VEHICLE ROUTING PROBLEM IN COLD CHAIN BASED ON SWEEP ALGORITHM WITH LOAD DISTANCE

BY

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ABSTRACT

Due to the current epidemic situation that is COVID-19, most people are changing behavior to be the new normal that is mostly staying at home and making us turn to online platforms to order and deliver. including ordering fresh food and ready-to-eat food. That makes us interested in the way how to deliver products to customers by using vehicle routing problems to organize the shortest route for the delivery which has a requirement to deliver fresh food products that should keep at a low temperature to maintain the temperature and reduce the rotten product before it reaches to the customer. That brings us to the vehicle routing problem in cold chain systems, this paper creates a mathematical model with the goal of minimize total distance. A vehicle routing problem with adding load in each node based on the sweep algorithm with load distance that designs solutions to solve the problem and plan which route should select to routing to reduce the total distance.

Computational results on the dataset by excel solver compare with CPLEX solver in terms of problem-solving ability and find the optimal route for delivery Python.

Keywords: VRP, Vehicle routing problem, Cold chain, Serve customer, Time windows, Pickup and delivery, Cold chain logistics, Minimum distance, short route, Nearest neighbor algorithm.

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Pattaraporn Sajchavisate

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LIST OF SYMBOLS/ABBREVIATIONS

Symbols/Abbreviations	**Terms**
SIIT	Sirindhorn International Institute of Technology
TU	Thammasat University
VRP	Vehicle routing problem
VRPT	Vehicle Routing Problem with Transshipment
VRPOT	Vehicle routing problem with optional transshipment demands
VRPTW	Vehicle Routing Problem with Time Windows
VRPLD	Load-Dependent Vehicle Routing Problem
ALNS	Adaptive large neighborhood search
KNN	Nearest neighbor algorithm
OPL	Optimization Programming Language

CHAPTER 1
INTRODUCTION

In this chapter let presented a vehicle routing problem by adding load in each node based on the sweep algorithm with load distance, which can be divided into four parts which are 1.1) Introduction 1.2) Problem Statement 1.3) Research Objective 1.4) Research scope and limitations 1.5) Overview of this research.

1.1 Introduction

Vehicle routing problem (VRP) issues are related to the design of the optimal route to be used to transport goods to serve customer segments. It was first proposed by Dantzig and Ramsar in 1959.

At present, with the current epidemic situation that is COVID-19 the delivery which has the requirement to deliver fresh food products that should keep at a low temperature to maintain the temperature and reduce the rotten product before it reaches the customer has become a new factor of the delivery company for plan the routing with use vehicle routing problems with load to solving it is critical in helping to facilitate the movement of goods and services from one place to another place.

1.2 Problem Statement

The company wants to deliver products when the customer order to deliver goods to customers without a rotten by using vehicle routing problem with adding load in each node based on the sweep algorithm with load distance to design the shortest routes for delivery.

1.3 Research Objective

This project aims to learn and understand the problems of vehicle routing problems with adding load in each node based on the sweep algorithm with load distance to help in planning the route that increases the efficiency and finds the shorted route of transportation. This project has specific objectives as follows:

- To develop an optimization model to minimize load distance in cold chain logistics.
- To find all possible routes that include solution from counter-clockwise and solution from clockwise.
- To plan the routing of the truck.
- To be able to support the needs of customers.
- To develop the model that gets the best solution.

1.4 Research scope and limitation

This paper is solving the vehicle routing problems by adding load in each node based on the sweep algorithm with load distance on a single objective vehicle routing problem in cold chain logistics.

1.5 Overview of this research

This paper consists of the mathematical model of the vehicle routing problem with adding load by using the sweep algorithm with load distance to segmentation of customers that can be done in two ways, which are counterclockwise and clockwise based on Euclidean distance.

CHAPTER 2
REVIEW OF LITERATURE

2.1 Research gaps

This research gaps have a lot of paper in the area of vehicle routing problems, making it provide a wide and credible study area but some research papers are not interesting and can’t use in my independent study then I select only Vehicle routing problem (VRP), Vehicle Routing Problem with Transshipment demands (VRPT), Vehicle routing problem with optional transshipment demands (VRPOT), Vehicle Routing Problem with Time Windows (VRPTW), Load-Dependent Vehicle Routing Problem (LDVRP), Adaptive large neighborhood search (ALNS), Sweep algorithm, Tabu search and Neighbor algorithm there that can be applied in my independent study and this topic has wide of research gaps but I select around 25 literature that can be applied in my independent study that shows in table 2.1.

Table 2.1 Summary of literature review

No	Authors	VRP	VRPT	VRPOT	VRPTW	LDVRP	ALNS	Tabu search	Sweep algorithm	neighbor algorithm
2.1	Leelertkij, T., Parthanadee, P., & Buddhakulsomsiri, J. (2021).	X	X	X						
2.2	Chen, L., Liu, Y., & Langevin, A. (2019).				X		X	X		
2.3	Zhu, S., Fu, H., & Li, Y. (2021).				X					
2.4	Yuanguo, Y., Shenyu, & He. (2018).	X								
2.5	Taş, D., Dellaert, N., Van Woensel, T., & De Kok, T. (2013).				X					
2.6	Ancele, Y., Hà, M. H., Lersteau, C., Matellini, D. B., & Nguyen, T. T. (2021).	X			X					
2.7	Chen, L., Liu, Y., & Langevin, A. (2019).	X			X			X		
2.8	Juan, A. A., Goentzel, J., & Bektaş, T. (2014).					X				
2.9	Lang, Z., Yao, E., Hu, W., & Pan, Z. (2014).	X						X		
2.10	Lang, Z., Yao, E., Hu, W., & Pan, Z. (2014).	X			X					
2.11	Zhang, Y., & Chen, X. D. (2014).	X			X					
2.12	Zhao, Z., Li, X., & Zhou, X. (2018).	X			X					
2.13	Zhao, Z., Li, X., & Zhou, X. (2014).	X			X					
2.14	Zirour, M. (2008).	X			X			X		
2.15	Suraraksa, J., & Shin, K. S. (2019).	X			X			X		
2.16	Suthikarnnarunai, N. (2008).	X			X					
2.17	Desaulniers, G., Desrosiers, J., & Soumis, F. (2002).	X			X			X		
2.18	Liu, G., Hu, J., Yang, Y., Xia, S., & Lim, M. K. (2020)	X								
2.19	Hsiao, Y. H., Chen, M. C., & Chin, C. L. (2017).				X					
2.20	Wang, S., Tao, F., Shi, Y., & Wen, H. (2017).	X			X			X		
2.21	Thammano, A., & Rungwachira, P. (2021).	X						X	X	
2.22	Gu, W., Cattaruzza, D., Ogier, M., & Semet, F. (2019).	X					X			
2.23	Euchi, J., & Sadok, A. (2021).	X					X		X	
2.24	Du, L., & He, R. (2012).	X			X			X		X
2.25	Mohammed, M. A., Abd Ghani, M. K., Hamed, & Alallah, A. H. (2017).				X			X		X
	This paper	X				X			X	X

2.2 Compile objectives

From Table 2.1: Summary of the literature review, the objectives of the previous research can be divided into 5 groups as follows:

- Find the routes that can fulfill both ordinary requests and parcel requests (Zirour, 2008 ; Leeletkij, Parthanadee, & Buddhakulsomsiri, 2021).

- Minimize the total distribution cost that include including of freshness-keeping cost, traditional refrigeration cost, keeping cost in process of transportation and unloading goods, cargo damage cost, fixed cost, green cost and penalty cost, insertion cost (Suthikarnnarunai, 2008; Zirour, 2008; Taş, Dellaert, Van Woensel, & De Kok, 2013; Zhang & Chen, 2014; Zhao, Li, & Zhou, 2014; Hsiao, Chen, & Chin, 2017; Wang, Tao, Shi, & Wen, 2017; Yuanguo, Shenyu, & He, 2018; Zhao, Li, & Zhou, 2018; Chen, Liu, & Langevin, 2019; Chen, Liu, & Langevin, 2019; Gu, Cattaruzza, Ogier, & Semet, 2019; Liu, Hu, Yang, Xia, & Lim, 2020; Zhu, Fu, & Li, 2021).
- Minimize distance (Juan, Goentzel, & Bektaş, 2014; Mohammed, Abd Ghani, Hamed, & Alallah, 2017; Suraraksa & Shin, 2019; Ancele, Hà, Lersetau, Matellini, & Nguyen, 2021; Thammano & Rungwachira, 2021).
- Minimize fuel consumption (Lang, Yao, Hu, & Pan, 2014).
- Minimizes the total travel time (Desaulniers, Desrosiers, & Soumis, 2002; Du & He, 2012; Lang, Yao, Hu, & Pan, 2014; Buchi & Sadok, 2021).

2.3 Sweep algorithm

The sweep algorithm is a strategy for grouping customers. They are grouped under geographical constraints and must be able to serve the need of customers much as many possible by the same vehicle. The steps of the sweep algorithm are as follow.

Step 1: Find the distance between warehouse and customer and set it as a center of transportation.

Step 2: Sweeping in all locations of customers until the end of the list of customers.

Step 3: Sweep adding customer until full of tuck capacity.

Step 4: Redo steep 2-3 agrin until the customer has been included in a cluster.

2.4 Nearest neighbor algorithm

The Nearest Neighbor algorithm is a basic algorithm that stores all available problem and sort incoming data or problem based on a similarity measure. It is typically used to classify a data point based on the point in a given data set that is closest to a given point.

Pros of KNN

- It's simple to implement.
- It can be more effective in large training data.
- It naturally to handles multi-class cases.

Cron of KNN

- It's always necessary to identify the value of K (number of nearest neighbors), which might be complex in some time.
- The computational cost is quite high since we need to calculate the distance of each query instance to all training examples.

2.5 VRP VS VRPLD

Vehicle routing problem (VRP) is to find optimal routes that are the shortest distance for vehicles visiting a set of customers but vehicle routing problem with load distance (VRPLD) is add more constrain about the vehicle's limited capacity that needs to pick up or deliver items ith known demand for a single commodity at various locations without exceeding the vehicle's maximum limit capacity.

2.6 The best way to find results

Real-world data derived from real problems make complicated relevant factors, including traffic instability restrictions of transport under temperature control make it harder to troubleshoot problems from generating data. But it fits more to solve the problem and may get better solution.

CHAPTER 3
METHODOLOGY

This chapter presents an important process for diagnosing and solving problems in vehicle routing problem with adding load in each node based on the sweep algorithm with load distance. This methodology comprises 3.1) VRPLD Mathematical model 3.2) Collect data 3.3) Solver 3.4) Sweep Algorithm with load distance 3.5) Python. The steps is shown in Figure 3.1.

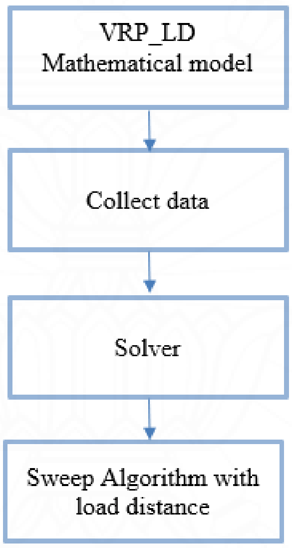

Figure 3.1 Workflow chart

3.1 VRPLD Mathematical model

Mathematical models consist of 3.1.1) Index 3.1.2) Parameters 3.1.3) Decision variables 3.1.4) Objective function and 3.1.5) Mathematics model.

Index

I Set of demand nodes $I \in \{1,2,..,n\}$.

N Set of all nodes include depot $N \in \{0, 1,...,n\}$.

K Set of truckloads $K = 1,2,...,m$.

Parameters

C Vehicle capacity.

D_{ij} Transportation distance associated with traveling from nodes i to j, where i,j ∈ I, i ≠ j.

R_i Amount of regular demand at node i ∈ I.

n Several nodes including the depot.

m Several truckloads including at the depot.

S_j Subtour j.

k Sequences of delivery or number of arcs connecting two nodes within a route.

Decision variables

L_k A total load of a vehicle at node k after loading the order for that node

L_{ijk} Load of a vehicle at node k after loading the order from nodes i to j

y_{ijk} Binary decision variables that include loading the order from nodes i to nodes j.

x_{ij} Binary decision variable from nodes i to nodes j.

Objective function

$$Min \sum_{i \in N} \sum_{j \in N} D_{ij}(km.) \sum_{k \in K} L_{ijk}(ton) + 5(ton) * \sum_{i \in N} \sum_{j \in N} D_{ij}\,(km.) * \; X_{ij} \qquad (3.1)$$

Equation (3.1) shows the objective function. After delivery of all goods to the customer, the load of the truck is equal to 0 that makes the calculation of the distance when return to the depot are not correct since

D_{ij} * L_{ijk} = 0 so it required to add the weight of the vehicle. It was determined that the weight of every vehicle = 5 ton to calculate the total load distance.

Constraints

Constraints from the original VRP

$\sum_{i\in N} x_{ij} = 1 \ ; \ \forall j \in N, i \neq j$ (3.2)

Equation (3.2) shows go to every node.

$\sum_{i\in N} x_{ij} - \sum_{i\in N} x_{ji} = 0 \ ; \ \forall i,j \in N, i \neq j$ (3.3)

Equation (3.3) shows flow in = flow out.

$\sum_{i\in N} y_{0jk} = 1$ (3.4)

Equation (3.4) shows departure from the depot.

$\sum_{i \in N} \sum_{j\in N} R_i x_{ij} \leq C$ (3.5)

Equation (3.5) shows that demand is not over capacity.

$S_j - S_i \geq 1 - |N|\left(1 - X_{ij}\right) \ ; \ \forall i,j \in N, i \neq j$ (3.6)

Equation (3.6) shows subtour constraint.

Constraints from the original VRP_LD.

$\sum_{k\in K} y_{ijk} \leq 1; \forall i,j \in N \ , i \neq j$ (3.7)

Equation (3.7) shows not going to the same route. (LHS is less than RHS)

$\sum_{i\in N} \sum_{j\in N} y_{ijk} = 1; \ \forall k \in K, i \neq j$ (3.8)

Equation (3.8) shows go to every sequence.

$L(1) = \sum_{i\in N} \sum_{j\in N} R_i x_{ij}$ (3.9)

Equation (3.9) shows the total load on the first arc.

$(k) = L(k-1) - \sum_{i\in N} \sum_{j\in N} R_i y_{ijk} \ ; \ \forall k \in K, k > 1, i \neq j$ (3.10)

Equation (3.10) shows cumulative load on arc k after unloading the order on the previous node (arc $k-1$) k must be more than 1.

$\sum_{i\in N} y_{ijk} = \sum_{i\in N} y_{jik+1} \ ; i \neq j \ and \ k = \{1,2,\dots,m\}$ (3.11)

Equation (3.11) shows loading constraint for the case of arc $k = 1$. In this case, the truck must leave the depot ($i = 0$) and go to node j. After, the truck leaves node j and goes to another node.

$C \times y_{ijk} \geq L_{ijk} \ ; \ \forall i,j \in N, k \in K$ (3.12)

Equation (3.12) shows limit capacity truck constraints.

$L_{ijk} \geq L(k) - C \times (1 - y_{ijk}); \forall i, j \in N, k \in K$ (3.13)

Equation (3.13) shows loading constraints.

$x_{ij} = \sum_{k \in K} y_{ijk}\ ; \forall i, j \in N, i \neq j$ (3.14)

Equation (3.14) shows equality constraints.

$y_{ijk} = \{0,1\}$ and $x_{ij} = \{0,1\}$ (3.15)

Equation (3.15) shows binary variable.

$y_{ijk} \geq 0$ and $L_{ijk} \geq 0$ (3.16)

Equation (3.16) shows non negative variable.

3.2 Collect data

The data that used in this research consisted of three datasets, each containing a different number of customers and vehicle capacity are 3 sets as follows

Set 1: 24 nodes. This data set contains information from Robinson and Central Plaza distribution centers in Bangkok, Pathum Thani, Nonthaburi, Samut Sakhon, and Samut Prakan.

Table 3.1 24 Node of customers and Distribution center

Node	Locations	Node	Locations
0	Distribution center	13	Central Chidlom
1	Robinson Mahachai	14	Central Plaza Grand Rama IX
2	Robinson Lifestyle Center Samut Prakan	15	Central Plaza Pinklao
3	Robinson MEGA Bangna	16	Central Festival EastVille
4	Central Plaza Rama 2	17	Central Plaza Ladprao
5	Central Plaza Bangna	18	Robinson Fashion Island Ramindra
6	Robinson Seacon Square	19	Central Plaza Rattanathibet
7	Central Plaza Rama 3	20	Central Ramindra
8	Robinson Bangkae	21	Central Westgate
9	Robinson Bangrak	22	Central Plaza Chaengwattana
10	Robinson Ladkrabang	23	Robinson Sri Samarn
11	Central Silom Complex	24	Central Future Park Rangsit
12	Robinson Sukhumvit		

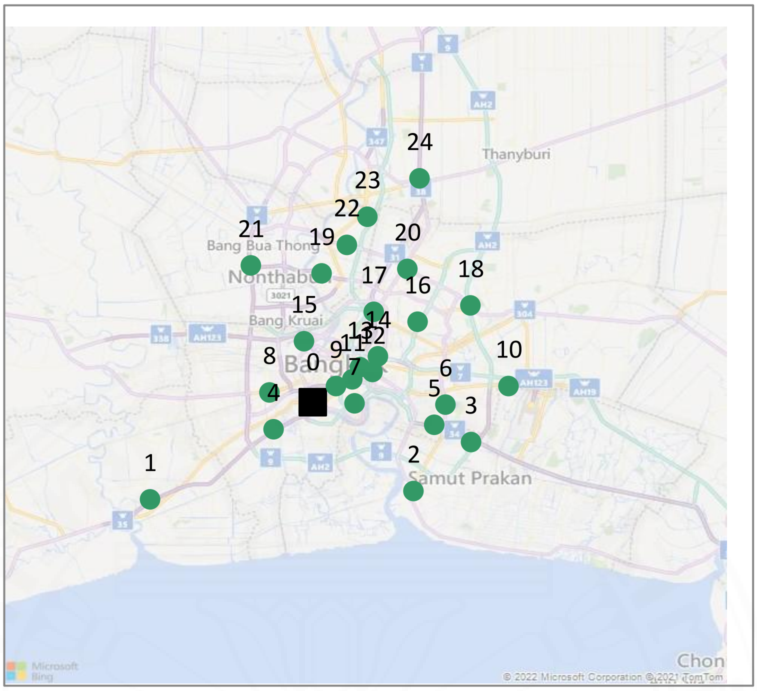

Figure 3.2 Node and Location for 24 nodes

The demand for customers in each node is as follows in table 3.2 with total demand of 63.

Table 3.2 Demand of customers

Node	Demand	Node	Demand
DC	0	13	1
1	3	14	4
2	4	15	1
3	3	16	2
4	3	17	1
5	3	18	2
6	1	19	5
7	3	20	2
8	2	21	1
9	3	22	3
10	5	23	3
11	2	24	2
12	4		

Table 3.3 Capacity limit for 24 nodes

Truck No.	Capacity limit
1	26
2	26
3	26

Set 2: 32 nodes**.** This data set consisted of 31 customers with 1 distribution center.

Table 3.4 32 Node of customers and Distribution center

Node	x	y	Node	x	y
0	82	76	16	88	51
1	96	44	17	91	2
2	50	5	18	19	32
3	49	8	19	93	3
4	13	7	20	50	93
5	29	89	21	98	14
6	58	30	22	5	42
7	84	39	23	42	9
8	14	24	24	61	62
9	2	39	25	9	97
10	3	82	26	80	55
11	5	10	27	57	69
12	98	52	28	23	15
13	84	25	29	20	70
14	61	59	30	85	60
15	1	65	31	98	5

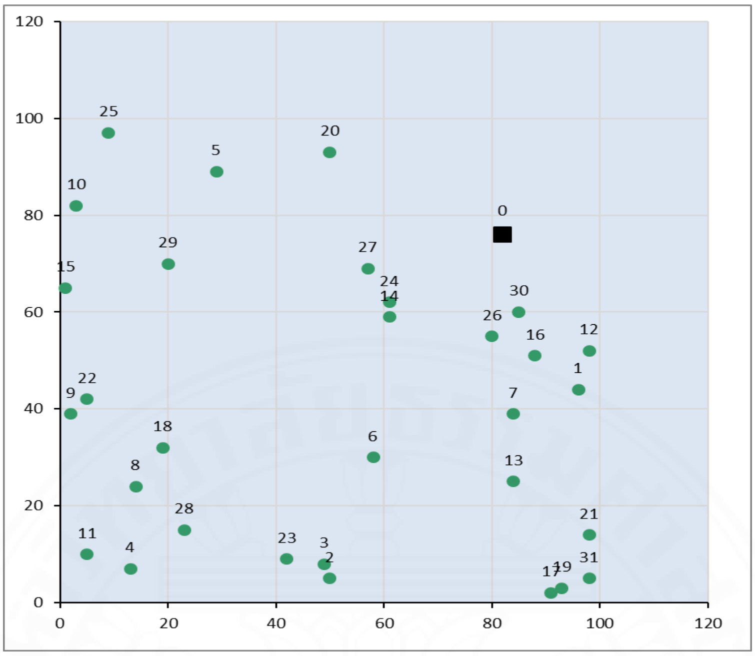

Figure 3.3 Node and Location for 32 nodes

The demand for customers in each node is as follows in table 3.5. with total demand of 410.

Table 3.5 Demand for 32 nodes

Node	Demand	Node	Demand
0	0	16	18
1	19	17	19
2	21	18	1
3	6	19	24
4	19	20	8
5	7	21	12
6	12	22	4
7	16	23	8
8	6	24	24
9	16	25	24
10	8	26	2
11	14	27	20
12	21	28	15
13	16	29	2
14	3	30	14
15	22	31	9

This dataset requires the capacity limit of each tuck as follows in table 3.6.

Table 3.6 Capacity limit for 32 nodes

Truck No.	Capacity limit
1	100
2	100
3	100
4	100
5	100

Set 3: 34 nodes. This data set consisted of 33 customers with 1 distribution center.

Table 3.7 34 Node of customers and Distribution center

Node	X	Y	Node	X	Y
0	73	39	17	27	91
1	67	91	18	49	25
2	39	21	19	29	93
3	3	9	20	71	27
4	97	15	21	31	43
5	91	65	22	27	9
6	55	75	23	67	99
7	55	71	24	87	81
8	57	85	25	23	81
9	21	15	26	89	33
10	47	57	27	71	91
11	51	97	28	19	77
12	11	11	29	65	77
13	43	59	30	87	79
14	63	69	31	19	83
15	55	77	32	1	59
16	35	11	33	55	7

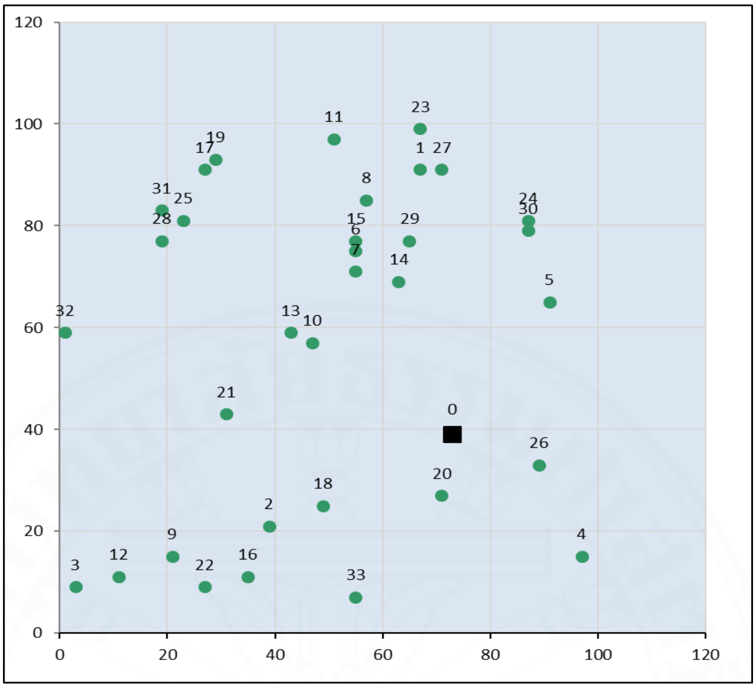

Figure 3.4 Node and Location for 34nodes

The demand for customers in each node is as follows in table 3.8. with total demand of 460.

Table 3.8 Demand for 34 nodes

Node	Demand	Node	Demand
0	0	17	15
1	23	18	9
2	3	19	16
3	24	20	13
4	15	21	16
5	15	22	13
6	24	23	24
7	7	24	20
8	25	25	23
9	13	26	20
10	5	27	3
11	7	28	15
12	5	29	12
13	14	30	19
14	13	31	4
15	5	32	15
16	24	33	1

This dataset requires the capacity limit of each tuck as follows in table 3.6.

Table 3.9 Capacity limit for 34 nodes

Truck No.	Capacity limit
1	100
2	100
3	100
4	100
5	100

3.3 Solver

- Excel Solver. The process of finding the answer from Excel can be done by setting constrain according to the specified conditions of a mathematical model that has been created by putting the range of theconstraint and objective function in the solver parameter in the open solver.

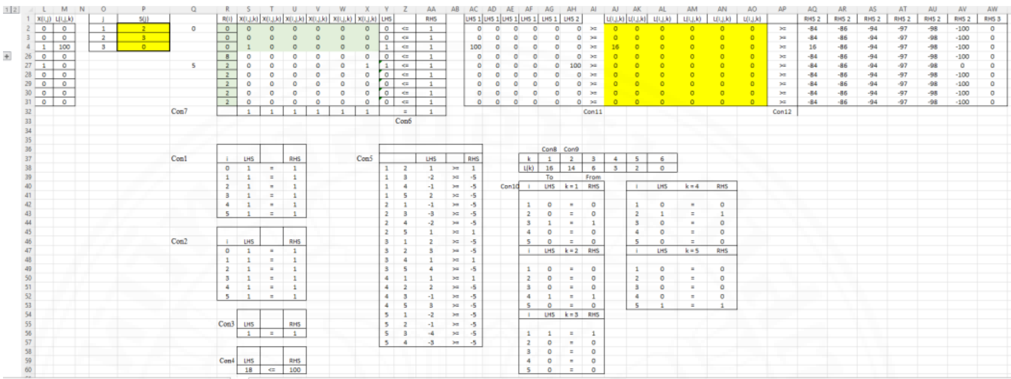

Figure 3.5 Constraint setting in excel

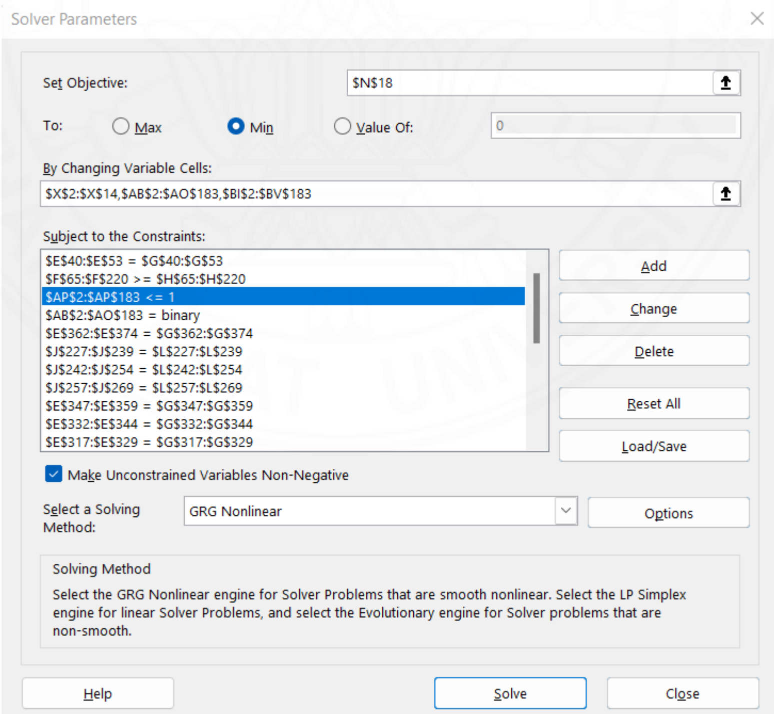

Figure 3.6 Solver parameter setting in open solver

- CPLEX solver.The process of finding answers by CPLEX can be done by following step.

  Step 1: Setting problem size and defined type of variable in the opl model.

  Step 2: Defined parameter and decision variable in the opl model.

  Step 3: Create an objective function and constraints constrain according to the mathematical model that has been created in the opl model.

```
*Model_VRPLD.mod
//number of customers, 1 depot
int n=...;
//1 vehicle>> int v=...;
range N=0..n;
int k=...;
range K=1..k;
int i=...;
range I=1..i;
int b = k+1;

//Parameter
float distance[N][N]=...;
int maxcapacity=...;
float demand[N]=...;

//Decision variable
dvar boolean x[N][N];
dvar boolean y[N][N][K];
dvar int+ S[1..n];
dvar int+ L[N][N][K];
dvar int+ l[1..k];

//Objective fuction
dexpr float z=sum(i,j in N , k in K )distance[i][j]*L[i][j][k];
minimize z;

//Constraints
subject to
{
//visit and leave node
forall (j in N)
  sum (i in N)x[i][j]==sum (i in N)x[j][i];
//Departure depot
forall (i in N:i==0)
  sum (j in N)x[i][j]<=1;
//Go to every nodes
forall (j in N)
  sum (i in N)x[i][j]==1;
```

Figure 3.7 Opl model setting

Step 4: Connect Excel sheet to retrieve data by function "SheetConnection" in opl data.

```
/*********************************************
 * OPL 22.1.0.0 Data
 * Author: Acer
 * Creation Date: May 24, 2022 at 10:41:09 AM
 *********************************************/
n=3;
k=4;
i=3

SheetConnection sheet("VRP_load-dependent_one truck.xlsx");
maxcapacity from SheetRead(sheet,"'P1'!B12");
distance from SheetRead(sheet,"'P1'!B2:E5");
demand from SheetRead(sheet,"'P1'!B7:B10");

x to SheetWrite(sheet,"'P1'!B17:E20");
z to SheetWrite(sheet,"'P1'!B21");
```

Figure 3.8 Opl data setting

3.4 Sweep Algorithm with load distance

In arranging routes for the Sweep Algorithm with load distance is determined by the value of polar angle and can be classified into two types of routing: counter-clockwise and clockwise.

For counter-clockwise routing order the polar angles from ascending, For clockwise routing order the polar angles from descending and fulfill customer demand much as much as possible

after that use Excel solver, and Python to find the possible route that minimizes distance and then redo again in the customer group 2,3 until the end of the list of customers.

Process step of Sweep Algorithm with load distance.

Step 1: Transformed coordinates x and y into polar angle values in radians by using arctan of x and y.

Step 2: Sort the polar angles from ascending order or descending order depending on the types of Sweep Algorithm with load distance.

Step 3: Choose a random customer from the customer order in step 3.1.2. as the first node each the truck and arrange the order of the customer starting from the node that selects until the vehicle capacity is reached.

Step 4: Re-arrange step 3.1.3 until all customers be the first customer.

Step 5: Find the optimal solution by the objective function and find the total distance.

3.5 Python

The process of generating individual vehicle routes from the Sweep Algorithm with load distance by Python can be done by importing data and putting constraints in the Sweep Algorithm with load distance steps, and then using a for loop to repeat until all customers be the first customer, where each vehicle must not exceed the capacity limit and must visit all customers.

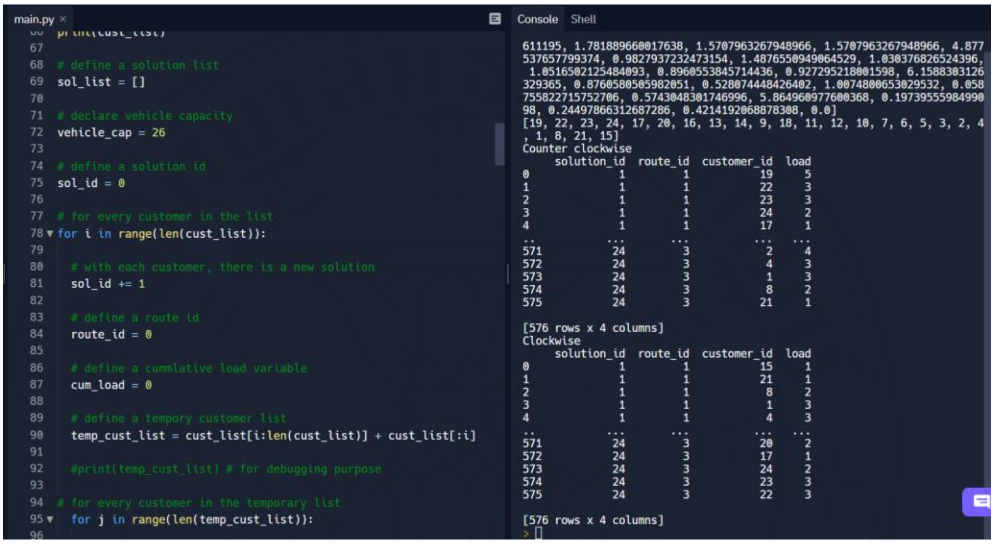

Figure 3.9 Python

CHAPTER 4
RESULT AND COMPARISON

This chapter presents the limits of each program, which are Microsoft excel and CPLEX solver as well as presents the results of the Sweep algorithm with load distance and a comparison of the results between this model with Clustering algorithm with load distance and the Saving algorithm with load distance models include as follows 4.1) Limit of Excel solver 4.2) Limit of CPLEX solver 4.3) Answer from Sweep Algorithm with load distances 4.4) Comparison 4.5) Development.

4.1 Limit of Excel solver

The capacity limit of the Excel solver can be solved with only 9 nodes or 8 customers with1 depot.

4.2 Limit of CPLEX solver

The capacity limit of the CPLEX solver can be solved only16 nodes or 15 customers with1 depot then it will show an Exception from IBM ILOG CPLEX Error 1001: Out of memory.

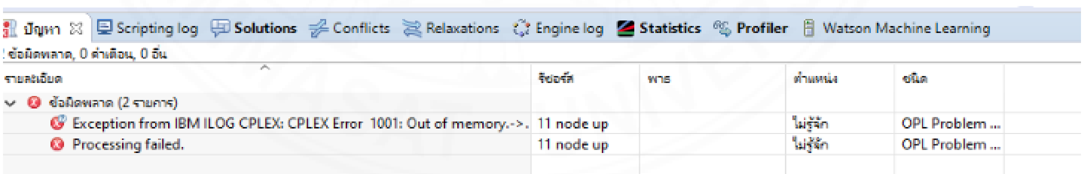

Figure 4.1 Limit of CPLEX solve

4.3 Answer from Sweep Algorithm with load distances

The answer from Sweep Algorithm with load distance is separated into three parts according to 3 dataset as follows set 1: 24 nodes, set 2: 32 nodes and set 3: 34 nodes. Each data set includes answers from arranged routes by clockwise and counter-clockwise.

Set 1: 24 nodes

Table 4.1 Answer of 24 nodes from Sweep Algorithm

Sweep with load distance			
Route No.		Clockwise	Counter-clockwise
1	VRPLD_OBJ	9,186.67	8,490.35
	VRP_OBJ	510.55	524.29
	Route	3	3
2	VRPLD_OBJ	9,339.88	8,546.82
	VRP_OBJ	525.17	533.61
	Route	3	3
3	VRPLD_OBJ	8,342.95	9,402.99
	VRP_OBJ	510.35	555.25
	Route	3	3
4	VRPLD_OBJ	8,240.82	9,337.77
	VRP_OBJ	554.19	555.48
	Route	3	3
5	VRPLD_OBJ	8,422.42	7,792.08
	VRP_OBJ	539.71	536.30
	Route	3	3
6	VRPLD_OBJ	8,536.95	8,043.57
	VRP_OBJ	515.06	540.49
	Route	3	3
7	VRPLD_OBJ	7,849.23	9,166.92
	VRP_OBJ	507.70	566.44
	Route	3	3
8	VRPLD_OBJ	7,757.10	8,378.27
	VRP_OBJ	508.94	570.36

Sweep with load distance			
Route No.		Clockwise	Counter-clockwise
9	VRPLD_OBJ VRP_OBJ Route	9,186.67 510.55 3	8,490.35 524.29 3
10	VRPLD_OBJ VRP_OBJ Route	9,339.88 525.17 3	8,546.82 533.61 3
11	VRPLD_OBJ VRP_OBJ Route	8,342.95 510.35 3	9,402.99 555.25 3
12	VRPLD_OBJ VRP_OBJ Route	8,240.82 554.19 3	9,337.77 555.48 3
13	VRPLD_OBJ VRP_OBJ Route	8,422.42 539.71 3	7,792.08 536.30 3
14	VRPLD_OBJ VRP_OBJ Route	8,536.95 515.06 3	8,043.57 540.49 3
15	VRPLD_OBJ VRP_OBJ Route	7,849.23 507.70 3	9,166.92 566.44 3
16	VRPLD_OBJ VRP_OBJ Route	7,757.10 508.94 3	8,378.27 570.36 3
17	VRPLD_OBJ VRP_OBJ Route	8,196.54 514.73 3	8,499.02 565.18 3
18	VRPLD_OBJ VRP_OBJ Route	8,386.09 498.75 3	8,903.50 550.33 3
19	VRPLD_OBJ VRP_OBJ Route	8,789.41 512.09 3	9,945.23 578.77 3
20	VRPLD_OBJ VRP_OBJ Route	8,341.53 502.86 3	8,953.64 523.89 3

Sweep with load distance			
Route No.		Clockwise	Counter-clockwise
21	VRPLD_OBJ	8,207.53	8,852.43
	VRP_OBJ	498.67	533.58
	Route	3	3
22	VRPLD_OBJ	9,253.52	7,927.98
	VRP_OBJ	558.78	530.14
	Route	3	3
23	VRPLD_OBJ	8,684.14	8,744.05
	VRP_OBJ	551.55	515.32
	Route	3	3
24	VRPLD_OBJ	9,482.68	7,945.90
	VRP_OBJ	564.76	515.17
	Route	3	3

The best answer from Sweep Algorithm with load distance are as follow table 4.2.

Table 4.2 The best answer from 24 nodes

	Sol No.	Clockwise	Sol No.	Counter - clockwise
VRPLD_OBJ VRP_OBJ Route	15	7,341.18 481.64 3	15	7,630.49 505.24 3

Solution number 15 is the best answer from Clockwise. The following is the order of distribution from distribution centers to customers.

- Route 1: Start from Dc > node 9 > node 14 > node 13 > node 16 > node 20 > node 17 > node 24 > node 23 > node 22 > node 19 and back to Dc.
- Route 2: Start from Dc > node 15 > node 21 > node 5 > node 1 > node 4 > node 2 > node 3 > node 5 > node 6 and back to Dc.
- Route 3: Start from Dc > node 7 > node 10 > node 12 > node 11 > node 18 and back to Dc.

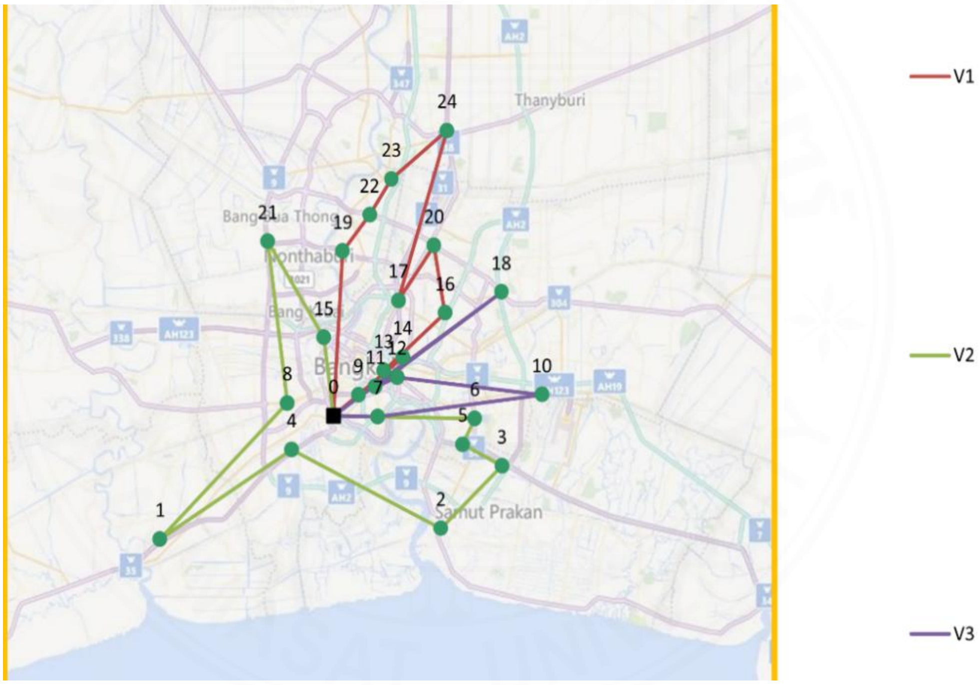

Figure 4.2 Route from Counter-clockwise from 24 nodes

Solution number 15 is the best answer from Counter-clockwise. The following is the order of distribution from distribution centers to customers.

- Route 1: Start from Dc > node 7 > node 6 > node 5 > node 3 > node 2 > node 4 > node 1 > node 8 > node 21 > node 15 and back to Dc.
- Route 2: Start from Dc > node 19 > node 22 > node 23 > node 24 > node 17 > node 20 > node 16 > node 13 > node 14 > node 9 and back to Dc.
- Route 3: Start from Dc > node 18 > node 11 > node 12 > node 10 and back to Dc.

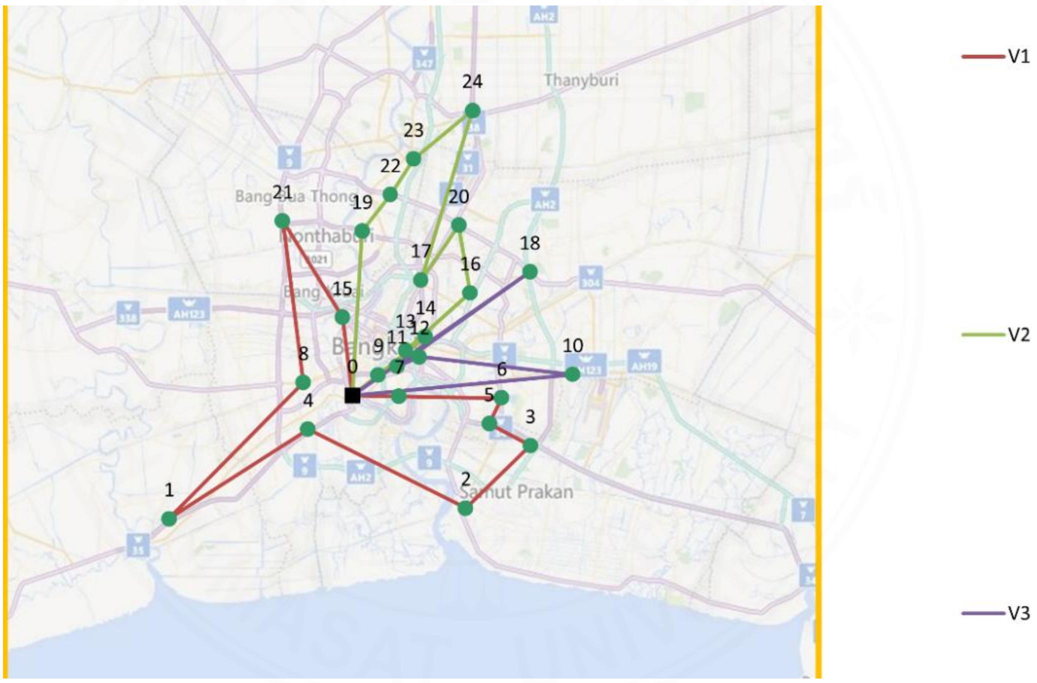

Figure 4.3 Route from clockwise from 24 nodes

Set 2: 32 nodes.

Table 4.3 of 32 nodes from Sweep Algorithm

Sweep with load distance			
Route No.		Clockwise	Counter-clockwise
1	VRPLD_OBJ VRP_OBJ Route	55,813.00 1,387.00 5	82,975.00 1,561.00 5
2	VRPLD_OBJ VRP_OBJ Route	80,063.00 1,561.00 5	83,681.00 1,630.00 5
3	VRPLD_OBJ VRP_OBJ Route	69,141.00 1,411.00 5	70,557.00 1,511.00 5
4	VRPLD_OBJ VRP_OBJ Route	81,169.00 1,469.00 5	78,497.00 1,491.00 5
5	VRPLD_OBJ VRP_OBJ Route	79,148.00 1,364.00 5	60,258.00 1,384.00 5
6	VRPLD_OBJ VRP_OBJ Route	68,674.00 1,344.00 5	60,276.00 1,354.00 5
7	VRPLD_OBJ VRP_OBJ Route	60,728.00 1,437.00 5	65,761.00 1,533.00 5
8	VRPLD_OBJ VRP_OBJ Route	75,503.00 1,537.00 5	72,318.00 1,533.00 5
9	VRPLD_OBJ VRP_OBJ Route	60,945.00 1,374.00 5	82,473.00 1,611.00 5
10	VRPLD_OBJ VRP_OBJ Route	82,624.00 1,564.00 5	68,052.00 1,454.00 5

Sweep with load distance			
Route No.		Clockwise	Counter-clockwise
11	VRPLD_OBJ VRP_OBJ Route	96,713.00 1,387.00 5	74,597.00 1,448.00 5
12	VRPLD_OBJ VRP_OBJ Route	75,820.00 1,386.00 5	75,243.00 1,552.00 5
13	VRPLD_OBJ VRP_OBJ Route	64,661.00 1,479.00 5	58,880.00 1,432.00 5
14	VRPLD_OBJ VRP_OBJ Route	61,078.00 1,432.00 5	58,880.00 1,432.00 5
15	VRPLD_OBJ VRP_OBJ Route	68,416.00 1,434.00 5	69,090.00 1,535.00 5
16	VRPLD_OBJ VRP_OBJ Route	71,905.00 1,541.00 5	69,615.00 1,536.00 5
17	VRPLD_OBJ VRP_OBJ Route	62,859.00 1,451.00 5	73,943.00 1,633.00 5
18	VRPLD_OBJ VRP_OBJ Route	83,591.00 1,633.00 5	71,192.00 1,594.00 5
19	VRPLD_OBJ VRP_OBJ Route	79,838.00 1,535.00 5	70,648.00 1,594.00 5
20	VRPLD_OBJ VRP_OBJ Route	80,282.00 1,535.00 5	77,612.00 1,541.00 5
21	VRPLD_OBJ VRP_OBJ Route	77,546.00 1,622.00 5	67,511.00 1,520.00 5
22	VRPLD_OBJ VRP_OBJ Route	67,208.00 1,518.00 5	68,509.00 1,521.00 5

Sweep with load distance			
Route No.		Clockwise	Counter-clockwise
23	VRPLD_OBJ VRP_OBJ Route	75,154.00 1,520.00 5	65,289.00 1,370.00 5
24	VRPLD_OBJ VRP_OBJ Route	63,938.00 1,448.00 5	70,183.00 1,564.00 5
25	VRPLD_OBJ VRP_OBJ Route	52,738.00 1,331.00 5	70,183.00 1,564.00 5
26	VRPLD_OBJ VRP_OBJ Route	77,193.00 1,611.00 5	78,010.00 1,537.00 5
27	VRPLD_OBJ VRP_OBJ Route	76,071.00 1,533.00 5	81,676.00 1,606.00 5
28	VRPLD_OBJ VRP_OBJ Route	71,786.00 1,512.00 5	75,488.00 1,626.00 5
29	VRPLD_OBJ VRP_OBJ Route	81,090.00 1,520.00 5	65,233.00 1,365.00 5
30	VRPLD_OBJ VRP_OBJ Route	81,089.00 1,522.00 5	60,515.00 1,386.00 5
31	VRPLD_OBJ VRP_OBJ Route	64,812.00 1,363.00 5	63,393.00 1,469.00 5

The best answer from Sweep Algorithm with load distance is as table 4.4

Table 4.4 The best answer from 32 nodes

	Sol No.	Clockwise	Sol No.	Counter-clockwise
VRPLD_OBJ VRP_OBJ Route	25	52,738.00 1,331.00 5	13	58,880.00 1,432.00 5

Solution number 25 is the best answer from Clockwise. The following is the order of distribution from distribution centers to customers.

- Route 1: Start from Dc > node 27 > node 15 > node 29 > node 10 > node 25 > node 20 and back to Dc
- Route 2: Start from Dc > node 12 > node 1 > node 21 > node 16 > node 31 > node 30 and back to Dc.
- Route 3: Start from Dc > node 19 > node 17 > node 7 > node 13 > node 26 > node 2 and back to Dc.
- Route 4: Start from Dc > node 3 > node 6 > node 23 > node 28 > node 4 > node 11 > node 14 > node 8 > node 18 and back to Dc.
- Route 5: Start from Dc > node 24 > node 16 > node 4 and back to Dc.

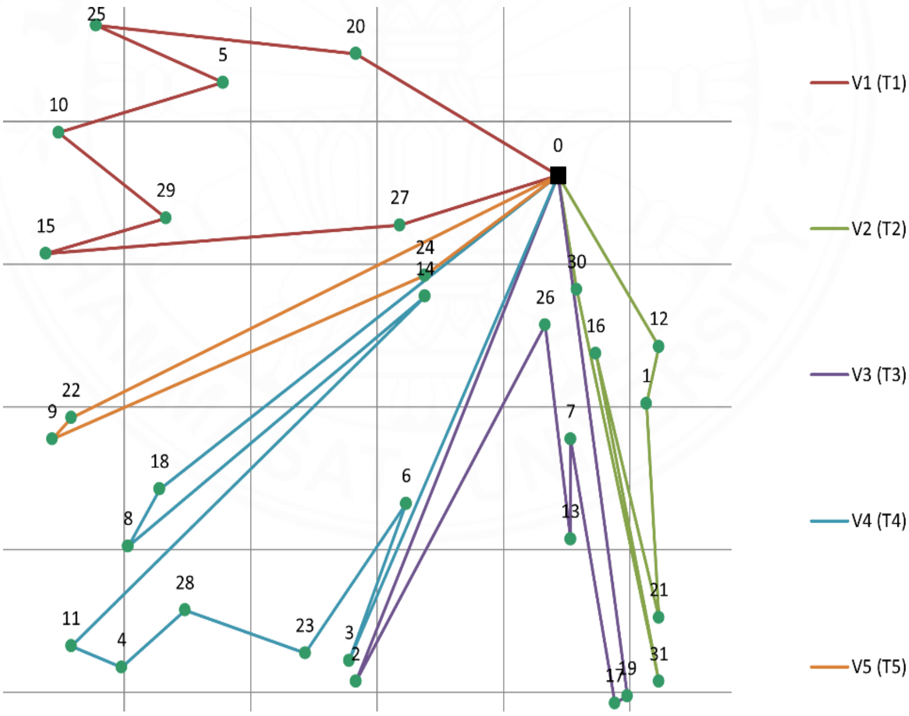

Figure 4.4 Route from clockwise from 32 nodes

Solution number 13 is the best answer from Counter-clockwise. The following is the order of distribution from distribution centers to customers.

- Route 1: Start from Dc > node 14 > node 11 > node 4 > node 28 > node 23 > node 6 > node 3 > node 2 > node 26 and back to Dc.
- Route 2: Start from Dc > node 13 > node 7 > node 17 > node 19 > node 30 > node 31 and back to Dc.
- Route 3: Start from Dc > node 16 > node 21 > node 1 > node 12 and back to Dc.
- Route 4: Start from Dc > node 20 > node 25 > node 5 > node 10 > node 29 > node 15 > node 27 > node 22 and back to Dc.
- Route 5: Start from Dc > node 9 > node 24 > node 18 > node 8 and back to Dc.

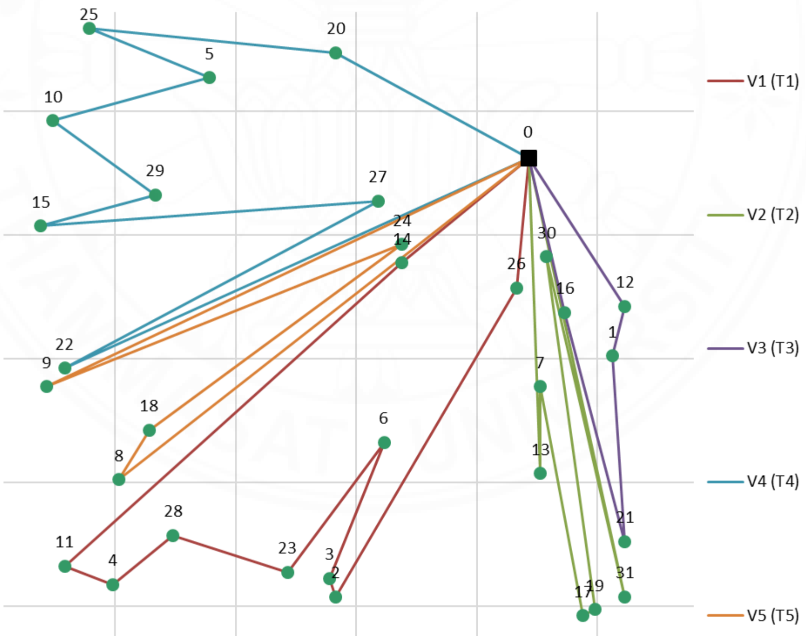

Figure 4.5 Route from Counter-clockwise from 32 nodes

Set 3: 34 nodes.

Table 4.5 Answer of 34 nodes from Sweep Algorithm

Sweep with load distance			
Route No.		Clockwise	Counter-clockwise
1	VRPLD_OBJ VRP_OBJ Route	42,696.00 924.00 6	48,714.00 1,034.00 6
2	VRPLD_OBJ VRP_OBJ Route	51,050.00 1,014.00 5	49,916.00 930.00 5
3	VRPLD_OBJ VRP_OBJ Route	48,119.00 1,017.00 5	47,001.00 926.00 5
4	VRPLD_OBJ VRP_OBJ Route	47,711.00 926.00 5	54,388.00 1,009.00 5
5	VRPLD_OBJ VRP_OBJ Route	47,133.00 967.00 5	54,520.00 1,035.00 5
6	VRPLD_OBJ VRP_OBJ Route	46,147.00 930.00 5	49,705.00 1,120.00 6
7	VRPLD_OBJ VRP_OBJ Route	43,176.00 939.00 6	49,916.00 930.00 5
8	VRPLD_OBJ VRP_OBJ Route	92,797.00 980.00 6	45,793.00 1,070.00 6
9	VRPLD_OBJ VRP_OBJ Route	44,887.00 1,001.00 6	47,001.00 926.00 5
10	VRPLD_OBJ VRP_OBJ Route	47,679.00 995.00 5	54,520.00 1,035.00 5

Sweep with load distance			
Route No.		Clockwise	Counter-clockwise
11	VRPLD_OBJ VRP_OBJ Route	48,119.00 1,017.00 5	50,515.00 1,118.00 6
12	VRPLD_OBJ VRP_OBJ Route	47,133.00 967.00 5	50,449.00 1,114.00 6
13	VRPLD_OBJ VRP_OBJ Route	50,551.00 1,062.00 6	49,546.00 930.00 5
14	VRPLD_OBJ VRP_OBJ Route	46,147.00 930.00 5	49,456.00 838.00 5
15	VRPLD_OBJ VRP_OBJ Route	45,787.00 994.00 6	46,226.00 1,080.00 6
16	VRPLD_OBJ VRP_OBJ Route	45,827.00 994.00 6	47,001.00 926.00 5
17	VRPLD_OBJ VRP_OBJ Route	48,126.00 1,033.00 6	54,173.00 1,036.00 5
18	VRPLD_OBJ VRP_OBJ Route	48,119.00 1,017.00 5	54,230.00 1,165.00 6
19	VRPLD_OBJ VRP_OBJ Route	47,133.00 967.00 5	43,495.00 1,008.00 6
20	VRPLD_OBJ VRP_OBJ Route	49,222.00 1,102.00 6	45,253.00 975.00 6
21	VRPLD_OBJ VRP_OBJ Route	45,568.00 930.00 5	49,916.00 930.00 5
22	VRPLD_OBJ VRP_OBJ Route	46,147.00 930.00 5	44,770.00 1,013.00 6

Sweep with load distance			
Route No.		Clockwise	Counter-clockwise
23	VRPLD_OBJ VRP_OBJ Route	45,757.00 1,004.00 6	47,001.00 926.00 5
24	VRPLD_OBJ VRP_OBJ Route	45,477.00 976.00 6	55,762.00 1,057.00 5
25	VRPLD_OBJ VRP_OBJ Route	48,119.00 1,017.00 5	54,520.00 1,035.00 5
26	VRPLD_OBJ VRP_OBJ Route	47,133.00 967.00 5	49,215.00 1,079.00 6
27	VRPLD_OBJ VRP_OBJ Route	47,366.00 1,030.00 6	47,039.00 1,020.00 6
28	VRPLD_OBJ VRP_OBJ Route	46,147.00 930.00 5	47,471.00 1,020.00 6
29	VRPLD_OBJ VRP_OBJ Route	44,016.00 969.00 6	49,010.00 893.00 5
30	VRPLD_OBJ VRP_OBJ Route	50,493.00 1,043.00 5	51,245.00 967.00 5
31	VRPLD_OBJ VRP_OBJ Route	48,119.00 1,017.00 5	47,001.00 926.00 5
32	VRPLD_OBJ VRP_OBJ Route	47,133.00 967.00 5	54,854.00 1,021.00 5
33	VRPLD_OBJ VRP_OBJ Route	46,147.00 930.00 5	54,520.00 1,035.00 5

The best answer from Sweep Algorithm with load distance are as follow table 4.6

Table 4.6 The best answer from 34 nodes

	Sol No.	Clockwise	Sol No.	Counter-clockwise
VRPLD_OBJ		42,696.00		44,770.00
VRP_OBJ	1	924.00	22	1,013.00
Route		6		6

Solution number 1 is the best answer from Clockwise. The following is the order of distribution from distribution centers to customers. centers to customers.

- Route 1: Start from Dc > node 26 > node 4 > node 20 > node 33 > node 16 > node 22 > node 18 > node 2 and back to Dc.
- Route 2: Start from Dc > node 9 > node 12 > node 3 > node 21 > node 32 > node 13 > node 10 and back to Dc.
- Route 3: Start from Dc > node 28 > node 31 > node 25 > node 17 > node 7 and back to Dc.
- Route 4: Start from Dc > node 6 > node 15 > node 11 > node 8 > node 14 > node 29 and back to Dc.
- Route 5: Start from Dc > node 1 > node 23 > node 27 > node 24 > node 30 and back to Dc.
- Route 6: Start from Dc > node 15 and back to Dc.

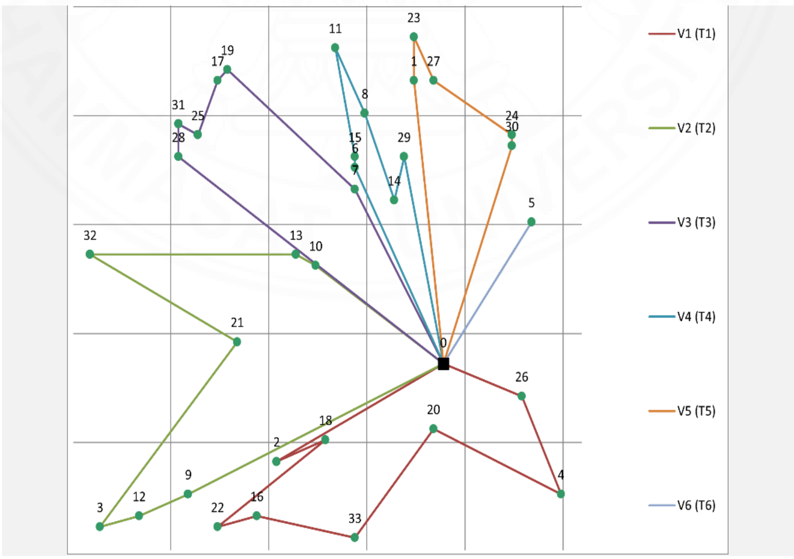

Figure 4.6 Route from Clockwise from 34 nodes

Solution number 22 is the best answer from Counter-clockwise. The following is the order of distribution from distribution centers to customers.

- Route 1: Start from Dc > node 14 > node 8 > node 11 > node 15 > node 6 > node 7 > node 19 and back to Dc.
- Route 2: Start from Dc > node 17 > node 25 > node 31 > node 28 > node 10 > node 13 > node 32 and back to Dc.
- Route 3: Start from Dc > node 21 > node 3 > node 12 > node 9 > node 7 > node 18 and back to Dc.
- Route 4: Start from Dc > node 16 > node 33 > node 20 > node 4 > node 26 > node 5 and back to Dc.
- Route 5: Start from Dc > node 30 > node 24 > node 27 > node 23 > node 1 and back to Dc.
- Route 6: Start from Dc > node 29 and back to Dc.

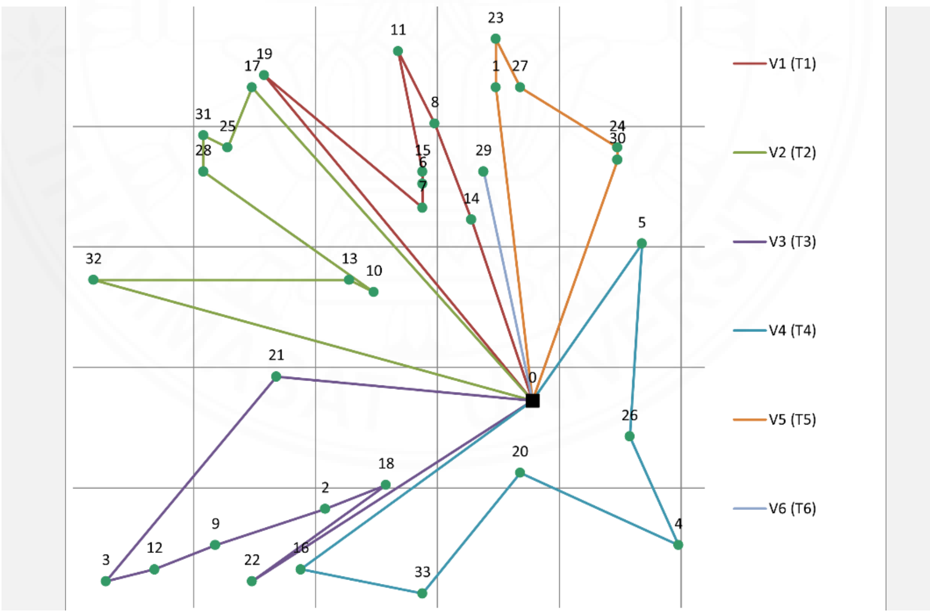

Figure 4.7 Route from Counter-clockwise from 34 nodes

4.4 Comparison

The results are compared using three algorithms that are the Sweep algorithm with load distance, the Clustering algorithm, and the Saving algorithm with load distance of 3 data set that includes 24 nodes, 32 nodes, and 34 nodes.

Table 4.7 Comparison of 24 nodes

24 nodes	Clustering	Sweep	Saving
VRPLD_OBJ	4,947.24	7,341.18	5,371.74
VRP_OBJ	388.03	481.64	382.67
Route	3	3	3

Table 4.8 Comparison of 32 nodes

32 nodes	Clustering	Sweep	Saving
VRPLD_OBJ	-	52,738.00	34,566.00
VRP_OBJ	-	1,331.00	936.00
Route	-	5	6

Table 4.9 Comparison of 34 nodes

34 nodes	Clustering	Sweep	Saving
VRPLD_OBJ	-	42,696.00	30,385.00
VRP_OBJ	-	924.00	945.00
Route	-	6	7

Note: Clustering is insufficient to find an optimal solution in its own way. it requires the Sweep or the Saving algorithm to help cluster first and then uses that route to recalculate the solution by CPLEX solver.

The comparison of three algorithms in tables 4.7 - 4.9 discovered that the results of the Sweep Algorithm with load distance are not good enough in terms of performance. The results have the highest value of optimal solution than the Saving Algorithm with load distance.

4.5 Development

The new method that uses to improve the performance of the Sweep algorithm with load distance is a Nearest neighbor algorithm with load distance (NN-LD). The step to find the answer are as follow figure 4.8.

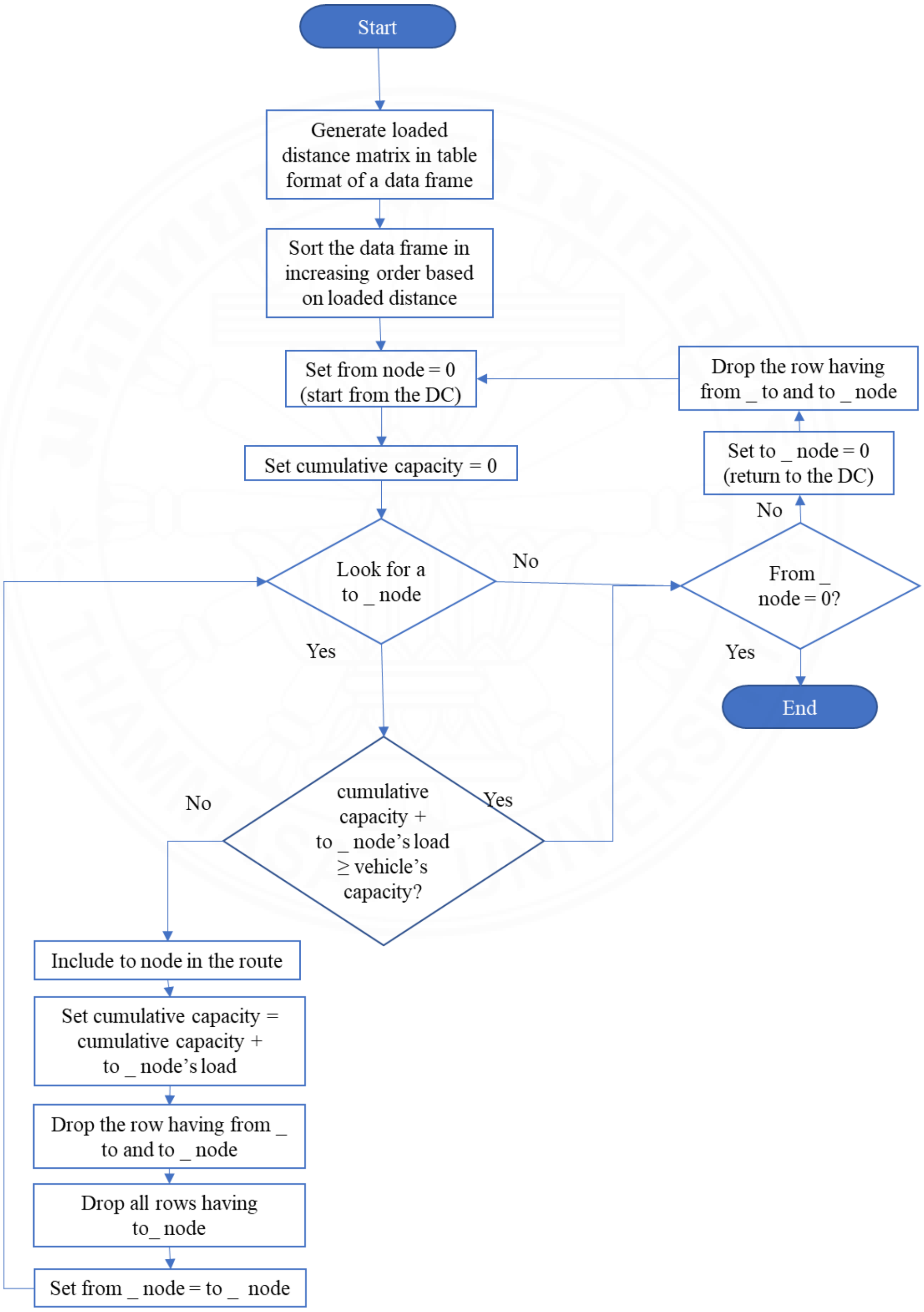

Figure 4.8 NN-LD flowchart

The results from a Nearest neighbor algorithm with load distance (NN-LD) compared with the Sweep algorithm with load distance, and the Saving algorithm with load distance are compared together to test the performance.

Table 4.10 Development of 24 nodes

24 nodes	Sweep	Re-route Sweep by Clustering	NN-LD	Re-route NN-LD by Clustering	Saving
VRPLD_OBJ	7,341.18	5,332.42	7,646.71	5,480.18	5,371.74
VRP_OBJ	481.64	401.05	562.43	406.99	382.67
Route	3	3	3	3	3

Table 4.11 Development of 32 nodes

32 nodes	Sweep	Re-route Sweep by Clustering	NN-LD	Re-route NN-LD by Clustering	Saving
VRPLD_OBJ	52,738.00	34,522.00	49,562.00	39,562.00	34,566.00
VRP_OBJ	1,331.00	943.00	1,317.00	1,180.00	936.00
Route	5	5	5	5	6

Table 4.12 Development of 34 nodes

34 nodes	Sweep	Re-route Sweep by Clustering	NN-LD	Re-route NN-LD by Clustering	Saving
VRPLD_OBJ	42,696.00	35,808.00	48,825.00	41,139.00	30,385.00
VRP_OBJ	924.00	701.05	1,050.00	974.00	945.00
Route	6	5	5	5	6

The comparison together with the Sweep algorithm, a Nearest neighbor algorithm with load distance that is the new method, the Saving Algorithm, and the results after re-route with Clustering algorithm found that the nearest neighbor algorithm with load distance does not perform well only some result is outperformed than the Sweep algorithm with load distance and bad perform when compare with the

Saving algorithm but results of both the Sweep algorithm and a Nearest neighbor algorithm with load distance can be improved when re-route with the clustering algorithm.

CHAPTER 5
CONCLUSION AND DEVELOPMENT

In the conclusion of the study on vehicle routing problem in cold chain based on the Sweep algorithm with load distance are designing all possible routes for each vehicle under the conditions of the Sweep algorithm with load distance and select an optimal route from the route that gets the smallest value of the optimal objective function to be the route for distribution to the customers.

The results of the Sweep algorithm with load distance are not good enough in terms of performance it gets the bad results than the Saving algorithm with load distance therefore, I developed another method to achieve a better result which is a Neighbor algorithm with load distance, but the new algorithm does not achieve the target that to generates better results than the Sweep algorithm with load distance due to some result from testing data set are not outperformed.

The results of both Sweep algorithm with load distance and a Neighbor algorithm with load distance can be improved the performance when re-routed with the clustering algorithm.

The further study directions are as follows 1) developed another method 2) Use more real data.

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