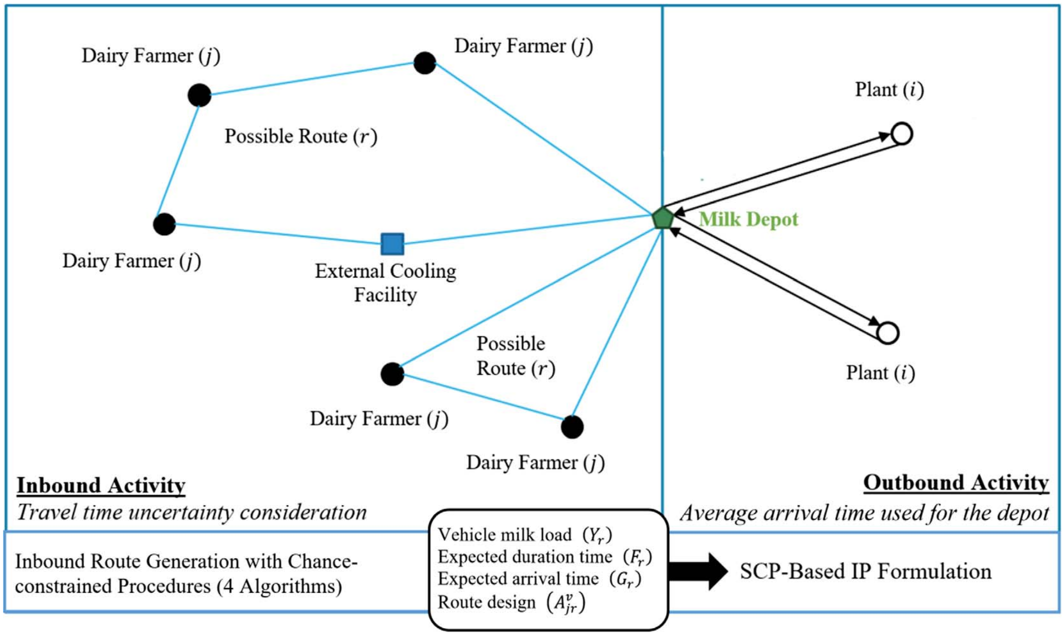

Fig. 3. Illustration of the concept of the SCP-based formulation with chance-constrained procedures.

the inbound activity. Constraint (19) determines the binary variable, o^v, which indicates whether or not a vehicle goes to an ECF. Constraint (20) denotes the accumulated route time for a vehicle, starting from the milk depot and ending at the milk depot or the ECF. Constraint (21) ensures that the difference between the accumulated route time (represented by u^v) and the departure time of any inbound supply node is less than the time limitation in order to avoid a deterioration in milk quality. In particular, whether or not an ECF is used is taken into account. Constraint (22) determines the ending time of a vehicle at the milk depot for the inbound activity. This determined ending time of a vehicle in the inbound operation also leads to the availability of that vehicle for the outbound operation. The last two constraints, Constraints (23) and (24), specify the arrival time at the milk plant for the outbound operation and defines the transfer feasibility between one pair of inbound and outbound vehicles (represented by w and v). The rest of the constraints are for defining the characteristics of the variables.

3.3. SCP-based model formulation

It is very difficult to solve the IP model of (1)–(33) to optimality for any practical-sized problem as the computational load is beyond the capability of today's personal computers. We thus have adopted an alternative approach, the set covering problem formulation, to serve as the basis to develop a solution procedure to generate a good approximate solution. The illustration of the proposed solution approach is shown in Fig. 3. One advantage of the SCP-based approach is that, when the complexity of the VRP-type problems increases (such as the inclusion of a route length limitation and time windows, etc.), the complicated problem features can easily be taken into account (Song et al., 2015). Basically, all kinds of requirements can be dealt with when determining the sets or the qualified (feasible) routes. Another reason for adopting the SCP-based approach is its readiness to utilize the historical good inbound routes, given that the locations of the pick-up nodes (farmers) remain unchanged for the dairy industry. This consideration is further elaborated and tested in the second part of the numerical experiment.

One more reason to adopt the SCP-based approach is to make use of its readiness to consider the stochastic features of the problem. Travel time uncertainty, for example, due to traffic congestion or weather condition, may create a chain effect making the operation more vulnerable. In particular, we have incorporated the chance-constrained concept in the generation of the complicated inbound routes to deal with the associated travel time uncertainty issue. As illustrated in the Fig. 3, the expected route duration time of each feasible inbound route can be determined, after taking into account all operational considerations. Meanwhile, the expected route ending time at the depot can also be determined, and it serves as the interface to link the delivery phase, in which the relatively simple direct-shipping decision is made based on the expected value from the previous phase.

In general, the decision variable related to the vehicle flow x_{jk}^v is changed to the variable regarding the route x_r^v, $r \in U$, where U is the set of feasible routes for inbound delivery. Given the definition of the new binary decision variable x_r^v as the indicator regarding whether route r is used, the original IP model of (1)–(33) can then be transformed as the new SCP-based IP model. In particular, one related binary parameter A_{jr}^v is defined to represent whether route r served by vehicle v covers dairy farmer j. In addition, F_r is the expected duration time of inbound route r, and G_r is the route expected ending time given a fixed operation beginning time. Finally, Y_r is the sum of the loads of the dairy farmers included in route r. The rest of the notations defined in the previous section remain unchanged.

Objective Function:

$$\min \sum_{r\in U}\sum_{v\in V} F_r x_r^v + \sum_{i\in N_I}\sum_{w\in V} c_i^w T_{0i} \tag{34}$$

Subject to:

$$\sum_{r\in U}\sum_{v\in V} A_{jr}^v x_r^v \geqslant 1 \quad \forall\, j \in N \tag{35}$$

$$\sum_{r\in U} x_r^v \leqslant 1 \quad \forall\, v \in V \tag{36}$$

$$\sum_{i\in N_I} c_i^w \leqslant 1 \quad \forall\, w \in V \tag{37}$$

$$\sum_{w\in V}\sum_{i\in N_I} s_{vw}^i \leqslant \sum_{r\in U} x_r^v Y_r \quad \forall\, v \in V \tag{38}$$

$$\sum_{w\in V}\sum_{v\in V} s_{vw}^i - D_i \geqslant 0 \quad \forall\, i \in N_I \tag{39}$$

$$\sum_{v\in V} s_{vw}^i \leqslant c_i^w Q^w \quad \forall\, w \in V, i \in N_I \tag{40}$$

$$\sum_{i\in N_I} s_{vw}^i \leqslant z_{wv} M \quad \forall\, v,w \in V \tag{41}$$

$$p^v = \sum_{r\in U} G_r x_r^v \quad \forall\, v \in V \tag{42}$$

$$b_i^w - T_{0i} \geqslant p^v + (z_{wv}-1)M \quad \forall\, v,w \in V, i \in N_I \tag{43}$$

$$b_i^w - T_{0i} \geqslant p^w + (z_{wv}-1)M \quad \forall\, v,w \in V, i \in N_I \tag{44}$$

$$E_i \leqslant b_i^w \leqslant L_i \quad \forall\, i \in N_I, w \in V \tag{45}$$

$$x_r^v \in \{0,1\} \quad \forall\, v \in V, r \in U \tag{46}$$

$$s_{vw}^i \geqslant 0 \quad \forall\, v,w \in V, i \in N_I \tag{47}$$

$$c_i^w \in \{0,1\} \quad \forall\, i \in N_I, w \in V \tag{48}$$

$$z_{wv} \in \{0,1\} \quad \forall\, v,w \in V \tag{49}$$

$$b_i^w \geqslant 0 \quad \forall\, i \in N_I, w \in V \tag{50}$$

$$p^v \geqslant 0 \quad \forall\, v \in V \tag{51}$$

$$p^w \geqslant 0 \quad \forall\, w \in V \tag{52}$$

The objective function of this formulation shown in (34) minimizes the total travel time for performing both inbound and outbound activities. Constraint (35) is a typical constraint for an SCP-based formulation for a VRP-type problem. It determines how the dairy farmers are covered by the routes chosen from the set of feasible inbound routes. Constraint (36) ensures that at most one route is assigned to a vehicle. Constraint (37) requires that a vehicle not be used twice for the outbound activity. Constraints (38) and (39) represent the variable for milk transfer between the inbound and outbound phases, similar to Constraints (11) and (12). Constraint (40) requires that the capacity constraint of the outbound vehicle not be violated by the overall transferred quantity. Constraint (41) defines the relationship between the two variables z_{wv} and s_{vw}^i, related to the transfer between inbound vehicle v and outbound vehicle w to plant i. Constraint (42) determines the expected route ending time at the milk depot for each inbound vehicle. Based on the expected value from the collection phase, Constraints (43) and (44) specify the arrival time at the plant for the outbound operation after considering the availability between one pair of inbound and outbound vehicles (represented by w and v). Constraint (45) describes the time window restriction for the plants.

For above SCP-based formulation, the most attractive advantage is that all kinds of VRP-type operational considerations can be examined and accommodated when determining the feasibility of a route. In particular, for the chance-based constraints due to travel time uncertainty, a route with a chance lower than the threshold for meeting the requirements will be filtered out. For example, the confidence level, denoted by α_1, can be imposed for serving a farmer node within the time window. In addition, the other parameter α_2 can be defined as the confidence level for the route duration limitation related to milk quality. Suppose the arrival time at node j served by vehicle v is denoted by a_j^v. Then, a route is thought as feasible if the following relationship $Prob\{E_j \leqslant a_j^v \leqslant L_j\} \geqslant \alpha_1$ is satisfied for each combination of inbound node and vehicle. Similarly, if the route duration for vehicle v arriving at the milk depot or an ECF is denoted by u^v, the following relationship can be enforced to reduce milk spoilage, $Prob\{u^v \leqslant H\} \geqslant \alpha_2$. A higher value of thresholds of α_1 and/or α_2 may result in a smaller set of feasible routes being considered.

However, the number of possible combinations increases dramatically when the problem size gets bigger. Therefore, four algorithms, presented in the next section, have been developed to generate promising routes without enumerating all potential inbound routes. In addition, we have chosen to simplify the way of modeling the outbound operation by using the expected route ending time from the collection phase as shown in Constraints (43) and (44). This simplification leads to the compromise of satisfying Constraint (45), for which there is a chance of failing to meet the time window of the plants if the actual depot arrival time of either vehicle involving the transfer is delayed. Then, the resulting problem will have to be dealt with in the field in an ad-hoc fashion.

Regarding the estimation of the expected time duration (i.e., the parameter F_r) and the expected depot arrival time (i.e., the parameter G_r) of the routes, link travel times are considered as random parameter with a known probability distribution in this study. There are several commonly used distributions, such as normal, log-normal, gamma, shifter-gamma, and skewed distribution (Kenyon and Morton, 2003; Kaparias et al., 2008; Li et al., 2010; Tas et al., 2013). In particular, Arroyo and Kornhauser (2007) and Kaparias et al. (2008) mention that the log-normal distribution can be the most suitable one as it has a non-negative value and provides a better fit when compared with others. Therefore, we also have assumed that link travel time follows the log-normal distribution. For estimating the values of F_r and G_r, we have further assumed that the travel times between links are independent as in most VRP past research works (*e.g.*, Fan, et al., 2005; Russel and Urban, 2008; Li et al., 2010; Tas et al., 2013) due to the concerns over modeling simplicity and data unavailability.

4. Solution approach

The transformation of the formulation of (1)–(33) to the formulation of (34)–(52), for further taking into account the stochastic features of the inbound operation, is also helpful for dealing with a problem that is larger in size. However, it still takes too much time to generate all potentially feasible inbound routes (sets) and to solve the new IP problem. Thus, we have chosen to generate a partial set of routes to reduce the computational load so typical commercial IP solvers can derive a good solution. Thus, set U is no longer a full set of all feasible routes. Instead, focusing on their simplicity and computational advantage, we make use of two common VRP solution techniques, the sweep heuristics and the saving heuristics, to generate some potentially promising routes for the inbound delivery to be selected by the SCP-IP model. Besides, in addition to the typical concepts in the literature, we have further designed two node-based variants that focus on generating the routes for each node to enrich and improve the partial set of routes. The four route generation procedures are presented in the following paragraphs. In particular, in each procedure, the generated routes are examined to ensure their feasibility with respect to the two types of chance-based constrains (route duration and node time window) by the route-qualification process described in Section 3.3.

Basic Saving (BS) Algorithm, adapted from Ghiani et al. (2004)

Step 0: Let R^{BS} be the set of routes initially with the routes that only cover one dairy farmer, i.e., with the route structure as $\{0,j,0\}, j \in N$.
For each pair of vertices $j,k \in N, j \neq k$, compute the saving s_{jk} by using $s_{jk} = c_{0j} + c_{0k} - c_{jk}$.
Sort the savings in a non-increasing order to create the ordered list L.
Step 1: Extract a saving s_{jk} from the top of the list L. If vertices j and k belong to two separate routes in R^{BS}, merge them to generate a new route in R^{BS} by replacing the edges $(0,i)$ and $(0,j)$ with the edge (i,j), subject to the constraints for vehicle capacity and deterministic time windows.
Step 2: Re-order the node sequence for the new route generated by merging to minimize the total travel time, subject to the deterministic time window constraint and the chance-based constraints to ensure feasibility. Move to Step 3, if $L = \varnothing$. Otherwise, go back to Step 1.
Step 3: Perform the Two-Opt Procedure (Croes, 1958) to modify the routes in the set R^{BS}, subject to the deterministic time window constraint and the chance-based constraints to ensure feasibility.

Node-Based Saving (NS) Algorithm

Step 0: Let M initially be the set of all dairy farmers, i.e., $M = N$.
Step 1: Extract one customer k from M. For each vertex j, $j \in N$ $j \neq k$, compute the saving s_{kj} by using $s_{kj} = c_{0k} + c_{0j} - c_{kj}$.
Let L_k be the ordered list derived by sorting the saving value s_{kj} in a non-increasing order. Let R_k^{NS} be a set of routes based on k, initially containing only the first/shortest route covering k, i.e., with the route structure as $\{0,k,0\}$.
Step 2: Extract a saving s_{kj} from the top of list L_k. Add a new route to R_k^{NS} by inserting farmer j in the longest route in R_k^{NS} at the position with the least cost increase, subject to the constraints for vehicle capacity and deterministic time windows as well as the chance-based constraints to ensure feasibility.
Step 3: If it is infeasible to insert farmer j or $L_k = \varnothing$, move to Step 4. Otherwise, go back to Step 2.
Step 4: If $M = \varnothing$, move to Step 5. Otherwise, go back to Step 1.
Step 5: Combine the routes in R_k^{NS} $k \in N$ to form the route set of R^{NS}. Perform the Two-Opt Procedure (Croes, 1958) to modify the routes in the set R^{NS}, subject to the deterministic time window constraint and the chance-based constraints to ensure feasibility.

Angle-Based Sweep (AW) Algorithm (adapted from Toth and Vigo (2002)

Step 0: Let Ω be the set of angles for the dairy farmers with respect to the depot in the two-dimensional plane. Its member, the angle of dairy farmer k, can be computed and denoted as $\omega_k = \tan^{-1}\left(\frac{y_k - y_0}{x_k - x_0}\right)$. Let β be the starting angle of the sweep procedure and set it as 0° initially.
Step 1: Let L_β be the ordered list derived by sorting the value of $(\omega_k - \beta)^+$, where 360° is added for a negative value of $(\omega_k - \beta)$, in a non-increasing order. Let R_β^{AW} be a set of routes based on β that initially contains only the route that is formed by extracting the first farmer node from L_β as the single visited node.
Step 2: Extract a farmer node k from the top of list L_β. Add it to the developing route in R_β^{AW} and re-order the node sequence to minimize the total travel time, subject to the constraints for vehicle capacity and deterministic time windows as well as the chance-based constraints to ensure feasibility.
Step 3: If it is infeasible to insert farmer k, create a new developing route in R_β^{AW} and go back to Step 2. If $L_\beta = \emptyset$, move to Step 4. Otherwise, go back to Step 2.
Step 4: Increment the starting angle by setting $\beta = \beta + 5$. If $\beta > 360$, move to Step 5. Otherwise, go back to Step 1.
Step 5: Combine the routes in R_β^{AW} for all starting sweeping angles to form the route set of R^{AW}. Perform the Two-Opt Procedure (Croes, 1958) to modify the routes in the set R^{AW}, subject to the deterministic time window constraint and the chance-based constraints to ensure feasibility.

Node-Based Sweep (NW) Algorithm

Step 0: Let Ω be the set of angles for the dairy farmers with respect to the depot in the two-dimensional plane. Its member, the angle of dairy farmer k, can be computed and denoted as $\omega_k = \tan^{-1}\left(\frac{y_k - y_0}{x_k - x_0}\right)$. Let M be the ordered list of all dairy farmers by sorting ω_k.
Step 1: Extract one dairy farmer k from M. Calculate the absolute angle difference with respect to node k for dairy farmers, $g_j = |\omega_j - \omega_k|, j \in N, j \neq k$. Let L_k be the ordered list derived by sorting g_j in a non-increasing order. Let R_k^{NW} be a set of routes based on k, initially containing only the first/shortest route covering k, i.e., with the route structure as $\{0,k,0\}$.Step 2: Extract an absolute angle difference g_j from the top of list L_k. Add a new route to R_k^{NW} by inserting farmer j in the longest route in R_k^{NW} at the position with the least cost increase, subject to the constraints for vehicle capacity and deterministic time windows as well as the chance-based constraints to ensure feasibility.
Step 3: If it is infeasible to insert the farmer j or $L_k = \emptyset$, move to Step 4. Otherwise, go back to Step 2.
Step 4: If $M = \emptyset$, move to Step 5. Otherwise, go back to Step 1.
Step 5: Combine the routes in R_k^{NW} $k \in N$ to form the route set of R^{NW}. Perform the Two-Opt Procedure (Croes, 1958) to modify the routes in the set R^{NW}, subject to the deterministic time window constraint and the chance-based constraints to ensure feasibility.

5. Numerical experiment

In this section, the solution algorithm presented in the previous section is tested. The Python code and the Gurobi IP solver are utilized to derive the solution. In the first sub-section, the design of the test problems is presented. It is followed by the sub-sections that show the numerical results for the three parts of the testing, namely the base scenario, the experiment on the problem features, and the database scenario. All computational results are based on a desktop computer with 64-bit Intel Core i5 and 8 GB DDR3 RAM.

5.1. Data and problem design

Real data based on the dairy cooperatives in Indonesia were used to test the solution algorithm. The data consist of the co-ordinates of the suppliers, ECFs and the milk depot as well as the average daily demand and the time windows for each dairy farmer. The locations of the nodes for the base case are shown in Fig. 4. Dairy farmers are mostly clustered in three areas, namely, R1, R2, and

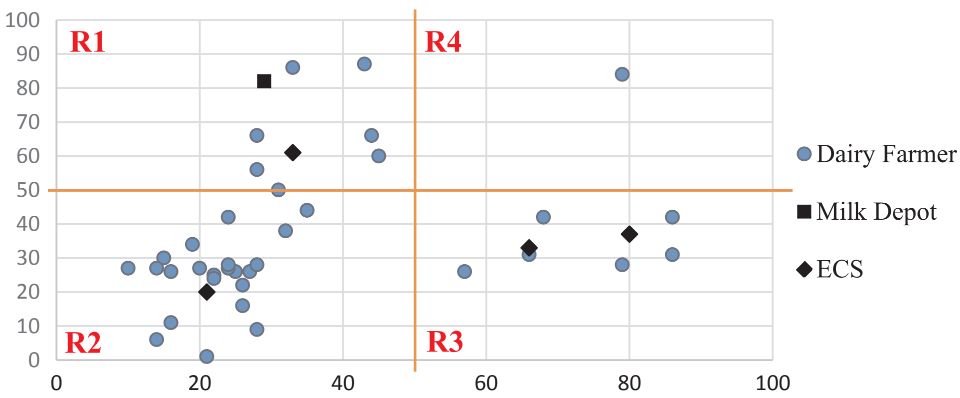

Fig. 4. Node locations of the base case (based on actual geographical location).

Table 1
The settings of the test problems.

Parameter	Values
Vehicle capacity type	1 type
Milk time limitation	120 min
Number of ECFs	4 units
Average dairy farmer supply	1268 L (min: 106 L & max: 3146 L)
Average Supplier time window	Start: 4:05AM (Stdev.: 8.9 min) End: 6:10AM (Stdev.: 13.5 min)
Number of milk plants	2 plants
Milk plant time window	1st plant: Start = 6:00AM and End = 9:30AM 2nd plant: Start = 7:00AM and End = 11:00AM
Milk Plant Demands	1st plant needs 50% of total milk collected 2nd plant needs 40% of total milk collected

R3. In each cluster, at least one ECF is available to support the collection activity.

In general, ten test instances, denoted as P1-P10, are generated based on the base case. In order to generate the random test instances, the coordinates were further divided into four regions as shown in Fig. 4. For each region, the distribution with the best fit for the x and y coordinates is examined. Then, the locations of the dairy farmers are randomly generated accordingly, given that the location of the depot and ECFs remain unchanged.

For the expanded version of the test problem sets under the route database scenario described in the last sub-section, 40 sets of farmer supply quantities are generated by assuming a normal distribution with the original supply quantities as the mean and 10% of it as the standard deviation for each problem with the same location and time window of the dairy farmers. Among them, 30 sets of farmer supply quantities are used to represent the historical decision problems, whose solutions constitute the routes in the database. The rest of the 10 sets of farmer supply quantities are used to perform the test for showing the benefit from including the routes in the database in the current inbound route set. The summary of the problem settings is shown in Table 1.

The uncertain link travel times are assumed to follow a log-normal distribution with the mean and the standard deviation denoted by μ_{ij} and σ_{ij} for every $i,j \in N_A$ and $i \neq j$. Two threshold parameters for the CCP are used. The coefficient of variation is set as 0.2 for all nodes. The threshold for the chance to be within the time window constraint is set as $\alpha_1 = 0.85$ and that for the route duration limitation is set as $\alpha_2 = 0.95$, a relatively higher standard.

5.2. Computational results of the base scenario

In addition to the type of test problems described in the previous sub-section, the other type of test problems without the maximum route time was also created. The purpose is to examine the possible future situation that all of the trucks are equipped with cooling equipment. The developed algorithm in general results in good performance on the generated test problems. The average values are recorded in Table 2, including the number of inbound routes generated and the solution gap. The solution quality of the algorithm is measured by comparing the heuristics results with the optimal results based on enumerating all inbound routes and solving the SCP-based model of (34)–(52) to optimality. The optimal results are limited to the problem size of 20 dairy farmers, due to the inability to enumerate all inbound routes and solve the SCP-IP model. The average gap is about 3% across 10 test instances for the problem size of 10–20 dairy farmers under the maximum computation time of 10 min for the heuristics algorithm.

By only generating a set of potentially good routes, instead of enumerating all possible inbound routes, the algorithm can handle

Table 2
The average results of all problem sets for the heuristic algorithm in the base scenario.

Problem Size	With Milk Route Time Limitation			Without Milk Route Time Limitation		
	Enumeration	Heuristics Results		Enumeration	Heuristics Results	
	Inbound Routes Generated	Inbounds Routes Generated	Solution Gap	Inbound Routes Generated	Inbounds Routes Generated	Solution Gap
5	79.18	30.18	0.00%	85.73	35.36	0.01%
10	3976.18	100.27	2.82%	5115.27	138.55	2.08%
15	6150.55	132.91	2.65%	10185.55	185.82	3.47%
20	7355.00	156.82	2.48%	14713.91	228.27	2.47%
25		220.18			340.27	
30		291.82			469.82	
35		431.30			725.73	
40		533.70			921.45	
45		580.13			1046.73	
50		700.30			1216.45	

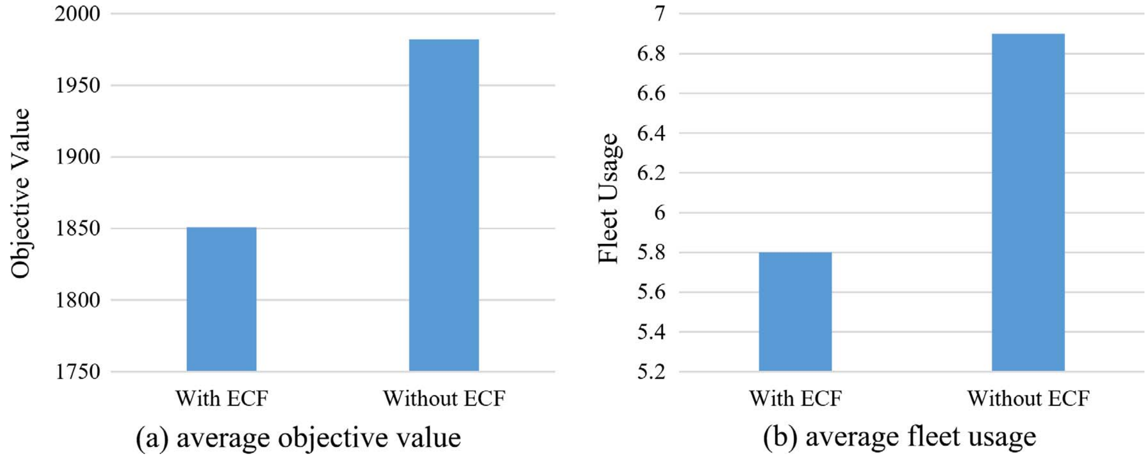

Fig. 5. Improvement introduced by the ECF strategy.

the problems that are larger in size with a shorter computation time. The solution gap is acceptable for the smaller problems, and the computational time is feasible for the larger problems.

5.3. Experimental on important problem features

Two important problem features have made this study significantly different from the Dairy Transportation Problem (DTP) in the literature, namely the introduction of the external cooling facility and the fleet sharing of the two distinct phases of collection and delivery.

5.3.1. Benefit of external cooling facility

The ECF might be considered to be an important strategy for the dairy industry. It is designed to help improve the vehicle utility and reduce the overall vehicle travel time. In our experiment, ECF is found to lead to some improvement in two respects, namely, reducing the objective function and the fleet usage. For the problems with the size of 20 farmers, the average values over 10 test instances solved to optimality are summarized in Fig. 5. The overall objective value is improved by about 7.10%, and the usage of almost 1 truck is saved, or a 19% fleet usage reduction on average. Although the fleet size is not part of our objective function, the reduction in the number of trucks can be the source of a potential improvement.

It is worthwhile to note that not every collection trip can benefit from the ECF strategy. Longer trips are the most outstanding type of collection with the greatest potential. However, since the trip length also depends on the time windows of the plants, not all inbound routes can necessarily be long. Some of the routes need to be short to support the early outbound trips to the plant. Thus, the improvement made by the ECF is limited in this regard.

5.3.2. Inbound and outbound fleet sharing

One of the key contributions in this study is the integrated planning of the inbound and outbound operations. The fleet sharing in the inbound and outbound transportation is the main reason why these two route plans cannot be decoupled. The integrated plan allows the fleet to be better utilized, subject to the inter-related operational factors including milk volume collected and accumulated, inbound arrival time, and outbound departure time.

As shown in Fig. 6 based on an example of 20 farmers, the quantity of milk needs to accumulate to a certain amount before being sent out of the depot to the plants. Both the arrival time of the inbound fleet and the departure time of the outbound fleet must be considered simultaneously to satisfy the window requirement of the plants. The inbound trucks do not necessarily have to be dispatched right away after arriving at the depot from the collection operation. Some of the trucks may need to wait for some time until the amount of milk accumulated is sufficient. Given these concerns, treating the inbound and outbound operations as two separate processes leads to quite different results when compared with integrated inbound and outbound planning.

5.4. Computational results of the database scenario

A database scenario was created to examine one of the alternatives used to improve solution quality without really making too much effort to improve the solution quality based on the same heuristics algorithm. Milk production by dairy farmers may be varied on a daily basis due to some conditions, such as the weather, the cattle's health, the availability of resources, etc. These milk production variations may affect the milk collection route from one day to the next. The past executed inbound routes can be collected to supplement the current inbound route set to obtain a better quality solution.

As shown in Table 3 based on the 10 test instances of the problems with the size of 50 farmers, about a 1.15% improvement can be contributed by adding the historical good routes from the previous days. When using a new set including the extra routes from the

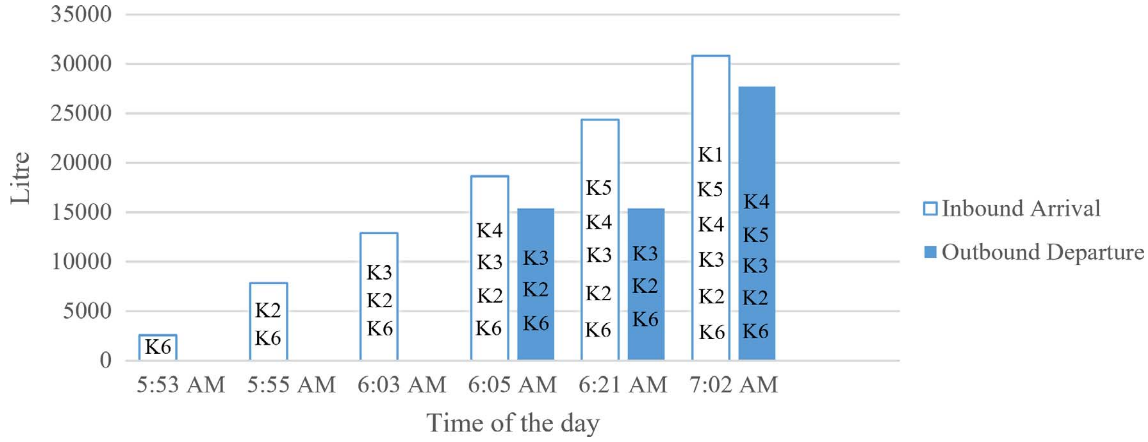

Fig. 6. Illustration of the milk accumulation and truck dispatching in both phases.

database, the computational time is affected slightly by about a 28% increase.

6. Conclusions

Based on the field operations of dairy cooperatives in Indonesia, this study formulates a mathematical programming model that integrates the decision regarding the collection of raw milk from the dairy farmers and the delivery of that milk to the dairy product plants. As milk is highly perishable, the truck collecting the raw milk from the dairy farmers needs to return to the milk depot within a fixed period of time for cooling and pre-processing. Alternatively, the collected milk can be sent to an external cooling facility before eventually reaching the milk depot. However, truck travel time may be affected by several factors, which may cause the route duration to be highly variable so as to impact the quality of the milk. The decision process is further complicated by local practices, with the same fleet of trucks also being used to transport the pre-processed milk to the plants.

This study develops a solution approach based on the set covering problem (SCP) and several classic routing heuristics. The SCP-based approach is selected mainly because of its flexibility in handling complicated operational requirements and its alignment with the decision environment in the dairy industry. According to the numerical experiment based on the real operations of the dairy cooperatives, the proposed solution algorithm can provide quality solutions with approximately a 3% gap from the optimal solution for the smaller size problem within a reasonable computational time.

The alternative external cooling facility that is available in relation to this problem has proved to be effective to the overall solution as it can reduce the objective value by about 7% and the fleet usage by 19%. Finally, the improvement arising from using the database of the routes based on historical operations can be useful. The advantage is particularly important for the DTP-type problems since the locations of the demand nodes are basically fixed, and the production quantities vary from one day to another, as highlighted by Lahrichi et al. (2015).

For research extensions, one immediate direction would be to enhance the route generation procedures to generate a better partial set of routes. At this moment, only the simple saving heuristics and the sweep heuristics have been used. More sophisticated techniques can generate good routes without too much computational effort. The other research direction would be to further consider the stochastic features of the DTP as milk is a perishable product. Real-world uncertainty can be crucial to achieving a better balance between the logistics cost and food safety.

Table 3
Average improvement based on the route database.

Problem sets	Objective function			Computation time			Inbound routes		
	Before	After	Gap (%)	Before	After	Gap (%)	Before	After	Gap (%)
P1	2513.90	2450.00	2.54	77.78	60.16	22.65	1396.60	1689.00	−20.94
P2	3379.10	3339.20	1.18	498.72	466.28	6.50	1388.00	1615.80	−16.41
P3	3294.50	3262.00	0.99	396.95	515.12	−29.77	1374.20	1698.60	−23.61
P4	3482.00	3441.10	1.17	546.25	606.94	−11.11	1089.80	1353.50	−24.20
P5	3038.80	3020.30	0.61	192.93	220.89	−14.49	1698.20	1868.90	−10.05
P6	3441.30	3407.80	0.97	574.47	606.29	−5.54	1048.10	1288.10	−22.90
P7	3258.20	3223.20	1.07	348.09	496.41	−42.61	1421.70	1756.10	−23.52
P8	3340.40	3306.40	1.02	506.08	510.81	−0.93	1270.70	1563.70	−23.06
P9	3360.90	3323.90	1.10	606.30	560.70	7.52	1351.50	1551.10	−14.77
P10	3299.20	3271.10	0.85	265.83	282.46	−6.26	1214.10	1416.20	−16.65
Average	3240.83	3204.50	1.15	401.34	432.61	−7.40	1325.29	1580.10	−19.61

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.tre.2018.01.018.

References

Adenso-Diaz, B., Gonzales, M., Garcia, E., 1998. A hierarical approach to managing dairy routing. Interfaces 28, 21–31.
Apte, U.M., Viswanathan, S., 2000. Effective cross docking for improving distribution efficiencies. Int. J. Logist. Res. Appl. 3, 91–302.
Arroyo, S., Konrhauser, A.L., 2007. Modeling travel time distributions on a road network. In: 11th World Conference on Transport Research.
Basnet, C., Foulds, L., Wilson, J., 1997. A decision aid for milk tanker run collection. J. Oper. Res. Soc. 48, 786–792.
Caramia, M., Guerriero, F., 2010. A milk collection problem with incompatibility constraint. Interfaces 40, 130–143.
Croes, G.A., 1958. A method for solving traveling salesman problems. Oper. Res. 6, 791–812.
Fan, Y.Y., Kalaba, R.E., Moore, J.E., 2005. Arriving on time. J. Optim. Theory Appl. 127, 497–513.
Gendreau, M., Laporte, G., Seguin, R., 1996. Stochastic vehicle routing. Eur. J. Oper. Res. 88, 3–12.
Ghiani, G., Laporte, G., Musmanno, R., 2004. Introduction to Logistics System Plannning and Control. John Wiley & Sons, Chichester.
Hsu, C.-I., Hung, S.-F., Li, H.-C., 2006. Vehicle routing problem with time-windows for perishable food delivery. J. Food Eng. 80, 465–475.
Kaparias, I., Bell, M.G.H., Belzner, H., 2008. A new measure of travel time reliability for in-vehicle navigation system. J. Intell. Transport. Syst. 12, 202–211.
Kenyon, A., Morton, D., 2003. Stochastic vehicle routing with random travel time. Transport. Sci. 37, 69–82.
Lahrichi, N., Crainic, T.G., Gendreau, M., Rei, W., Rousseau, L.-M., 2015. Strategic analysis of the dairy transportation problem. J. Oper. Res. Soc. 66, 44–56.
Li, X., Tian, P., Leung, S.C.H., 2010. Vehicle routing problems with time windows and stochastic travel and service times: models and algorithm. Int. J. Prod. Econ. 125, 137–145.
Masson, R., Lahrichi, N., Rousseau, L.-M., 2016. A two-stage solution method for the annual dairy transportation. Eur. J. Oper. Res. 251, 36–43.
Russel, R.A., Urban, T.L., 2008. Vehicle routing with softwime windows and erlang travel times. J. Oper. Res. Soc. 59, 1220–1228.
Sankaran, J., Ubgade, R., 1994. Routing tankers for dairy milk pickup. Interfaces 24, 59–66.
Segura, E., Benitez, R., Lozano, A., Flores, I., 2014. Optimization of milk distribution for maximum demand coverage in Chihuahua, Mexico. Proc. – Soc. Behav. Sci. 160, 519–528.
Sethanan, K., Pitakaso, R., 2016. Differential evolution algorithms for scheduling raw milk transportation. Comput. Electron. Agric. 121, 245–259.
Song, L., Chen, H., Gu, H., Huang, H., Du, H., 2015. Set covering in fuel-considered vehicle routing problems. Theorit. Comput. Sci. 607, 471–479.
Tarantilis, C., Kiranoudis, C., 2001. A meta-heuristic algorithm for the efficient distribution of perishable foods. J. Food Eng. 50, 1–9.
Tas, D., Dellaert, N., Woensel, T., de Kok, A.G., 2013. Vehicle routing problem with stochastic travel time including soft time windows and service costs. Comput. Oper. Res. 40, 214–224.
Tas, D., Gendreau, M., Dellaert, N., van Woensel, T., de Kok, A.G., 2014. Vehicle routing with soft time windows and stochastic travel times: a column generation and brach-and-price solution approach. Eur. J. Oper. Res. 236, 789–799.
Toth, P., Vigo, D., 2002. The Vehicle Routing Problem. Society for Industrial and Applied Mathematics, Philadelphia.
Wardhani, M., Kusnadi, N., 2010. Optimalisasi produksi susu pasteurisasi di KPBS pengalengan kabupaten bandung jawa barat. Bogor Agricultural University, Bogor (in Indonesian).