A Simulated Annealing Heuristics for Delivery Time Equality of the Couriers in an Expedition Company

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Abstract

The COVID-19 pandemic has affected a person's habits, especially when it comes to online shopping. This situation has increased the need for goods delivery services. Therefore, extra assistance is needed for goods delivery activities which require couriers to prioritize the accuracy and speed of delivery time to each customer location. Selection of the correct route is one of the main factors. Demand becomes a benchmark, but other limitations such as working hours and load capacity need to be considered. This study proposes the Simulated Annealing (SA) algorithm to regulate the working hours, referred to as delivery time, required by couriers to aim for equality of the workloads. From these calculations, the results show that the SA can be used in determining the optimal route with a reduction in the gap reaching 3.78 % of the expected working hours. There are 26 couriers assigned for 52 routes formed from the Simulated Annealing (SA). Therefore, 26 couriers can distribute all of the goods. All destination points have been handled correctly, with an average working hour of 7.7 hours, closer to the expected total delivery time of eight hours.

Keywords:
Courier, Delivery Time, Goods, Route, Simulated Annealing

1. Introduction

The Coronavirus disease (COVID-19), caused by SARS-Virus CoV-2, was first identified in December 2019 in the Chinese city of Wuhan and was declared a global pandemic by the World Health Organization (WHO) on 11 March 2020 (Lai et al., 2020). The pandemic has spread rapidly outside of China, in fact, almost every country globally, one of which is Indonesia. The Indonesian government is increasingly implementing defense strategies to fight the epidemic, such as social distancing, use a mask until work from home. COVID-19 has affected millions of people, both health and habits, such as choosing to shop from home. According to the results of a survey from the Indonesian Internet Providers Association in 2019-2020 regarding the behavior of internet users during the COVID-19 pandemic, the majority of users access the internet more than eight hours a day to access social media, message communication, online games, and online shopping (Asosiasi Penyelenggara Jasa Internet Indonesia, 2021). Meanwhile, fashion and beauty products, household products, and electronic products are the three most purchased products by users when shopping online during this pandemic.

This phenomenon has increased the need for freight forwarding or expedition company services. Furthermore, to compete for the market, companies engaged in shipping services need to make continuous service improvements. One of the efforts made by the company to maintain customer satisfaction is the provision of extra services for the delivery of goods. In this case, the courier must prioritize punctuality. The goods must be delivered and arrive at the recipient's hands on time. It has the deadline that the goods to those promised in each type of delivery service product chosen by the sender during the transaction.

This study is based on real problem faces by an expedition company in Indonesia. This company has twenty seven couriers that should work every day with only three days off. The company expect to give four days off for each courier. Therefore, they should make the schedule to determine the best route for each courier. In this current condition the assignment for each courier is based on the sub-district. For couriers who get to sub-district with low delivery demand, the delivery is complete within six hours. However, for couriers who assigned to sub-district with many deliveries demands every day, the total delivery time is up to ten hours. Thus, it causes a difference in working hours between couriers, which is ranging from six hours to ten hours in one day. The difference in working hours is influenced by the number of items sent to each district handled by each courier. This situation results in inequality in the workload between each courier. If this is allowed, the courier's work performance will be less than optimal because they feel they are not treated fairly by the company.

Research on the scheduling of both crew and vehicles has been carried out previously. Hanafi et al (2014) studies minimize the number of assignments to the staff by reducing the amount of transition time for each crew's idle time. Haridass et al., (2014) investigates minimizing total truck distance. Janacek et al., (2017) minimized total transit costs. Boyer et al., (2018) minimizes total operating costs based on vehicle use and driver wages according to work schedules. Vermuyten et al (2018) optimizes medical staff working hours by considering other variables such as days worker holidays. Compared to previous researches, this research minimizes the number of courier working hours with a maximum working hour limit of 8 hours a day and holidays for each courier every month.

This research is an effort to improve the delivery route of goods by each courier to create an actual workload or delivery time by addressing two main research questions (RQs):
RQ1: How is the optimal scheduling of work assignments according to each courier's route distribution to achieve an equal distribution of workloads?
RQ2: How to determine the optimal route for courier delivery activities according to the delivery area handled?

In answering this RQs, we use Operational Research techniques for optimal scheduling planning (Medard & Sawhney, 2007). By using optimization approaches, we solve worker scheduling problems. Optimization can also be used to solve large-scale linear programming techniques and integer programming and Artificial Intelligence methods such as Simulated Annealing, Neural Network Fuzzy Logic, and Genetic Algorithms (Kerati et al., 2002). In this case, the research focuses on Simulated Annealing (SA) in determining the courier assignment schedule at the company. The Simulated Annealing algorithm is the suitable method for job scheduling problems and several other problems (Santosa & Willy, 2011).

2. Literature Review

2.1 Vehicle Routing Problem

The courier delivery network is one of the essential infrastructures operated by courier companies (Lin et al., 2019). The optimization of the distribution route network influences delivery times. In this case, route determination or selection is considered a combination of the facility location problem (FLP) and the traveling salesman problem (TSP) (Applegate et al., 2006; Gutin & Punnen, 2006) or the Vehicle Routing Problem (VRP) (Dantzig & Ramser, 1959).
TSP and VRP are pretty familiar with combinatorial optimization. Where, after mapping which locations were visited, along with the routes they have, the provision of vehicle load capacity constraints will become a Capacitated Vehicle Routing Problem (CVRP)(Achuthan & Caccetta, 1991; Ralphs et al., 2010). Meanwhile, the addition of the time constraint will become the Vehicle Routing Problem with Time Windows (VRPTW) (Baños et al., 2013; El-Sherbeny, 2010; Santosa, 2017). A general description of VRPTW has been described in a paper journal (El-Sherbeny, 2010), which discusses many appropriate methods, heuristic, and meta-heuristic methods. In addition to minimizing the total travel time or distance (Baños et al., 2013), it is also considered to minimize the imbalance between routes using the Simulated Annealing algorithm.

2.2 Scheduling and Workload

Unsuitable scheduling will undoubtedly create an uneven workload. In this case, a particular method is needed to create an equal workload. Several solutions to problems related to workload have been presented in several articles. The study by Hanafi et al (2014) minimizes the number of assignments to railway crews by minimizing the number of long idle transition times for each railway crew. The results are near-optimal crew scheduling with acceptable computation time using Simulated Annealing. Furthermore, Vermuyten et al (2018) optimize medical staff working hours by considering other variables such as worker holidays using the Diving Heuristic & Variable Neighborhood Decomposition Search method. Then, Salazar-Aguilar et. al (2011) balance the workload by considering the number of customers as a performance criterion in a bottled beverage distribution company in Mexico. Camacho-Vallejo et al. (2019) propose to minimize deviation to the workload between delivery zones and customer waiting time (latency). The company will distribute its products to the delivery service zone area or district, which is served by a single shipper, resulting in routing planning.

3. Research Methods

Simulated Annealing (SA) is an algorithm that mimics the physical behavior of the steel cooling process in which the steel is initially heated to a specific temperature and then slowly cooled (Santosa & Willy, 2011). Another meaning of Simulated Annealing is a random search technique that uses the analogy of how to cool iron and freeze it into a minimum crystallization energy structure (annealing process) and look for the minimum value in the system as a whole, forming the basis of optimization techniques for combinatorial problems and other problems (Santosa, 2017). The Simulated Annealing method mimics the slow cooling process of boiling steel/metal to achieve the minimum value of a function in minimization problems. Annealing itself has a meaning as a process of melting solid material and cooling it slowly by reducing the temperature (Santosa & Willy, 2011). The particles of the material try to organize themselves during the cooling process. This cooling process is carried out by determining parameters similar to temperature, then controlled again using the Boltzmann Probability Distribution concept. The Boltzmann Probability Distribution states that the energy (E) of a system in heat equilibrium at temperature T is distributed probabilistically, referring to the formula:

$$\boldsymbol{P(E) = e^{(\Delta E/kT)}} \quad (1)$$

where:
$P\ (E)$ = Chance of reaching the E energy level
k = Boltzmann's constant
T = Temperature
ΔE = The difference in energy levels before and after the energy change

Equation (1) means that at high temperature, the system has a nearly uniform probability of the interval [1, 0] being at any state. Whereas at low temperatures, the system will have a low probability of a high energy state. This situation shows that if the solution search process follows the Boltzmann convergence probability distribution, the simulated annealing algorithm can be adjusted by adjusting the temperature T.

4. Data Collection

In this study, the target company is a company engaged in the service sector, namely shipping services or expedition for goods sent by land, sea, or air. The company was founded in addition to reducing the cost of electricity. It is also hoped that the company can guarantee delivery services according to the company motto, which is "on time every time." This company has a distribution coverage covering five sub-districts in the South Surabaya region consisting of 24 sub-districts. In this distribution activity, the company has 27 couriers ready to be assigned to deliver goods to the customer's location by dividing the couriers into five groups districts based on the number of sub-districts handled by the company's DC (Delivery Center). Table 1 shows the data and sequences of 54 delivery routes carried out by 27 couriers per day in a month. The number of group is formed according to the number of sub-districts handled by the company. The data we collected from the company are as follows:

1. The covering the districts area are: (i). Gunung Anyar (four sub-districts), (ii). Rungkut (six four sub-districts), (iii) Wonokromo (four sub-districts), (iv) Tenggilis Mejoyo (five four sub-districts) and (v) Wonocolo (five sub-districts).
2. Every sub-districs has Rukun Warga (RW) area. RWs area is a group of household area (the exact delivery location) that narrower than the sub-districts. We give the code number of the RW starting from first district and first sub-district and the following are the second sub-district and so forth. For example: Code 1-9 are for nine RWs that located in sub-district Gunung Anyar Tambak, district Gunung Anyar and then Code 10-16 are for seven RWs that located in sub-district Gunung Anyar, district Gunung Anyar. Therefore, we have Node 1-218 that needed to be served.
3. DC is delivery center that is the starting and end point of each courier.

4. Demand data. The demand of each RWs we used in this study are the data of the company from January-March 2021.
5. Distance and Time Matrix. Based on the RWs, Sub-Districts and District, we generate the Distance and Time Matrix from the real distance in Google Maps, and using them to generate the routes. Since we use the real distance, the delivery time from A to B is not the same as B to A.
6. Each route that generated must not exceed the capacity of each courier each day, which is 100 unit of goods per courier/day.
7. The expected delivery time for each courier in each day is 8 hours or 480 minutes by dividing into two rounds: first delivery round in the morning and second delivery round in the afternoon.

5. Results and Discussion

5.1 Problem Description

In the delivery of goods, the company has 27 couriers ready to be assigned to deliver goods to the customer's location by dividing the couriers into five groups based on the number of districts handled by the company's DC (Delivery Center). While the number of group members is formed according to the number of sub-districts from each sub-district handled by the company, covering the area between Gunung Anyar (four sub-districts) Rungkut (six four sub-districts), Wonokromo (four sub-districts), Tenggilis Mejoyo (five four sub-districts) and Wonocolo (five sub-districts). The current problem is that the working hours for each courier are different, which is between six hours and ten hours in one day. The difference in working hours is influenced by how many and how few goods are sent to each district handled by each courier. For couriers who get to sub-district with low delivery demand, the delivery is complete within six hours. However, for couriers who in charge to send the goods to sub-districts with many deliveries demands every day, the total delivery time needed is ten hours. This situation results in inequality in the workload of each courier.

5.2 Simulated Annealing Algorithm

The simulated annealing algorithm adopted in this study refers to Vincent et al. (2019), as follows:

1. Determine Simulated Annealing parameters such as setting the initial temperature (T_0) where $T_0 = T$, final temperature (T_f), alpha value (α).
2. Generate Initial solution or initial route selection, as the current initial solution denoted by X (X_b) in the SA process, which has been pre-formed using Nearest Neighbor (*NN*).
   - The current best initial solution (X) is denoted by X_{best} (X_b)
   - The objective function of X (Obj (X)) is denoted by F_{best} (F_b)
3. Determine of the new solution (Y) resulting from the improvement of the previous solution X and based on the value of p. Where, the p is a random result that appears randomly after random generation (r), with p is $0 < p < 1$. The new solution (Y) can be formed by *Swapping Mutation*, *Flipping Mutation* or *Sliding Mutation*. The new solution is used as input for Iteration 2.
   - Swapping mutation, if $p \leq 0.33$. The swapping mutation procedure is illustrated in Figure 1 as follows:

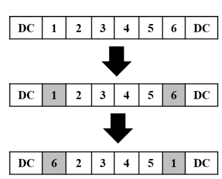

Figure 1. Swapping Mutation

   - Flipping mutation, if $0.34 \leq p \leq 0.66$. The flipping mutation procedure is illustrated in Figure 2 as follows:

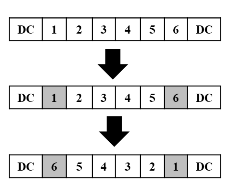

Figure 2. Flipping Mutation

- Sliding mutation, if p $\geq$ 0.67. The sliding mutation procedure is illustrated in Figure 3 as follows:

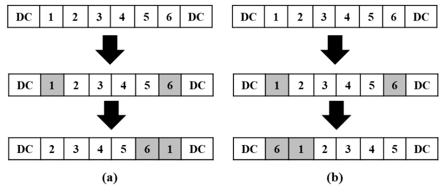

Figure 3. Sliding Mutation, (a) Forward Sliding and (b) Backward Sliding

4. Evaluate each objective function value of X (Obj (X)) and do comparison. Evaluation is done with the formula Δ = Obj (Y) - Obj (X).
   - If $\Delta \leq 0$, then the objective value of Y is better than X, therefore X is replaced by Y.
   - If $\Delta > 0$, it is possible to replace X into Y with the first step, which is to generate a random value (r) then perform calculations using the formula e ($-\Delta / kT$). The result of this calculation is the value of $r < e^{(-\Delta / kT)}$. If the value of $r < e^{(-\Delta / kT)}$ then changes the value of X to Y. If not, then accepting X is still the best solution and go back to Step 3.
5. Perform annealing schedule by reducing the initial temperature (T_0) using the formula $T = \alpha T$, where α is a constant for deriving control parameters with a value of α <1.
6. Terminate the algorithm if the current temperature T_0 is lower than the final temperature (T_f) or the best solution at this time *Xbest* is not further improved as much as N (Non-improving) in successive temperature reduction.
   The illustration of the routing problem in this study is shown in Figure 4.

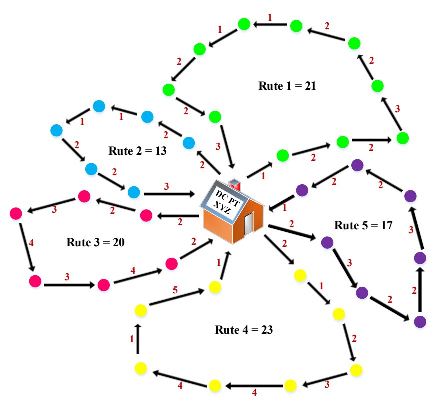

Figure 4. Routing Problem Illustration and the Number of Goods Carried by the Courier

5.3 Mathematical Model

Based on the problem description mentioned above, the mathematical formulation of the problem is adopted from the traditional vehicle routing problem with time constraints (Desrochers et al., 1992) and we added the capacity of the courier in each routenconstraints, the expression is follows:

<u>Notation</u>

Decision Variables:

x_{ij}^k = 1, if route travel from node i to node j in route k, 0 if otherwise

Parameters:

k = route travelled by couriers (k = 1…n)

c_{ij} = travel distance from node i to node j (i = 0…218 and j = 0…218)

t_{ij} = delivery time from node *i* to node *j*
d_i = demand in node *i*
Q = capacity each courier in each route

Objective Function: minimize the total delivery time each route

$$z = \sum_{k=1}^{n} \sum_{i=0}^{218} \sum_{j=0}^{218} c_{ij}\, x_{ij}^{k} \quad (2)$$

Table 1. Existing Delivery Route by Each Courier

Coverage Area		Courier Code	Number of RW	Existing Delivery Route																			Total Delivery Time		Gap to Expected Time (minutes)	Gap Percentage (%)	Delivery time ≤ 480 minutes?
District	Sub-district			First Delivery Route									Second Delivery Route										Minutes	Hours			
GUNUNG ANYAR	Kel. Gunung Anyar Tambak	A	9	DC	9	8	7	6	5	DC			DC	4	3	2	1	DC					444,55	7,41	-35,45	-7,39%	Yes
	Kel. Gunung Anyar	B	7	DC	10	11	12	13	DC				DC	14	15	16	DC						472,81	7,88	-7,19	-1,50%	Yes
	Kel. Rungkut Tengah	C	8	DC	20	21	22	23	DC				DC	24	18	19	17	DC					464,38	7,74	-15,63	-3,26%	Yes
	Kel. Rungkut Menanggal	D	7	DC	26	27	28	DC					DC	29	30	31	25	DC					511,85	8,53	31,85	6,64%	No
RUNGKUT	Kel. Kalirungkut	E	15	DC	39	40	41	42	43	44	45	DC	DC	46	37	38	35	36	34	33	32	DC	444,53	7,41	-35,48	-7,39%	Yes
	Kel. Rungkut Kidul	F	6	DC	47	48	49	DC					DC	50	51	52	DC						464,70	7,75	-15,30	-3,19%	Yes
		G	6	DC	58	57	56	DC					DC	55	54	53	DC						467,09	7,78	-12,91	-2,69%	Yes
	Kel. Medokan Ayu	H	14	DC	63	64	65	66	67	68	69	DC	DC	70	71	72	59	60	61	62	DC		512,61	8,54	32,61	6,79%	No
	Kel. Wonorejo	I	10	DC	76	77	78	79	80	DC			DC	81	82	73	74	75	DC				429,38	7,16	-50,63	-10,55%	Yes
	Kel. Penjaringan Sari	J	12	DC	85	86	84	83	88	87	DC		DC	91	90	89	94	93	92	DC			478,50	7,98	-1,50	-0,31%	Yes
	Kel. Kedung Baruk	K	10	DC	95	96	97	98	99	DC			DC	100	101	102	103	104	DC				532,40	8,87	52,40	10,92%	No
WONOKROMO	Kel. Wonokromo	L	8	DC	108	109	110	111	DC				DC	112	105	106	107	DC					362,20	6,04	-117,80	-24,54%	Yes
	Kel. Jagir	M	11	DC	114	115	116	117	118	119	DC		DC	120	121	122	123	113	DC				447,79	7,46	-32,21	-6,71%	Yes
	Kel. Ngagel Rejo	N	12	DC	132	133	134	135	124	125	DC		DC	126	127	128	129	130	131	DC			517,83	8,63	37,82	7,88%	No
	Kel. Ngagel	O	5	DC	139	140	136	DC					DC	137	138	DC							361,38	6,02	-118,63	-24,71%	Yes
TENGGILIS MEJOYO	Kel. Kutisari	P	5	DC	148	149	146	DC					DC	147	142	DC							368,70	6,15	-111,30	-23,19%	Yes
		Q	4	DC	145	144	DC						DC	143	141	DC							364,90	6,08	-115,10	-23,98%	Yes
	Kel. Kendangsari	R	6	DC	151	152	153	DC					DC	154	155	150	DC						366,93	6,12	-113,08	-23,56%	Yes
	Kel. Tengilis Mejoyo	S	10	DC	164	165	157	158	159	DC			DC	160	161	162	163	156	DC				435,95	7,27	-44,05	-9,18%	Yes
	Kel. Panjang Jiwo	T	7	DC	168	169	170	171	DC				DC	172	167	166	DC						554,75	9,25	74,75	15,57%	No
	Kel. Prapen	U	3	DC	175	174	DC						DC	173	DC								449,10	7,49	-30,90	-6,44%	Yes
WONOCOLO	Kel. Siwalan Kerto	V	3	DC	179	180	DC						DC	181	DC								427,45	7,12	-52,55	-10,95%	Yes
		W	3	DC	178	177	DC						DC	176	DC								488,60	8,14	8,60	1,79%	No
	Kel. Jemur Wonosari	X	10	DC	189	190	187	188	182	DC			DC	183	184	185	186	191	DC				493,98	8,23	13,98	2,91%	No
	Kel. Margorejo	Y	8	DC	198	199	193	194	DC				DC	195	196	197	192	DC					472,18	7,87	-7,82	-1,63%	Yes
	Kel. Sidosermo	Z	8	DC	204	205	206	207	DC				DC	203	202	201	200	DC					435,10	7,25	-44,90	-9,35%	Yes
	Kel. Bendul Merisi	AA	11	DC	209	210	211	212	213	214	DC		DC	215	216	217	218	208	DC				400,56	6,68	-79,44	-16,55%	Yes
Total		27	218	Average Total Delivery Time																			450,75	7,51	-29,25	-6,10%	

Constraints:

- Each node is only visited exactly once by one courier

$$\sum_{k=1}^{n} \sum_{j=0,j\neq i}^{218} x_{ij}^{k} = 1 \quad (3)$$

- The total demand on a route does not exceed the capacity of the courier serving that route.

$$\sum_{i=0}^{218} d_i \sum_{j\neq 1}^{218} x_{ij}^{k} \leq Q \quad (4)$$

- The total delivery time on a route does not exceed t_{max}

$$\sum_{i=0}^{218} t_{ij} \sum_{j=0,j\neq i}^{218} x_{ij}^{k} \leq t_{max} \quad (5)$$

- Each courier delivery route starts and ends at the delivery center (DC)

$$\sum_{k=1}^{n} \sum_{j=0}^{218} x_{0j}^{k} = 1 \quad (6)$$

- Each courier delivery route starts and ends at the delivery center (DC)

$$\sum_{k=1}^{n} \sum_{j=0,}^{218} x_{i,j-1}^{k} = 1 \quad (7)$$

- Couriers who visit a node, after finishing serving will leave the node

$$\sum_{j=0}^{218} x_{ij}^{k} - \sum_{j=0}^{218} x_{ji}^{k} = 0 \quad (8)$$

5.4 Algorithm Validation

We do the validation using enumeration in which we find the exact solution from all of the possible routes. Table 2 shows the data of distance matrix, delivery time, demand to be delivered and service time, with 1 DC and 3 Nodes. The maximum capacity of each courier is 5 goods and maximum delivery time of a courier is 15 minutes.

Table 2. Data with a DC and Three Nodes

From/To	Distance Matrix				Delivery Time Matrix				Demand	Service Time
	DC	RW 1	RW 2	RW 3	DC	RW 1	RW 2	RW 3		
DC	0	1	1,5	2	0	1,5	2,25	3	0	0
RW 1	1,5	0	1,3	3	2,25	0	1,95	4,5	2	1
RW 2	2,5	2	0	2	3,75	3	0	3	3	1
RW 3	1	3	2,3	0	1,5	4,5	3,45	0	2	1

Based on the data shown in Table 2 we can obtain all of the possible routes of each courier from DC and back to DC. The enumeration result is shown in Table 3.

According to Table 3, 15 routes may appear when determining a new solution in the SA process. The total time (in minutes) generated also varies with each possibility. The optimum solution from the problem is route number 12 in which there are two delivery routes that should be carried by a courier. The total delivery time is 13,5 minutes, and the goods that carried by the courier is ≤ 5. Validation is done to show that the Simulated Annealing Algorithm can perform in finding the optimum solution at the same problem in Table 2. The validation of Simulated Annealing Algorithm are explained as follows:

1. Parameter Simulated Annealing
   - Initial (T_0) where $T_0 = T_1$ = 10˚C
   - Final Temperature (T_f) = 0.4˚C
   - Alfa (α) = 0.2
   - *N* (Non-improving) = 1
   - *I* (iteration in each temperature) = 2
   - $k = 1$
2. Initial route selection
   Initial Solution generation is the current initial solution denoted by X (X_b) in the SA process, which was pre-formed using Nearest Neighbor. Initial Solution is:
   Route I (X) = DC – RW1 – RW2 – DC – DC – RW3 – DC = 15 minutes

Table 3. Enumeration Result

Number of Routes	Route Number	Courier's Route					Delivery Time	Service time	Total Delivery Time	Demand	Feasible?
1	1	DC	RW1	RW2	RW3	DC	11,7	3	14,70	7	No
	2	DC	RW1	RW3	RW2	DC	12	3	15,00	7	No
	3	DC	RW2	RW1	RW3	DC	13,2	3	16,20	7	No
	4	DC	RW2	RW3	RW1	DC	13,2	3	16,20	7	No
	5	DC	RW3	RW1	RW2	DC	11,25	3	14,25	7	No
	6	DC	RW3	RW2	RW1	DC	7,95	3	10,95	7	No
2	7	DC	RW1	RW2	DC		7,5	2	15,00	5	Yes
		DC	RW3	DC			4,5	1		2	
	8	DC	RW2	RW1	DC		7,2	2	14,70	5	Yes
		DC	RW3	DC			4,5	1		2	
	9	DC	RW1	RW3	DC		9,75	2	18,75	4	No
		DC	RW2	DC			6	1		3	
	10	DC	RW3	RW1	DC		7,5	2	16,50	4	No
		DC	RW2	DC			6	1		3	
	11	DC	RW2	RW3	DC		10,2	2	16,95	5	No
		DC	RW1	DC			3,75	1		2	
	12*	DC	RW3	RW2	DC		6,75	2	13,50	5	Yes
		DC	RW1	DC			3,75	1		2	
3	13	DC	RW1	DC			3,75	1	4,75	2	Yes
	14	DC	RW2	DC			6	1	7,00	3	
	15	DC	RW3	DC			4,5	1	5,50	2	

*optimum result of enumeration

Iteration 1

3. The new solution (*Y*) obtained from the improvement of the previous solution *X* and based on *p*. Where the value of *p* is a random result that appears randomly after random generation, with *p* is $0 < p < 1$.
   The new solution (Y) is generated by *Swapping Mutation*, *Flipping Mutation* or *Sliding Mutation*. When the total delivery time on the new route is ≤ 15 minutes, then we allow the first node on the next route (Route II) to enter Route I. Suppose $p = 0.7$, then the *Sliding Mutation* is carried out on the previously formed route by shifting the RW1 node backwards.
   Previous Solution (*X*) = DC – RW1 – RW2 – DC – DC – RW3 – DC = 15 minutes
   New Route (*Y*) = DC – RW2 – RW1 – DC – DC – RW3 – DC = 14.7 minutes

4. Evaluating of each objective function value of *X* (Obj (*X*)) and compared. Evaluation is done with a formula: $\Delta E = \Delta = Obj(Y) - Obj(X)$.
   Previous Solution (*X*) = DC – RW1 – RW2 – DC – DC – RW3 – DC = 15 minutes
   New Route (*Y*) = DC – RW2 – RW1 – DC – DC – RW3 – DC = 14.7 minutes
   $\Delta = Obj(Y) - Obj(X)$ = 14.7 minutes – 15 minutes = -0.3 minutes
   If $\Delta \leq 0$, then the objective value of Y is better than X, therefore X is replaced by Y.
   Go back to step 3 by going to iteration 2, and route Y is the best choice.

Iteration 2

3. Determining of the new solution (*Y*) resulting from improvements to the previous solution *X* and based on the value of *p*.
   Suppose $p = 0.68$, then performed *Sliding Mutation* on the previously formed route.
   Previous Solution (*X*) = DC – RW2 – RW1 – DC – DC – RW3 – DC = 14.7 minutes
   New Route (*Y*) = DC – RW3 – RW2 – DC – DC – RW1 – DC = 13.5 minutes
   Checking the maximum time on the formed route, each route's maximum time is ≤ 15 minutes.
   The New Route (*Y*) has a total delivery time of ≤ 15 minutes which is 13.5 minutes, then continues the *SA* algorithm to step 4.

4. Evaluating of each objective function value of *X* (Obj (*X*)) and compared. Evaluation is done with a formula: ΔE

= Δ = *Obj(Y) – Obj(X)*.
Previous Solution (X) = DC – RW2 – RW1 – DC – DC – RW3 – DC = 14.7 minutes
New Route (Y) = DC – RW3 – RW2 – DC – DC – RW1 – DC = 13.5 minutes
Δ = Obj(Y) – Obj(X) = 13.5 minutes – 14.7 minutes = -1.2 minutes
If $\Delta \leq 0$, then the objective value of Y is better than X, therefore X is replaced by Y.
Since the iteration in this temperature is 2, we proceed to step 5 by updating the T and continue to iteration 3 using the new route.

5. Doing *Annealing Schedule* with a decrease in the initial temperature (T_0) using the formula $T = \alpha \times T$
$T_2 = \alpha \times T_1$ = 0.2 x 10 = 2 ˚C

Iteration 3

3. Determining of the new solution (Y) resulting from improvements to the previous solution X and based on the value of p.
Suppose $p = 0.25$, then performed *Swapping Mutation* on the previously formed route.
Previous Solution (X) = DC – RW3 – RW2 – DC – DC – RW1 – DC = 13.5 minutes
New Route (Y) = DC – RW2 – RW3 – DC – DC – RW1 – DC = 16.95 minutes
Checking the maximum time on the formed route, each route's maximum time is ≤ 15 minutes.
The New Route (Y) has a total delivery time ≥ 15 minutes, which is 16.95 minutes, then continues the *SA* algorithm to step 4.

4. Evaluating of each objective function value of X (Obj (X)) and compared. Evaluation is done with a formula: ΔE = Δ = Obj (Y) – Obj(X).
Previous Solution (X) = DC – RW3 – RW2 – DC – DC – RW1 – DC = 13.5 minutes
New Route (Y) = DC – RW2 – RW3 – DC – DC – RW1 – DC = 16.95 minutes
Δ = Obj(Y) – Obj(X) = 13.5 minutes – 16.95 minutes = 3.45 minutes
If $\Delta > 0$, meaning that there is no improvement, then we generate a random value (r) = 0.3
Then, perform calculations using the formula → $e^{(-\Delta / kT)} = e^{(-3.45 / 2)}$ = 0.178. The value of $r > e\ (-\Delta / kT)$ then accepting X is still the best solution and since there is no more improvement, we proceed to step 6.

6. Terminate the algorithm because the best solution at this time (X_{best}) is not further improved as much as N (Non-improving) in successive temperature reduction. Therefore, the best solution is X = DC – RW3 – RW2 – DC – DC – RW1 – DC = 13.5 minutes. This result is same as the enumeration result with the same data. By using Simulated Annealing, we can obtain the solution same as the exact solution from the enumeration. Therefore, we can conclude that the Simulated Annealing is valid.

5.5 Numerical Result

We have real data from the expedition company in the calculation process using *Simulated Annealing*. Instead of assigning the courier by sub-district as used in the current setting, we proposed to allocate the courier based on the closer distance. We start the SA algorithm by determining the *Initial Solution*, denoted by X. The initial solution is taken from the first route previously formed through *Nearest Neighbor*. The total delivery time for each courier should not exceed eight hours. However, it is allowed for each courier to have two delivery routes each day. The maximum time for each route is four hours (240 minutes) and eight hours (480) if the courier is assigned for two delivery routes. We generate each route by adding a new node closer to the latest node visited. If the total delivery time for the route is less than 4 hours or 240 minutes, then a new node will be added to the current route. The addition of these points must still meet the requirements of the expected total working time limit of two routes is less than or equal to 8 hours or 480 minutes. The vehicle load capacity limit is less than 100 items in one delivery. We do the *Nearest Neighbor* for each of 218 nodes and found that 53 routes should be served by 27 couriers, as shown in Table 4. In this result, the route delivery time is less than 240 minutes, which is better off than the existing.

Table 4. Routes obtained from Nearest Neighbor

No.	Courier Code	Nearest Neighbor Routes																					Time (minutes)	Gap to Expected Time (minutes)	Gap Percentage (%)	Delivery time ≤ 480 minutes?
		First Delivery Route												Second Delivery Route												
1	A	DC	39	40	41	42	43	44	45	46	37	38	DC	DC	47	48	49	DC					437,08	-42,93	-8,94%	Yes
2	B	DC	51	52	53	54	DC							DC	58	57	50	DC					467,89	-12,11	-2,52%	Yes
3	C	DC	76	77	78	79	80	81	82	DC				DC	73	74	75	DC					408,68	-71,33	-14,86%	Yes
4	D	DC	85	86	84	83	88	87	DC					DC	90	91	89	94	92	DC			453,75	-26,25	-5,47%	Yes
5	E	DC	93	95	96	97	98	99	DC					DC	189	190	187	188	DC				447,35	-32,65	-6,80%	Yes
6	F	DC	191	182	183	184	185	186	DC					DC	204	205	206	207	DC				469,50	-10,50	-2,19%	Yes
7	G	DC	209	210	211	212	213	214	215	216	DC			DC	208	218	217	198	199	DC			462,19	-17,81	-3,71%	Yes
8	H	DC	9	8	7	6	5	4	DC					DC	20	21	22	23	24	18	19	DC	477,50	-2,50	-0,52%	Yes
9	I	DC	26	27	28	29	30	DC						DC	65	66	DC						462,30	-17,70	-3,69%	Yes
10	J	DC	DC	103	104	101	102	100	DC					DC	114	115	116	117	118	DC			468,35	-11,65	-2,43%	Yes
11	K	DC	119	120	121	122	123	113	DC					DC	175	172	DC						451,99	-28,01	-5,84%	Yes
12	L	DC	179	180	DC									DC	203	202	201	DC					476,85	-3,15	-0,66%	Yes
13	M	DC	2	3	1	10	DC							DC	14	15	16	DC					438,31	-41,69	-8,68%	Yes
14	N	DC	31	25	32	33	34	35	36	DC				DC	59	60	61	DC					461,84	-18,16	-3,78%	Yes
15	O	DC	67	68	69	70	71	72	63	64	62	DC		DC	178	DC							463,28	-16,73	-3,48%	Yes
16	P	DC	139	140	138	137	DC							DC	146	147	DC						404,20	-75,80	-15,79%	Yes
17	Q	DC	148	149	141	142	DC							DC	11	12	DC						450,63	-29,38	-6,12%	Yes
18	R	DC	13	17	55	56	DC							DC	132	133	DC						461,31	-18,69	-3,89%	Yes
19	S	DC	164	165	157	158	159	160	161	DC				DC	168	169	DC						455,09	-24,91	-5,19%	Yes
20	T	DC	170	171	173	DC								DC	124	125	DC						451,86	-28,14	-5,86%	Yes
21	U	DC	135	134	131	130	129	128	DC					DC	151	152	153	DC					440,85	-39,15	-8,16%	Yes
22	V	DC	163	162	156	154	155	DC						DC	200	192	193	DC					468,59	-11,41	-2,38%	Yes
23	W	DC	105	106	107	108	109	110	DC					DC	111	112	136	DC					434,53	-45,48	-9,47%	Yes
24	X	DC	127	126	166	167	DC							DC	181	DC							402,36	-77,64	-16,17%	Yes
25	Y	DC	174	194	DC									DC	197	196	195	DC					460,46	-19,54	-4,07%	Yes
26	Z	DC	145	144	143	DC								DC	177	DC							460,46	-19,54	-4,07%	Yes
27	AA	DC	176	150	DC																		261,16	-218,84	-45,59%	Yes
Total	27	Average Total Delivery Time																					444,38	-35,62	-7,42%	

Table 5 Routes obtained from Simulated Annealing Algorithm

No.	Courier Code	Simulated Annealing Routes																						Time (minutes)	Gap to Expected Time (minutes)	Gap Percentage (%)	Delivery time ≤ 480 minutes?
		First Delivery Route												Second Delivery Route													
1	A	DC	39	40	41	42	43	44	45	46	38	37	DC	DC	47	48	49	51	DC					479,98	-0,03	-0,01%	Yes
2	B	DC	54	53	52	DC								DC	50	57	58	DC						469,39	-10,61	-2,21%	Yes
3	C	DC	82	81	80	79	78	77	76	DC				DC	73	74	75	85	DC					444,90	-35,10	-7,31%	Yes
4	D	DC	84	83	86	87	88	DC						DC	89	90	91	92	93	94	DC			456,21	-23,79	-4,96%	Yes
5	E	DC	99	98	97	96	95	DC						DC	187	188	189	190	191	DC				445,25	-34,75	-7,24%	Yes
6	F	DC	186	185	184	183	182	DC						DC	209	204	205	206	207	DC				459,65	-20,35	-4,24%	Yes
7	G	DC	216	215	214	213	212	211	210	DC				DC	218	217	198	199	208	114	DC			467,90	-12,10	-2,52%	Yes
8	H	DC	4	5	6	7	8	9	DC					DC	18	19	20	21	22	23	24	26	DC	454,73	-25,28	-5,27%	Yes
9	I	DC	27	28	29	30	DC							DC	104	65	66	DC						477,65	-2,35	-0,49%	Yes
10	J	DC	100	101	102	103	DC							DC	120	119	115	116	117	118	DC			445,80	-34,20	-7,13%	Yes
11	K	DC	113	121	122	123	DC							DC	203	172	175	DC						460,63	-19,38	-4,04%	Yes
12	L	DC	180	179	DC									DC	201	202	164	DC						476,55	-3,45	-0,72%	Yes
13	M	DC	10	3	2	1	DC							DC	14	15	16	59	DC					471,41	-8,59	-1,79%	Yes
14	N	DC	25	31	32	33	34	35	36	DC				DC	60	61	62	DC						473,80	-6,20	-1,29%	Yes
15	O	DC	67	68	69	70	71	72	64	63	DC			DC	178	146	DC							478,55	-1,45	-0,30%	Yes
16	P	DC	140	139	138	137	DC							DC	147	148	150	DC						445,52	-34,49	-7,18%	Yes
17	Q	DC	148	149	141	142	DC							DC	12	11	DC							450,48	-29,53	-6,15%	Yes
18	R	DC	13	17	55	56	DC							DC	132	133	DC							461,31	-18,69	-3,89%	Yes
19	S	DC	165	161	160	159	158	157	DC					DC	168	169	170	DC						472,88	-7,13	-1,48%	Yes
20	T	DC	173	171	DC									DC	124	125	126	127	DC					465,93	-14,08	-2,93%	Yes
21	U	DC	135	134	131	130	129	128	DC					DC	153	152	151	163	DC					475,08	-4,93	-1,03%	Yes
22	V	DC	162	154	155	156	DC							DC	200	193	192	105	DC					468,65	-11,35	-2,36%	Yes
23	W	DC	106	107	108	109	110	DC						DC	136	112	111	167	DC					470,93	-9,07	-1,89%	Yes
24	X	DC	181	DC										DC	176	166	DC							448,70	-31,30	-6,52%	Yes
25	Y	DC	194	174	DC									DC	195	196	197	DC						456,71	-23,29	-4,85%	Yes
26	Z	DC	145	144	143	DC								DC	177	DC								429,38	-50,63	-10,55%	Yes
Total	26	Average Total Delivery Time																						461,84	-18,16	-3,78%	

Furthermore, we do the simulated annealing algorithm as explained in 5.2. We found that 52 routes of 26 couriers have been formed. The entire route can handle 218 RW (Rukun Warga). The total delivery time on each route almost has the same load and less than 240 minutes delivery time. Besides the delivery time close to the actual working time, SA can also reduce the number of couriers from 27 couriers each day to 26 couriers each day. Table 5 shows the result of the routes and the gap improvement between the expected total time and the Simulated Annealing result. This result might help the company minimize the wages cost for the courier and create equal working time.

According to the result shown in Table 5, there are 26 couriers assigned to the 52 routes with the delivery time closer to actual working hours (eight hours) for each courier. The delivery time is close to equal when compared to the existing conditions. Moreover, reducing one courier assigned a day will make it easier for companies to schedule deliveries. For instance, a schedule in a month result in Table 5, used on day one, with the courier code AA has day-off. Sequentially for day two, courier code Z has a day-off and so forth. Therefore, our proposed Simulated Annealing result can obtain an effective schedule for the company to assign their couriers.

6. Conclusion

In this study, we determined the distribution route of each courier in the delivery of goods by considering the maximum capacity and working hours using Simulated Annealing. The results show that SA can be used in determining the optimal route with a reduction in the gap reaching 3.78% of the expected working hours. This gap is reduced compared to the existing route, which is 6.1%. There are 26 routes formed from the SA. Therefore, only 26 couriers with 52 routes will distribute all the nodes. These routes are more efficient than the existing route in which there are 27 couriers assigned for 54 routes. All destination points have been handled correctly, with an average working hour of 461.84 minutes or 7.7 hours. Using these proposed routes, we conclude that our SA can obtain the equally distributed workload for each courier.

Moreover, decreasing the number of couriers from 27 to 26 assigned in a day can make all of the couriers have one more day off. Therefore, they will have five days off in a month. Therefore the company can meet the delivery deadline and customer satisfaction and the courier equal working time. Further research can do by applying Simulated Annealing in mathematical software to generate a more efficient algorithm. Furthermore, expanding the RWs area to two districts in Surabaya and broader areas is also interesting to discuss.

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