

Vehicle routing problems in rice-for-the-poor distribution

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ABSTRACT

This paper characterizes the routing problems arising in distribution of rice-for-the-poor in a district and presents a generic mathematical formulation of vehicle routing problems (VRP) for solving the problems. The proposed generic model, framed as a mixed integer linear programming, is formulated in such a way to encompass three distinct features; namely multiple depots (MD) establishment, multiple trips (MT) transportation, and split delivery (SD) mechanism. This model is implemented for a real-world problem of rice-for-the-poor distribution in the Ponorogo district of Indonesia, involved for deliveries among 3 depots—8, 17, and 23 villages depended on the distribution period—using a fleet of 5 vehicles of homogeneous capacity. Three types of distribution model are identified as MD-MT-VRP, MD-VRP-SD and MD-MT-VRP-SD.

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1. Introduction

Following the 1998 Asian financial crisis, the Government of Indonesia introduced the so-called special market operation for rice as part of emergency relief package. Although, it was developed as a response to crisis, it has now become a permanent program and grown into one of Indonesia's largest social safety net programs in terms of government expenditure, as well as the longest serving of the current household-targeted social assistance transfer programs and the second largest social assistance initiative in terms of coverage. In 2002, this program was renamed the Rice-for-the-poor Family Program or abbreviated as Program RASKIN in Indonesia to put more emphasis on its target beneficiaries and, then, the Rice for the Prosperous Family Program (Program RASTRA) in 2016, even though RASKIN is still a more popular name. The program delivers rice for purchase at subsidized prices (75 to 80% lower than the market price), prioritized to poor and near-poor households. Every family under the regular RASKIN program receives 15 kg of rice at the price of IDR 1,600/kg (equivalent to \$119 per metric ton) per month. In 2016–2017, RASKIN targeted 15.5 households, and program expenditures amounted to IDR 22.5 trillion. In the middle of July 2017, the Indonesian Bureau

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of Logistics (BULOG) distributed a total of 1,051,000 metric tons of milled rice to the poor and vulnerable households in the society (USDA, 2017).

Beyond its positive potential, many studies reported that RASKIN failed to achieve fundamental social assistance goals in its operation. RASKIN suffered from dilution of benefits and inclusion errors, missing rice, and hidden financing burdens, all of which reduced the transfer values transmitted to the target households. Poor targeting, dilution of benefits, and missing rice are long-standing and well-known RASKIN issues (IMF, 2017). Instead of discussing RASKIN as a costly and low-effective program and its related policy recommendations, this study paid particular attention to the modelling aspect of the distribution of rice itself. BULOG, as a national-wide logistic management bureau, organizes rice distribution in the level of a city or district where a regional office of BULOG has been established. A three-level distribution mechanism is then adopted to periodically transfer the rice from the depots to target households. Distribution within one district is commonly served by more than one BULOG warehouses located at some sub-districts. From these depots, the rice is then delivered to a number of villages as distribution points using a fleet of vehicles according to the delivery order issued by BULOG. The next step of distribution process is conveying the rice to some community or neighbourhood groups (RT/RW) as demand points before finally being handed out to the target households. In most cases, the distribution process between distribution points and demand points and that between demand points and households do not require any fleet mobility.

This paper focuses only on the first stage of distribution process, where a number of vehicles are dispatched from depots to fulfil the requirements of the distribution points. Instead of searching the optimal route of the whole problem in all periods, some distinct features inherently possessed by distribution problems pertaining to all periods were characterized. A mixed integer linear programming to formulate a quite general VRP model, namely multiple depots (MD), multiple trips (MT) vehicle routing problems with split delivery (SD), abbreviated as MD-MT-VRP-SD, possibly with heterogeneous fleet capacity is then developed for solving the problems. The rest of this paper processed as follows. After an introductory part in this section describing the background study and research objective, Section 2 is dedicated to review the state-of-the-art of VRP model which includes the model variations, solution method and real-life applications. The problem description on the rice-for-the-poor distribution under consideration is explained in Section 3. The generic VRP model of interest is proposed in Section 4 using the mixed integer linear programming as the main framework of modelling. Solution to the model in terms of the optimal routes for rice-for-the-poor distribution in Ponorogo district is presented and discussed in Section 5. A concluding remark is given in Section 6.

2. VRP: model variants, solution method and applications

The vehicle routing problems (VRP) has been the topic of research in distribution management for decades and has become more popular in the academic literature. Much attention was primarily focused on the development of the problem characteristics and assumptions leading to an enormous number of problem variant statements as well as various heuristic and metaheuristic algorithms advancements to solve the problem. Since then, the vehicle routing problem has been the heart of supply chain and logistics management. VRP alongside the Traveling Salesman Problem, Chinese Postman Problem, and Rural Postman Problem are four classical routing problems that have been intensively studied by many researchers (Laporte & Osman 1995). The distribution of products among customers is considered to be one of the most challenging problems in supply chain management, in which a substantial portion of the total distribution expenses is devoted to transportation cost including routing-related cost. VRP has been the key approach in modelling the products coordination and material flows between nodes led to better scheduling decisions. VRP in particular is a terminology that refers to a problem of searching routes for a fleet of vehicles of known capacities for providing services to a number of customers with known locations and demands for a certain commodity, given a set of constraints. These constraints can include any combination of the following: each vehicle is originating and terminating at a depot upon completion of its route, each customer must be served by only one

vehicle, and each dispatched vehicle should visit at least one customer (Kumar & Panneerselvam, 2012; Kaur, 2013; Sen & Bulbul, 2008). Routes for the vehicles are sought to minimize some cost functions, such as the total distance travelled and the cost of distribution. Theoretical research and practical applications of the problem of vehicle routing were stimulated for the very first time by Dantzig and Ramser (1959) regarding the truck dispatching problem as a real-world application, concerning the delivery of product. In this pioneering paper, a problem of optimal route searching for a fleet of gasoline delivery trucks between a bulk terminal and a number of service stations was considered under the objective of total mileage minimization. It constitutes the first proposal of mathematical programming formulation and algorithmic approach for the VRP. Five decades after the appearance of this seminal paper, work in this field has escalated drastically (Golden et al., 2008). A large number of papers have been produced by many researchers in presenting different views of the problem, elaborating different features of the system and employing different strategies to solve the problem (Toth & Vigo, 2014). Since then, VRP became a central issue in the fields of transportation, distribution, and logistics. It became a well-organized management of the supply chain identified as a focal point of competitiveness and success for organizations in the field. The context under consideration was to mostly plan the route of delivering a product from a depot to the customers who had placed orders for that product, possibly integrating with production scheduling (Moons et al., 2017). Sufficient routing plans might provide significant savings for many distribution systems and, in many cases, it inspired the creation of big success stories in operational research applications. Current development on VRP includes the involvement of fuel consumption and stochastic travel speed (Feng et al., 2017) and total urban traffic system (Chen & Yang, 2017).

2.1 Model variants

Despite industrial interest in the VRP was as old as the problem, the VRP was still too simplistic an abstraction to properly describe many real distribution problems. Different requirements and conditions were then engaged by several researchers, leading to many modifications of the VRP—development on the basic VRP with additional features. The most basic and classical variant of the VRP is the capacitated vehicle routing problem (C-VRP), where the transportation requests consist of the distribution of products by vehicles with limited carrying capacity from a single depot to a given set of customers with finite demands (Kir et al., 2017; Lysgaard et al., 2004; Uchoa et al., 2017). Other direct extensions include the case where multiple depots are established to serve customers, which is known to be a multiple depots vehicle routing problem (MD-VRP)—see e.g., Salhi et al., (2014), Yalian (2016), and Muter et al., (2014) for the case vehicles that are allowed to stop at intermediate depots along their routes for replenishing; and, one where each customer can only receive a delivery or service in a specified window of time, i.e., vehicle routing problem with time windows (VRP-TW)—see e.g., Kirci (2016); Kumar and Panneerselvam (2012). Further development in addressing various conditions of real world problem produces numerous model variants such as multiple trips VRP (MT-VRP) when a vehicle is allowed to make several journeys during a planning period (Brandao & Mercer, 1998; Mingozzi et al., 2013); VRP with pickup and delivery (VRP-PD) where customers may return some products such that pickup demand and delivery demand must be satisfied by the same vehicle (Sombunthama & Kachitvichyanukul, 2010; Battarra et al., 2014; Doerner & Salazar-González, 2014; Nagy et al., 2015); VRP with backhauls (VRP-B) as a variant of VRP-PD (Sangeeta, 2015; Chávez et al., 2016; Jewpanya et al., 2016; Wassan et al., 2017); and, VRP with split delivery (VRP-SD) where each customer can be visited more than once by vehicles to fulfil his/her demand (Dror et al., 1994; Wilck & Cavalier, 2012; Bianchessi et al., 2016), as well as other mixture models.

Recent improvement of VRP embraces the inclusion of release date, i.e., the earliest time that the order is available to leave the depot for delivery, and due date, i.e., the time by which the order should ideally be delivered to the customer (Cattaruzza et al., 2016a; Shelbourne et al., 2017). In general, further development of VRP can be characterized based on the following perspectives: (road) network

structure, type of transportation requests, the constraints that affect each route individually, fleet composition and location, inter-route constraints, and optimization objectives (Irnich, et al., 2014).

2.2 Solution method

From the view point of solution method, numerous efficient algorithms and approaches have been proposed, stimulated by the fact that VRP is an NP-hard combinatorial optimization problem that can be exactly solved only for limited instances of the problem. In addition to the exact approaches (Contardo & Martinelli, 2014; Crainic et al., 2015), in the last two decades, heuristic and metaheuristic algorithms have demonstrated best results in practice and have emerged as the most promising direction of research for the VRP solving strategies. Chbichib et al. (2012) proposed that constructive heuristic approach was enhanced using Hill Climbing and Variable Neighbourhood Descent algorithm to solve profitable MT-VRP. Wassan et al. (2017) developed a two-level variable neighbourhood search to handle similar problem with backhauls (MT-VRP-B), and Zuhori et al. (2012) utilized the nearest neighbour classification method for grouping the customers, sum of subset, and greedy method to tackle MD-VRP with stochastic demands. Other methods relied their strategies on genetic algorithms (Cattaruzza et al., 2016a; Geetha et al., 2012; Sangeeta, 2015; Wang et al., 2008), tabu search (Brandao & Mercer, 1998; Cordeau et al., 1997; Crevier et al., 2007; Kirci, 2016), ant colony optimization (Chávez et al., 2016; Liu & Yu, 2013; Yalian, 2016) and particle swarm optimization (Geetha et al., 2012; Sombunthama & Kachitvichyanukul, 2010). Several works utilized heuristic search approaches (Chao et al., 1993; Lei et al., 2012; Neto & Pureza, 2016; Ray et al., 2014) and metaheuristics, which were considered as more robust methodologies for solving VRPs (Reyes-Rubiano et al., 2017; Wassan & Nagy, 2014; Zhen & Zhang, 2009). Golden et al. (2008) summarized significant methodological advances or new approaches for solving various types of VRP since 2000, including integer linear programming (ILP) local search, genetic algorithm, metaheuristics and branch-cut-and-price algorithms. Great book by Toth and Vigo (2014) is a comprehensive reference on VRP, as it comprises the latest development of both exact and heuristic methods developed in the last decades for the problem and some of its main variants in addition to the works of Laporte and Osman (1995) and Braekers et al. (2016).

2.3 Real-world applications

Applications of VRP in the real-world problem are abundant. A few of them include the applications of VRP-PD for a leading distribution company in Italy, time dependent VRP for freight distribution in Padua, Italy, and on-line VRP in Lugano, Switzerland, which can be found in Rizzoli et al. (2007), the use of evolutionary algorithm with intelligent search in freight carriers operations (Weise et al., 2009) and a real-world VRP arising in the air cargo road feeder service business (Derigs et al., 2011). In wider context, Feng et al. (2015) reviewed the literature on air cargo operations practical problems of airlines, freight forwarders, and terminal service providers. An excellent comprehensive survey on the real-world applications of product distribution over the past fifteen years was provided by Coelho et al. (2015), where a number of research papers in the field of oil, gas and fuel transportation, retail, waste collection and management, mail and package delivery, and food product distribution were overviewed. Success story on the application of VRP is enlightened by UPS (United Parcel Service), an American multinational package delivery and supply chain management company. ORION (On-Road Integrated Optimization and Navigation), a 10-year-long project developed by the UPS Operations Research group, revolutionized the company's pickup and delivery operations. ORION was utilized by 55,000 drivers, based across the United States to handle more than 5 million deliveries a day, under the objective of optimizing driver routing and reducing the total number of miles driven and fuel consumed, leading to cost savings, driver efficiency, production and safety, environmental friendliness, and customer service. ORION saved the company \$320 million by the end of 2015 due to 100 million miles less travelled and 10 million gallons of fuel unconsumed. This is beyond a reduction of 100,000 metric tons in CO₂ emissions per year and a significant increase in deliveries per driver per day (Horner, 2016).

3. Problem description

This part represents an implementation of the model for the distribution of rice-for-the-poor in Ponorogo district in Indonesia. Ponorogo is located in the southwest of East Java province, bordering with other seven districts and comprising of twenty-one sub-districts (see Fig. 1). Related to Program RASKIN, the regional office of BULOG at Ponorogo should distributes rice for at least 70 thousand target households spread over 307 villages. The distribution in one year is conducted within several stages, in which one stage is equivalent to one month and commonly consists of 12 delivery periods. In this work, only the distribution process in a few number of periods in a stage is considered. To organize the delivery, BULOG establishes three depots, namely UPGB Ngrupit (located at Jenangan sub-district), GSP Madusari (located at Siman sub-district), and GBB Babadan (located at Babadan sub-district), and a fleet consists of five vehicles with the same capacity. It is assumed here that each depot has a sufficient number of supplies to fulfil all demands. Furthermore, the distribution of rice is conducted between these three depots and a number of villages, and not between depots and households. UPGB Ngrupit and GSP Madusari operate 2 trucks for delivery and GBB Babadan dispatches only 1 truck, all with homogeneous capacity of 600 packs, in which 1 pack is equivalent to 15 kg of rice. Table 1 depicts the distribution plan with respect to periods including the number of villages should be served as well as their demand.



Fig. 1. Map of Ponorogo with its twenty-one sub-districts

Distribution plan in Table 1 is arranged by a distribution team and is merely based on the time and personnel availability as well as purchasing payment of each sub-district and village. Thus, in most cases, it was not organized according to any clustering mechanism based on the distance among villages. It can be seen that, for instance, distribution in period 7 comprises of 5 sub-districts that are entirely not adjacent each other. Moreover, two sub-districts Puduk and Ngrayun have the furthest distance among others. From the perspective of time efficiency, it can also be seen from Table 1 that the Ngrayun sub-district, which consists of 11 villages, is served within 7 periods, while demand for

all 19 villages in the Bungkal sub-district is fulfilled only in one period. The primary objective of this study is not to find the optimal route of all periods but rather to characterize a number of distinct features possessed by distribution problem in all periods. Based on the demand level of each village, three cases are identified pertaining to the type of VRP. In the first case, as the amount of rice demanded by villages exceeding the capacity of a single vehicle, then there are villages which should be visited by the truck more than once, i.e., a split delivery (SD) is expected. The second case illustrates a multiple trips problem, where the total demand exceeds the total capacity of fleet. This situation suggests that some trucks should be dispatched more than once from depots, i.e., multiple trips (MT). The last case demonstrates a situation where the combination of vehicle routing problem with multiple trips and split delivery is required (MT, SD). By realizing the existence of multiple depots (MD), then three types of VRP are distinguished, namely MD-VRP-SD, MD-MT-VRP and MD-MT-VRP-SD models. The first model is identified in period 12, the second model in periods 5, 7, 9 and the third model in periods 1–4, 6, 8, 10, 11 as indicated by the last column of Table 1.

Table 1
Distribution plan

Period	Sub-district	Number of Villages	Total Villages	Total Demand (packs)	Routing Problem
1	Ponorogo	18	34	5916	MT, SD
	Pulung	15			
	Ngrayun	1			
2	Ponorogo	1	32	5997	MT, SD
	Pulung	3			
	Siman	18			
	Sooko	6			
	Jenangan	2			
	Ngebel	1			
	Ngrayun	1			
3	Jenangan	15	32	7181	MT, SD
	Ngebel	7			
	Sukorejo	8			
	Ngrayun	2			
4	Sukorejo	10	32	6503	MT, SD
	Jetis	14			
	Mlarak	8			
	Ngrayun	2			
5	Mlarak	7	24	5753	MT
	Kauman	16			
6	Sambit	1	22	7378	MT, SD
	Badegan	10			
	Sampung	10			
7	Ngrayun	2	35	6491	MT
	Bungkal	19			
	Sampung	2			
	Babadan	9			
	Pudak	4			
8	Ngrayun	1	21	6493	MT, SD
	Jambon	11			
	Babadan	6			
	Pudak	2			
9	Ngrayun	2	26	5783	MT
	Jambon	2			
	Balong	15			
	Slahung	8			
10	Sambit	1	22	5570	MT, SD
	Slahung	14			
	Balong	5			
11	Sawoo	3	17	5027	MT, SD
	Sawoo	8			
12	Sambit	9	8	2333	SD
	Sawoo	5			
Total			307	70425	

As representatives of each case, Table 2 provides the distribution plan for periods 5, 11, and 12. Due to the reason of geographical accessibility, Gajah, a village of Sambit sub-district at period 5, is excluded from the distribution plan. Thus, period 5 consists of 23 villages in 2 sub-districts—period 11 manages 17 villages in 2 sub-districts, and period 12 organizes distribution process at 8 villages in 2 sub-districts. The same table also informs that all the villages act as distribution nodes and their demand level of rice are figured in packs, where one pack is equivalent to 15 kilograms of rice. A figure in parentheses preceding the label of each village indicates the index of the node.

Table 2
Distribution plan and demand for periods 5, 11 and 12

Period	Sub-district	Village	Demand (packs)	Total (packs)	
5	Mlarak	(4) Tugu	267		
		(5) Candi	171		
		(6) Ngrukem	190		
		(7) Siwalan	115		
		(8) Joresan	84		
		(9) Jabung	211		
		(10) Serangan	94	1,132	
		Kauman	(11) Tegalombo	257	
			(12) Nongkodono	179	
			(13) Sukosari	61	
	(14) Ngrandu		437		
	(15) Nglarangan		39		
	(16) Bringin		276		
	(17) Pengkol		361		
	(18) Gabel		277		
	(19) Ciluk		111		
	(20) Semanding		325		
	(21) Tosanan		176		
	(22) Maron		167		
	(23) Sumoroto		493		
	(24) Plosojenar		266		
	(25) Carat		226		
	(26) Kauman		429	4,080	
	Sambit	(27) Gajah	541	541	
	Total				5,753
	11	Sawoo	(4) Tumpuk	725	
			(5) Tempuran	905	
(6) Sriti			585		
(7) Sawoo			463		
(8) Prayungan			253		
(9) Grogol			487		
(10) Bondrang			127		
(11) Ngindeng			176	3,721	
Sambit			(12) Ngadisanan	180	
			(13) Maguwan	288	
			(14) Nglewan	281	
		(15) Campurrejo	215		
		(16) Campursari	34		
		(17) Sambit	62		
		(18) Wilangan	74		
		(19) Bangsalan	122		
		(20) Kemining	50	1,306	
Total				5,027	
12		Sambit	(4) Wringinanom	571	
			(5) Bedingin	171	
	(6) Bancangan		110		
	(7) Bulu		84		
	Sawoo	(8) Besuki	112	1,048	
		(9) Temon	807		
		(10) Tumpakpelem	425		
(11) Ketjo	53	1,285			
Total				2,333	

4. Model formulation

To facilitate formulation of the mathematical model, the following sets, variables, and parameters have been used throughout the paper. The set of all depots is denoted by \mathbb{D} and the set of all customers by \mathbb{C} . $\mathbb{D} \cup \mathbb{C}$ thus denotes the set of all nodes in the network. \mathbb{V}_i denotes the set of all vehicles belonging to depot i , where $i \in \mathbb{D}$. Thus, $\mathbb{V} = \bigcup_{i \in \mathbb{D}} \mathbb{V}_i$ is the set of all vehicles, and \mathbb{T} the set of all trips. The following parameters have been used throughout the paper:

- m : number of depots (unit), $\mathbb{D} = \{1, 2, \dots, m\}$
 n : number of customers (unit), $\mathbb{C} = \{m + 1, m + 2, \dots, m + n\}$
 k_i : number of vehicles at depot i and $k = \sum_{i \in \mathbb{D}} k_i$ (unit of vehicles). Thus, $\mathbb{V}_1 = \{1, 2, \dots, k_1\}$, $\mathbb{V}_2 = \{k_1 + 1, \dots, k_1 + k_2\}$, and so-forth.
 r : maximum number of trips of vehicle (times), thus $\mathbb{T} = \{1, 2, \dots, r\}$
 q_i : demand of customer i , where $i \in \mathbb{C}$ (unit of products)
 d_{ij} : distance between customer i and customer j , where $i, j \in \mathbb{C}$ (kilometer)
 Q_l : maximum capacity of vehicle l , where $l \in \mathbb{V}$ (unit of products)
 c_f : fixed cost (currency unit per trip)
 c_v : variable cost (currency unit per kilometer)

The following decision variables were introduced to capture a number of quantities such as the transportation request and the number of delivered products. p_{ilt} denotes the quantity of products delivered to customer i by vehicle l at trip t (unit of products). Furthermore, two binary variables are given as:

$$x_{ijlt} = \begin{cases} 1, & \text{if node } j \text{ is visited after node } i \text{ by vehicle } l \text{ at trip } t \\ 0, & \text{otherwise,} \end{cases}$$

$$z_{lt} = \begin{cases} 1, & \text{if vehicle } l \text{ is operated at trip } t \\ 0, & \text{otherwise.} \end{cases}$$

The mathematical model of MD-MT-VRP-SD can then be stated as the minimization of an objective function with respect to a number of constraints as follows:

$$\min C := \sum_{l=1}^k \sum_{t=1}^r c_f z_{lt} + \sum_{i=1}^n \sum_{j=1}^n \sum_{l=1}^k \sum_{t=1}^r c_v d_{ij} x_{ijlt} \quad (1)$$

subject to

$$\sum_{j=m+1}^{m+n} x_{ijlt} = z_{lt}, \quad \forall l \in \mathbb{V}_i, i \in \mathbb{D}, \quad \forall t \in \mathbb{T} \quad (2)$$

$$\sum_{j=m+1}^{m+n} x_{ijlt} = 0, \quad \forall l \notin \mathbb{V}_i, i \in \mathbb{D}, \quad \forall t \in \mathbb{T} \quad (3)$$

$$\sum_{i=m+1}^{m+n} x_{ijlt} = z_{lt}, \quad \forall l \in \mathbb{V}_j, j \in \mathbb{D}, \quad \forall t \in \mathbb{T} \quad (4)$$

$$\sum_{i=m+1}^{m+n} x_{ijlt} = 0, \quad \forall l \notin \mathbb{V}_j, j \in \mathbb{D}, \quad \forall t \in \mathbb{T} \quad (5)$$

$$x_{ijlt} \leq z_{lt}, \quad \forall i, j \in \mathbb{C}, \quad \forall l \in \mathbb{V}, \quad \forall t \in \mathbb{T} \quad (6)$$

$$x_{ijlt} = 0, \quad \forall i, j \in \mathbb{D}, \quad \forall l \in \mathbb{V}, \quad \forall t \in \mathbb{T} \quad (7)$$

$$x_{iillt} = 0, \quad \forall i \in \mathbb{D} \cup \mathbb{C}, \quad \forall l \in \mathbb{V}, \quad \forall t \in \mathbb{T} \quad (8)$$

$$u_{illt} - u_{jlt} + nx_{ijlt} \leq n - 1, \quad \forall i, j \in \mathbb{C}, \quad \forall l \in \mathbb{V}, \quad \forall t \in \mathbb{T} \quad (9)$$

$$\sum_{i=1, i \neq j}^{m+n} \sum_{l=1}^k \sum_{t=1}^r x_{ijlt} \geq 1, \quad \forall j \in \mathbb{D} \cup \mathbb{C}, \quad (10)$$

$$\sum_{i=1, i \neq s}^{m+n} x_{islt} - \sum_{j=1, j \neq s}^{m+n} x_{sjlt} = 0, \quad \forall s \in \mathbb{C}, \quad \forall l \in \mathbb{V}, \quad \forall t \in \mathbb{T} \quad (11)$$

$$p_{illt} \leq q_i \sum_{j=1}^{m+n} x_{ijlt}, \quad \forall i \in \mathbb{C}, \quad \forall l \in \mathbb{V}, \quad \forall t \in \mathbb{T} \quad (12)$$

$$\sum_{l=1}^k \sum_{t=1}^r p_{illt} = q_i, \quad \forall i \in \mathbb{C} \quad (13)$$

$$\sum_{i=m+1}^{m+n} p_{illt} \leq Q_l, \quad \forall l \in \mathbb{V}, \quad \forall t \in \mathbb{T} \quad (14)$$

$$\sum_{j=m+1}^{m+n} x_{ijlt} \geq \sum_{j=m+1}^{m+n} x_{ijl(t+1)}, \quad \forall i \in \mathbb{D}, \quad \forall l \in \mathbb{V}, \quad \forall t \in \mathbb{T} - \{r\}. \quad (15)$$

The objective function (1) consists of fixed cost that is amounted to all dispatched vehicles and variable cost that depends on the total distance travelled. Constraint (2) guarantees that not all vehicles must be operated and that once a vehicle is in duty, it must be dispatched from the designated depot, which then is contradicted by constraint (3). Constraints (4) and (5) make sure that all dispatched vehicles return back to the initial depots. Condition (6) assures that there is no customer visited by not-dispatched vehicles. Constraints (7) and (8) ensure that there are no trips between depots and that between the same customers, respectively. Constraint (9) eliminates subtour, i.e., it prohibits subtour that is free from the depot or connected to the depot but violates the capacity or distance restrictions (Achuthan et al., 1996). Condition (10) enables a customer to be visited by more than one vehicle. Constraint (11) enforces the route continuity guarantee. It means that as soon as a vehicle reaches a customer to deliver products, it should leave that place at once. Inequality (12) imposes that quantity of products delivered to a customer at each trip does not exceed its demand. Whereas, condition (13) ensures that the demand of a customer is exactly satisfied by delivery from all vehicles that visit the node at some trips. Capacity constraint of a vehicle is provided by (14). This constraint, however, enables us to operate a fleet of vehicles with heterogeneous capacities. The last constraint (15) is defined to impose the continuity of trips at each node, for guaranteeing that the trip t is performed just before trip $t + 1$.

5. Discussion

For the sake of notation, the set of all depots is denoted by $\mathbb{D} = \{1 = \text{UPGB Ngrupit}, 2 = \text{GSP Madusari}, 3 = \text{GBB Babadan}\}$ and the sets of all vehicles at depots 1, 2 and 3 respectively by $\mathbb{V}_1 = \{1,2\}$, $\mathbb{V}_2 = \{3,4\}$ and $\mathbb{V}_3 = \{5\}$. The maximum number of trips is set to $r = 2$ and maximum capacity is homogeneous, i.e., $Q_l = 600$ packs for all $l \in \mathbb{V}$. The fixed cost accused to each vehicle is IDR 1.5 million per trip ($c_f = 1,500,000$), and the variable cost is IDR 1,000 per kilometer ($c_v = 1,000$). The sets of all customers are given by $\mathbb{C} = \{(4) = \text{Tugu}, (5) = \text{Candi}, \dots, (26) = \text{Kauman}\}$ for period 5, $\mathbb{C} = \{(4) = \text{Tumpuk}, (5) = \text{Tempuran}, \dots, (20) = \text{Kemining}\}$ for period 11, and $\mathbb{C} = \{(4) = \text{Wringinanom}, (5) = \text{Bedingin}, \dots, (11) = \text{Ketro}\}$ for period 12. The demand of each customer, $q_i, i \in \mathbb{C}$, is given in Table 2. The distance between customers is known but not supplied in this paper. As an illustration, the furthest distance is 41.2 km, which is between GBB Babadan (depot) and Tumpuk village in period 11. While the nearest distance is 0.9 km, which is either between Kauman

and Ngrandu, or between Nglarangan and Bringin, all in period 5. On an average, the distance between two nodes is 12.72 km. In the model, instead of minimizing the number of multiple trips, i.e., the number of vehicles, (Derigs et al., 2011), minimizing the total depot establishment (Ray et al., 2014) or the total distance travelled by the vehicles as adopted by many papers (see e.g., Nagy et al., 2015), minimization of total operational cost like in Bozorgi-Amiri et al. (2015) and Surekha and Sumanthi (2011) has been adopted. The model includes the multiple depots establishment and it is explicitly declared that trip between depots is not possible. However, if for one reason such as vehicles may be replenished at intermediate depots along their route, then inter-depot trips will be allowed (see e.g., Crevier et al., 2007). The possibility of multiple trips procedure is represented by constraint (10). This specification makes multiple trip mode active for demand accomplishment. Comprehensive account on the topic of multiple trips VRP can be found in Cattaruzza et al. (2016b), Despaux and Basterrech (2014), and Kabcome and Mouktonglang (2015) for those with additional requirements such as multiple zones, multiple products, and time windows. Constraint (13) in the model obviously characterizes the split delivery property as discussed by Archetti and Speranza (2012), Gulczynski et al. (2011), and Vacca and Salani (2009). The proposed generic model is flexible and extensible, allowing the capture of richer real-world problems as well as repossession of more straightforward models. One interesting notion about MD-VRP may consult to the work of Montoya-Torres et al. (2015). This paper presents a literature review on the vehicle routing problem with multiple depots including its variants: hard, soft, and fuzzy service time windows, maximum route length, pickup and delivery, split delivery, backhauls, etc. It provides a complete analysis of scientific literature since the publishing of the first works of this problem from the mid-1980s until 2014.

5.1 MD-VRP-SD model

Distribution plan of period 12 includes the rice delivery for 8 villages in 2 sub-districts. One obvious fact that can be obtained from this period is that the demand of Temon village (807 packs) exceeds the maximum capacity of a single vehicle (600 packs). It means that the demand of Temon village (index 9) cannot be fulfilled by one vehicle in a single delivery. In other words, the delivery should be split by more than one vehicle, i.e., an MD-VRP-SD. For transport requests with the best route, the generic model with a small modification can be utilized. Constraint (15) can obviously be removed from the model as it deals with the multiple trips features, which is not the case. Relating to the splitting process, constraint (10) can be strengthened into:

$$\sum_{i=1, i \neq j}^{11} \sum_{l=1}^5 x_{ijl1} \geq 1, \quad j \in \{1, 2, 3, 9\} \quad (16)$$

$$\sum_{i=1, i \neq j}^{11} \sum_{l=1}^5 x_{ijl1} = 1, \quad j \notin \{1, 2, 3, 9\}. \quad (17)$$

Table 3

Distribution route and delivery of period 12

Vehicle	Distribution Route	Total Delivery (packs)
1	① → 4 (571) → ①	571
2	① → 10 (425) → 7 (112) → 11 (53) → ①	590
3	② → 9 (235) → 6 (84) → 5 (110) → 8 (171) → ②	600
4	② → 9 (572) → ②	572
5	Not operated	
Total		2,333

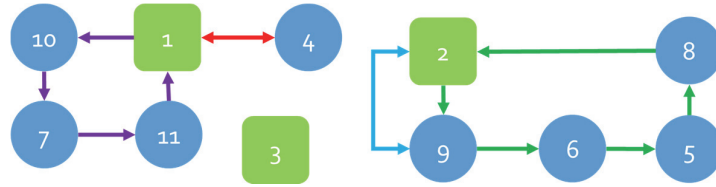


Fig. 2. Distribution route of period 12

Table 3 as well as Fig. 2 provide the optimal route to accomplish the delivery task during period 12. It is seen that all delivery requests can be satisfied by two depots (UPGB Ngrumpit and GSP Madusari) using 4 out of 5 vehicles. In particular, Temon village is served by two vehicles, where the third vehicle delivers 235 packs of rice and the fourth drops 572 packs. The total cost required to realize the distribution is IDR 6,22 million. In Table 3, ❶ and ❷ denote UPGB Ngrumpit and GSP Madusari depots, respectively. The figures in bold-face represent villages, and figures in the parentheses indicate the amount of rice delivered. In Fig. 2, a depot is represented by a green square, while a customer or village is symbolized by a blue disk. Lines with arrow show the direction that should be followed and their different colors indicate different vehicles.

5.2 MD-MT-VRP model

According to Table 2, the total rice demand in 23 villages of 2 sub-districts (not including Gajah village) in period 5 is 5,212 packs, whereas the total capacity of 5 vehicles is 3,000 packs. It means that even though all vehicles are dispatched under full capacity, there are still some villages under-fulfilled. Thus, it is required that some vehicles perform multiple trips, at least twice ($r = 2$). This feature suggests an MD-MT-VRP without a split delivery, as there is no village whose demand exceeds the maximum capacity of a vehicle. As a multiple trips variant has been established, constraint (13) is not mandatory as it deals with a split delivery case. Constraint (10) may be strengthened to the following two constraints:

$$\sum_{i=1, i \neq j}^{26} \sum_{l=1}^5 \sum_{t=1}^2 x_{ijlt} \geq 1, \quad j \in \{1,2,3\} \tag{18}$$

$$\sum_{i=1, i \neq j}^{26} \sum_{l=1}^5 \sum_{t=1}^2 x_{ijlt} = 1, \quad j \notin \{1,2,3\} \tag{19}$$

Constraint (18) will allow the depots to be visited more than once by vehicles, whereas constraint (19) makes sure that non-depot nodes can only be visited once. In addition, constraint (12) should also be modified to

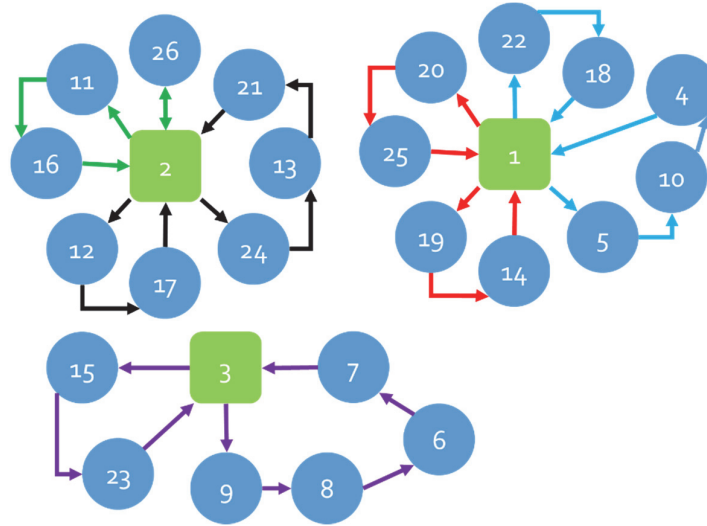
$$p_{ilt} = q_i \sum_{j=1}^{26} x_{ijlt}, \quad \forall i \in \{4,5, \dots, 26\}, \quad \forall l \in \{1,2, \dots, 5\}, \quad \forall t \in \{1,2\}, \tag{20}$$

as there is no split delivery case. Table 3 provides the distribution routes in period 5 and shows that the delivery process must be undertaken by dispatching all five vehicles from all depots. Each vehicle has to make two trips in the period—figures in parentheses give the amount of rice dropped to particular village in the first trip, whereas figures in brackets indicate that of the second trip. There are 2,547 packs of rice delivered in the first trip and 2,665 in the second. Therefore, a transfer of 5,212 packs of rice in total to 23 villages is made. The total minimum cost that should be expended is IDR 15,336,400. It can be easily verified by Table 4 and Fig. 3 that UPGB Ngrumpit delivers rice to 9 villages with a total supply of 2,075 packs—GSP Madusari serves 8 villages (2,005 packs) and GBB Babadan works for 6 villages (1,132 packs). It has previously been assumed that the supplies are ready stock in each depot.

Table 4

Distribution route and delivery of period 5

Vehicle	Distribution Route	Total Delivery (packs)	
		Trip 1	Trip 2
1	① → 5 (171) → 10 (94) → 4 (267) → ① → 22 [167] → 18 [277] → ①	532	444
2	① → 20 (325) → 25 (226) → ① → 19 [111] → 14 [437] → ①	551	548
3	② → 26 (429) → ② → 11 [257] → 16 [276] → ②	429	533
4	② → 24 (266) → 13 (61) → 21 (176) → ② → 12 [179] → 17 [361] → ②	503	540
5	③ → 15 (39) → 23 (493) → ③ → 9 [211] → 8 [84] → 6 [190] → 7 [115] → ③	532	600
Total		2,547	2,665

**Fig. 3.** Distribution route of period 5

5.3 MD-MT-VRP-SD model

Distribution activities in period 11 offer a more interesting situation, where they involve delivery to 17 villages with a total demand of 5,027 packs of rice, which is greater than the total capacity of all vehicles. From this side, it is understood that the distribution problem will be a multiple-trip variant. An additional challenging feature emerges by the fact that the two villages, Tumpuk and Tempuran in the Sawoo sub-district, have delivery requests exceeding the maximum capacity of a single vehicle. This fact, however, suggests a distribution problem with split delivery. In overall, the distribution process in period 11 can be represented as an MD-MT-VRP-SD, i.e., a combination of problems in periods 5 and 12. The problem raised above can then be addressed by minimizing cost function (1) subject to all constraints (2)-(15). As shown in the previous cases, constraint (7) can be reinforced to ensure either some nodes are visited by more than one vehicles or must be visited by exactly one vehicle, as given by (21) and (22) below. Recall that indices $j \in \{1,2,3\}$ denote those for three depots and $j \in \{4,5\}$ are for Tumpuk and Tempuran, respectively—nodes which have the biggest demand.

$$\sum_{i=1, i \neq j}^{20} \sum_{l=1}^5 \sum_{t=1}^2 x_{ijlt} \geq 1, \quad j \in \{1,2,3,4,5\}, \quad (21)$$

$$\sum_{i=1, i \neq j}^{20} \sum_{l=1}^5 \sum_{t=1}^2 x_{ijlt} = 1, \quad j \notin \{1,2,3,4,5\}. \quad (22)$$

Table 5
Distribution route and delivery of period 11

Vehicle	Distribution Route	Total Delivery (packs)	
		Trip 1	Trip 2
1	1 → 5 (600) → 1 → 9 [487] → 1	600	487
2	1 → 5 (9) → 6 (585) → 1	594	
3	2 → 10 (127) → 12 (180) → 4 (293) → 2 → 18 [74] → 8 [253] → 16 [34] → 2	600	361
4	2 → 7 (463) → 19 (122) → 2 → 4 [16] → 5 [296] → 13 [288] → 2	585	600
5	2 → 11 (176) → 20 (50) → 15 (215) → 4 (159) → 2 → 14 [281] → 17 [62] → 4 [257] → 2	600	600
Total		2,979	2,048

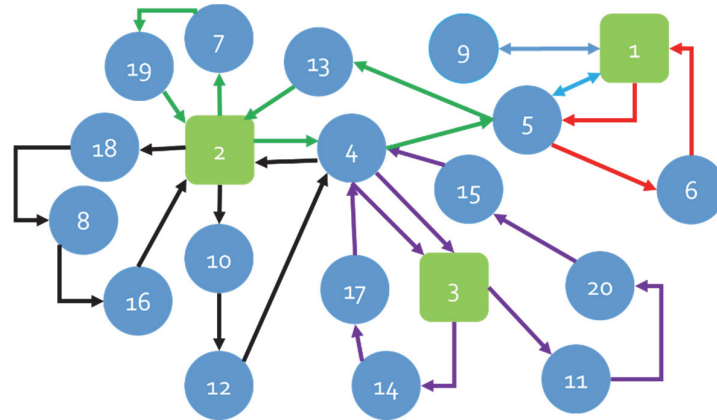


Fig. 4. Distribution route of period 11

Fig. 4 reveals that all vehicles, except Vehicle 2, perform two trips during the period of distribution when visiting Tempuran (node 5) and then Sriti (node 6). Noteworthy management is experienced by Tumpuk village (node 4), where four split deliveries are arranged by Madusari and Babadan depots to fulfil the demand. While, for the same case of excess demand in Tempuran (node 5), three split deliveries are required. From the supply side, it can be verified by Table 5 that an amount of 1,681 packs of rice have been supplied to 3 villages by UPGB Ngrupit, 2,146 packs for 9 villages by GSP Madusari, and another 1,200 packs for 6 villages by GBB Babadan, with a total distribution cost of IDR 14,148,400.

6. Conclusion

In this paper, a mixed integer linear programming model for product distribution between depot and customers by means a fleet of vehicles has been developed. The aim of the study was to fulfil transport requests in terms of distribution route for each dispatched vehicle as well as the number of delivered products while minimizing the operational cost. A generic VRP model that offers three features was introduced—namely multiple depots establishment, multiple trip transportation, and split delivery mechanism (MD-MT-VRP-SD model). This model can straightforwardly be streamlined for the assertion of simpler requirements. This model can also handle a routing problem with a fleet of different capacities. It was employed to a real-life problem of rice-for-the-poor distribution in Ponorogo district of Indonesia. Deliveries were conducted between 3 depots—8, 17 and 23 villages depended on the distribution period—using a fleet of 5 vehicles of homogeneous capacity. This local problem was surprisingly very interesting, as by utilizing the generic model, the three variants of VRP, namely MD-MT-VRP, MD-VRP-SD and MD-MT-VRP-SD models were characterized. For each model, the optimal distribution route and the number of delivered products were provided. An exact approach has been applied to solve the problem. Thus, it is suggested to consider heuristic and metaheuristic algorithms to address the problem, as they can often provide solutions with less computational effort than the optimization algorithms and iterative methods. This exertion was for anticipating more complicated and challenging requirements relating to the same problem, such as distribution problem

in a whole stage that consists of twelve periods or one that deals with inter-district distribution. For information, the BULOG regional office of Ponorogo is responsible for the distribution of rice among villages in the districts of Ponorogo, Pacitan and Magetan. From this perspective, the success of the distribution process depends heavily on good planning.

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