BAREKENG: Journal of Mathematics and Its Applications
March 2024 Volume 18 Issue 1 Page 0643–0656
P-ISSN: 1978-7227 E-ISSN: 2615-3017
https://doi.org/10.30598/barekengvol18iss1pp0643-0656

THE SAMPLE SCHEDULING APPLICATION OF THE ANT COLONY OPTIMIZATION ALGORITHM IN VEHICLE ROUTING PROBLEM TO FIND THE SHORTEST ROUTE

Mahfudhotin[1*], Ratnaning Palupi[2]

[1]*Sharia Banking Study Program, Institut Agama Islam Negeri Kediri*
Sunan Ampel Street No 7, Kediri City, 64127, Indonesia
[2]*Business Administration Study Program, Politeknik Negeri Malang*
Soekarno Hatta Street No 9, Malang City, 65141, Indonesia

*Corresponding author's e-mail: * **mahfudhotin@iainkediri.ac.id***

Article History:

Received: 27th December 2023
Revised: 16th February 2024
Accepted: 20th February 2024

Keywords:

Ant Colony Optimization;
Industrial Research and Standardization Center of Surabaya;
Vehicle Routing Problem;
Visual Basic;
Scheduling Software.

ABSTRACT

In this collaborative research initiative with the Industrial Research and Standardization Center of Surabaya, the primary objective is to obtain Indonesian National Standard certificates through the collection of samples from companies in East Java. The focal challenge revolves around the optimization of delivery routes for vehicles with specific capacities, constituting the Vehicle Routing Problem (VRP), and is addressed through the application of the Ant Colony Optimization (ACO) algorithm. The study confronts constraints, including the limitation of time and resources during the sample collection process, and grapples with challenges associated with travel distances that impact overall efficiency. The utilization of Sample Scheduling software (Si Dull) developed in Visual Basic introduces configurational constraints for route planning with the aim of minimizing distances. The overarching aim is to implement the ACO algorithm, culminating in the development of the Si Dull application, to elevate the efficacy of the sample collection process for industrial certification in Surabaya, thereby contributing to enhanced efficiency in travel distances for sample collection endeavors

How to cite this article:

Mahfudhotin and R. Palupi., "THE SAMPLE SCHEDULING APPLICATION OF THE ANT COLONY OPTIMIZATION ALGORITHM IN VEHICLE ROUTING PROBLEM TO FIND THE SHORTEST ROUTE," *BAREKENG: J. Math. & App.*, vol. 18, iss. 1, pp. 0643-0656, March, 2024.

Journal homepage: *https://ojs3.unpatti.ac.id/index.php/barekeng/*
Journal e-mail: *barekeng.math@yahoo.com; barekeng.journal@mail.unpatti.ac.id*

Research Article · Open Access

1. INTRODUCTION

The quality of both local and export products needs to be controlled and managed by Indonesian National Standards and others approved by the Product Certification Institute which has been accredited by the Industrial Research and Standardization Center of Surabaya. Moreover, this is also to improve the quality and competitiveness of Indonesian products both in national and international markets. Furthermore, the certificate also provides protection to the consumers. The companies or the producers have the right to use Indonesian National Standard and LSPro logo in their products through the product's certificate. This means that the product has standard warranty requirements.

According to [1], organizations that handle numerous projects frequently encounter the difficulty of choosing and scheduling the most effective combination of projects. The scheduling was strategic part of planning and production control process. It was working arrangement plan and resources allocation both the times and facilities for every operation to be completed. Furthermore, scheduling involves assigning resources to tasks with the aim of optimizing specific performance metrics, including waiting time, throughput, and makespan [2]. The input of scheduling included the sequence of dependency between operation (routing), the times process for each operation, and the facilities of each operation are required [3].

Before a company obtains an Indonesian National Standard certificate, the company will be asked to provide samples of its products by the Industrial Research and Standardization Center of Surabaya (Baristand). A lot of sampling demands from the cities in East Java Province to Industrial Research and Standardization Center of Surabaya required a program which can determine optimal scheduling to minimize travel distance and also the time obtained as expected [4].

Researchers had solved Vehicle Routing Problems (VRP) by applying the Ant Colony Optimization (ACO) algorithm which has the resources and mileage limitation in the Industrial Research and Standardization Center of Surabaya. Nowadays, VRP has potential application because it allows strategic competition studies between goods transport companies East Java. This case implicated a set of production point and demand nodes. According to [5], in the case of the pairing shuttle integration [6] or delivery made before pick-up, The problem that needs to be considered is that all items are in one direction, one of which tends to follow the pattern discussed in this research.

2. RESEARCH METHODS

This application was created using the ACO algorithm to solve cases of sampling goods at the Industrial Research and Standardization Center of Surabaya for companies in East Java with limited resources, which have three sampling operators to find the shortest route. The application software was called Si Dull of the Industrial Research and Standardization Center of Surabaya, and was made by applying the visual basic programming language.

The first appearance of Si Dull Software was as a project that gave a new form. The Project was made by utilizing the form as a tool for the interface. The following example is how to made the application using the form (trying the steps in visual programming, arranged the object and properties, then wrote the code).

1. The Data Collection

   The researcher collected the sources needed in making the program, while the proposal was completed by studying literature, browsing, and surveying. The data was obtained from the Industrial Research and Standardization Center of Surabaya.

2. The Problem Analysis

   The problem of the Industrial Research and Standardization Center of Surabaya was how to optimally determine the manufactured goods delivery route to other consumers in different cities of East Java.

3. Algorithm Making

   Based on these problems and data analysis, we also study the theory of the ACO algorithm, so the following ACO algorithm is: [7]

   Input: An instance x of a combine optimization problem **While**
   termination condition not met do
   Schedule activities
   Ant based solution construction ( )
   Pheromone update ( )
   Daemon actions ( )
   End scheduled activities
   S_{best} : best solution in the population of solutions **End while**
   Output: S_{best} candidate to optimal solution for x

4. Making the Program Application

   Researchers applied this algorithm with visual basic support to create the Si Dull software application based on the ACO algorithm through paths or *pheromones* in the ant colony so that the shortest route was obtained and then a line/track (graph) was formed. The application works as follows: First, the ant walked randomly, then if it found the food, it would return to the colony while leaving the *pheromone* track. If other ants found the track, they would not walk randomly but followed it [8]. Furthermore, they would reinforce the track if food is found. However, as time goes by, the *pheromone* path begins to evaporate, reducing the path's strength [9]. The more time it takes for the ant to walk and return, the more time it takes to evaporate the *pheromone* [10]. Thus, the shortest route made the fastest trip [11]. *Pheromone* evaporation has the advantage of avoiding locally optimal convergent solutions. If there is no evaporation, the first path the ant chooses is likely to be too desirable. Therefore, exploration of the solution space will be limited [12]. When the ant found the best way (the shortest route) from the colony to the food source, others tend to follow it and made positive feedback. Finally, all of the ant would be following one route. During each iteration, every ant in the colony autonomously creates a solution by relying on the construction graph G [13].

5. Evaluation

   In this step, the software of Si Dull would be evaluated by using the problem of the research in the Industrial Research and Standardization Center of Surabaya. The program is considered successful if it run properly and obtained the optimal solution. If it was not, the program application would continue further.

6. Practice

   The program applied the real case on found the shortest route in the Industrial Research and Standardization Center of Surabaya to obtain the optimal problem solving.

The Software in the scheduling of Vehicle Routing Problems (VRP) applied algorithm Ant Colony Optimization (ACO) in the Industrial Research and Standardization Center of Surabaya. The software was called “Sample Schedulling” (Si Dull) which could minimize the route of mileage and also optimize the short time in resources limitation. The purpose of the program is so that the companies engaged in goods and services such as the Industrial Research and Standardization Center of Surabaya which has sampling services to other companies in the cities of East Java Province can utilize it to obtain the Indonesian National Standard (SNI) certificate. The purposes of the program are:

a. Applying Ant Colony Optimization (ACO) Algorithm on scheduling Vehicle Routing Problem (VRP) in the Industrial Research and Standardization Center of Surabaya.

b. Making a program or application of ACO to find the shortest route in limitation of resources and mileage of production delivery to the companies in East Java.

c. Implementing the program or application in the case of determining sample scheduling in the Visual Basic program.

3. RESULTS AND DISCUSSION

3.1 The Network/Graph Used

The Minimum Spanning Tree is the spanning tree where the number of quality lines is smallest. There is another way to comprehend the minimum spanning tree. For instance, if there is a project in an area where funds are limited, traffic openings are kept to a minimum with the condition that each area must be connected to each other, even indirectly. If open areas are symbolized as nodes and traffic as arcs then the project problem above can be modeled as a minimum spanning tree problem.

As an example, the G network defined as a pair (V, E) with V is a vertex set and E is edge set. Using graph $G = (V, E)$, with $V = \{x_1, x_2, \ldots, x_6\}$ and $E = \{u_1 = (x_1, x_2), u_2 = (x_1, x_3), u_3 = (x_3, x_5), u_4 = (x_4, x_5), u_5 = (x_5, x_6)\}$then the graph formed is as follows:

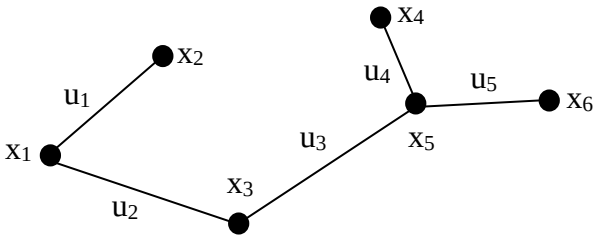

Figure 1. The spanning tree from graph G with 6 vertices and 5 edges

It can be obtained in **Figure 1.** that the graph G spanning tree is the connected graph without a cycle that contained all of the point in G graph. In transportation network, the cities are depicted as nodes, the roads as arcs, and the traffic as arc currents. The directed arc is an arc that has a direction. The directed graph defined as a graph where every single arc is directed. Furthermore, every directed arc is assigned a single starting node or ending nodes/terminal. To solve the minimum spanning tree problem, we can use the algorithm as follows:

Step 1. Choose the starting node (any kind)

Step 2. Determine the closest node to the starting node. Then, align the connected set C. The other nodes are in the set ~C (C's complement) of nodes that have not yet been selected or connected.

Step 3. Determine the nearest node (in set ~C) and the connected node (in set C). Then the selected node (the closest one) put it in set C and remove it from set ~C. Repeat process until ~C = Ø.

To make it easier to understand the results of data optimization, a route was created that connects nodes (Baristand to companies in East Java) according to the calculation results of the Ant Colony Optimization (ACO) algorithm with the Vehicle Routing Problems (VRP) schedule.

3.2 The Ant Colony Optimization (ACO) Algorithm

Ant Colony Optimization (ACO) was made from an experiment by using the ants *Iridomyrmex Humilis* (Argentina's ant). The experiment showed the ability of ants to work as a team to obtain the food source with the assistance of pheromone. It is a chemical from the endocrine glands that is used to recognize conspecifics within a species. The experiment is shown in **Figure 1**. Here, ant 1 and ant 2 left the anthill at the same time. The ants together arrive at choice point 1 and make the same decision probability to choose that branch. Ant 1 chooses the shorter branch and reaches the first food source (via point A), takes the food and returns to the ant nest. When returning to choice point 2, the ant detects a pheromone on the shorter branch (a pheromone deposited by ant 1 itself when walking towards the food source). Moreover, there is a high probability of choosing a branch point because the ants that choose (including ant 2) do not pay attention to choice point 2. In the end, neither those with a high probability nor further pheromone branches can be given reinforcement because there are no more ants to place pheromones on that path so the pheromone will evaporate and travel on the shortest path.

In general, ACO travels over a number of artificial ant populations to find the optimal solution to a combinatorial problem. This algorithm expresses the problem in the form of a graph, the ants travel along each branch from one node to another and create a path that represents the solution to the problem.

3.3 Vehicle Routing Problem (VRP)

VRP has an important role in distribution management and is one of the most studied combination optimization problems. VRP is the management of goods distribution that takes into account service, certain times, the number of consumers of a vehicle in one or more depots using the appropriate road network. **[14]**. The solution to VRP is to determine routes where each route served by vehicles starts and ends at the depot. According to **[15]** Vehicle Routing Problem (VRP) can be characterized as the challenge of determining the most efficient route, aiming to reduce travel distance, time and overall costs incurred during the distribution process.

3.4 The Method of The Problem on Route and Schedule

The optimal method for solving Vehicle Routing Problems (VRP) is improved if there are additional constraints in a case that must be resolved. The constraints in question are time limits (time windows), differences in vehicle capacity types, maximum total time for vehicle operators in delivery, travel obstacles, operator breaks in delivery, etc. There are two methods most commonly used to solve VRP problems, namely the sweep method and the savings method. They are heuristic VRP solution techniques. Basically, there are 3 types of VRP solutions:

1. Exact Solution

   It makes an approach by calculating the best solution. Branch and tie and branch and cut are examples of exact solutions.

2. Heuristic

   This method provides a way to solve more difficult optimization problems with better quality and a quicker solution compared to exact solutions. For example: Parsimony Based, Matching Based, Multi Route Improvement Heuristic, etc.

3. Sweep Method

   The sweep method is a simple calculation method, it can even solve big problems. The average error accuracy of this method is 10%. The surefire way is how to create a route. The process has two steps, the first is to determine the vehicle's stopping point. The second is to determine the sequence of route stopping points. This method cannot solve the total time route and time limit well because of these two steps.

3.5 The Visual Basic (VB)

Microsoft Visual Basic is a programming language to make an application of *Windows* based on graphic (GUI–*Graphical User Interface*). Visual Basic is event-driven programming, which means the program waits for a response from the user in the form of an event (button clicked, menu selected, etc.). When an event is detected, the code associated with the event will be executed.

Visual Basic is one of the computer programming languages. The programming language is an order that computer understand to do some tasks. It was developed by Microsoft in 1991, further developed from its predecessor, the BASIC (Beginner's All-purpose Symbolic Instruction Code) programming language which was developed in the 1950s. Visual Basic is a Development Tool which is a tool for creating various computer programs, especially those using the Windows operating system. Visual Basic is a computer programming language that supports objects (Object Oriented Programming or OOP).

3.6 Sample Scheduling (Si Dull)

The researcher established the partnership with the Industrial Research and Standardization Center of Surabaya to made the program. It has the problems of manufactured goods delivery route to other customers in different cities. The pace and the mileage on delivery process influenced the marketing and minimize the cost. This affected the market price control. The problems would be solved by applying the ACO algorithm method.

The application made by using the ACO algorithm to solve the sampling route of the Industrial Research and Standardization Center of Surabaya. This is an application to find the shortest route within resource limitations that has a sampling of three operators. Here the Si Dull software is created with the Visual Basic (VB) programming language.

Figure 2. The First Appearance of Si Dull

The emergence of the project creation process provides a new form. This project was created using forms as an interface tool. The following is an example of a model for creating an application using forms (trying visual programming steps: arranging objects/controls, then arranging properties and writing the code). **Figure 2** shows the first appearance of Si Dull. The way of how Sample Scheduling (Si Dull) works is as follows:

a. Select the city to visit by clicking order or enter a random number of cities. Moreover, including the name of the city is also a method that can be chosen.

b. Click the **Generate Graph**

c. If there is any error in inputting companies name, click **Reset** and back to the first step

d. Enter to the Schedule Submenu

e. Click the **Use Filter**

f. Choose the **Month** or the **Operator**

g. Click **Show**

The researcher limits the writing and concept of the problem to searching for the shortest sampling route so that the scope of the research is not broad, including:

a. The VRP used must return to the first city (depot).

b. The scope of delivery is focused on East Java Province because the Industrial Research and Standardization Center of Surabaya received requests for sampling goods from companies from East Java. Basically, Si Dull covers the entire region.

c. One vehicle is sent per delivery route.

d. Vehicles that did not return to the city were sampled.

e. The route does not take into account traffic hours, traffic light duration and road width

Si Dull is an application for finding the shortest route to save travel distance for sampling scheduling. There is another application for finding routes called Google Maps, but Si Dull is better at determining the order of cities or places visited than Google Maps. The advantages are finding the shortest route for all cities, determining the source of limitations, determining three companies in three cities in one day, general VRP completion, and there is a database in the program. The implementation results and steps of the Si Dull program are as follows:

a. The Main Menu Appearance

In the main menu display, there are several menus:

1. The company data entry;
2. The Employee data entry;
3. Ordering;
4. Report; and
5. Close

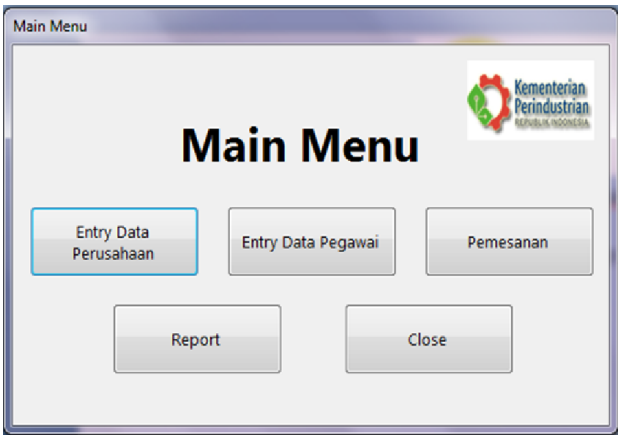

Figure 3. The Main Menu Appearance.

b. The Company Data Entry

In company data entry there are several company names. To add a new company is as follows: 1) Enter the company data by completing the name, the address, the product, contact person, the location; 2) Click **Add** then **Save**

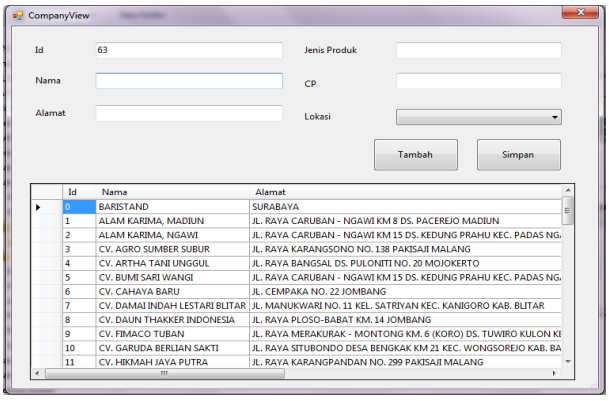

Figure 4. Company View Appearance.

c. The Employee Data Entry

In employee data entry there are a number of employee names. To add a new employee: 1) Enter the employee data by completing the name and the phone number; 2) Click **Add** then **Save.**

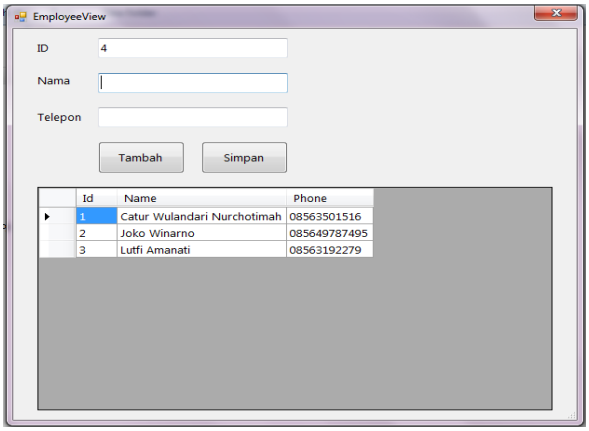

Figure 5. Employee View Appearance.

d. The Ordering

When the company send the mail for the sampling, the steps are:

1. Enter The Mail Demand Date in the Demand Date Column
2. Choose the name of company
3. Enter the Product total
4. Choose the company status:
   i. Done : the company was already sampled
   ii. In Progress : the company is currently sampling
   iii. Cancelled : the company was not sampled
5. Click Save then Save again

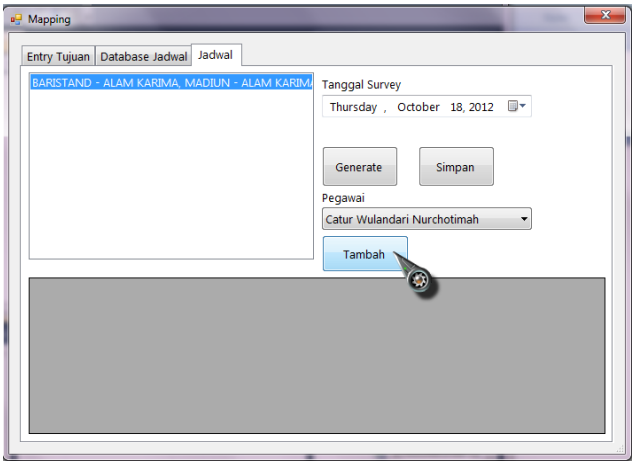

Figure 6. Transaction View Appearance.

6. For the data update the steps are:
   i. In "the **Order Data**" line that updated, click the left of Data ID
   ii. Edit the **Product Total** or **Status** as required
   iii. Click **Up date**
7. To show the sampling company into the month that required:
   i. Click the right of the **Company** column
   ii. Choose the **month** that required
   iii. Click **Show**

e. Report

The steps of sampling schedule:

1. The object of Submenu entry
   i. Choose and Add BARISTAND to the **Company** column
   ii. Followed by selecting and adding companies to the order menu in the Report Menu
   iii. Click **Generate Graph**
   iv. If there is a mistake upon entering the name of the companies, click **Reset** then back to the step 1
   v. Enter the Schedule Submenu

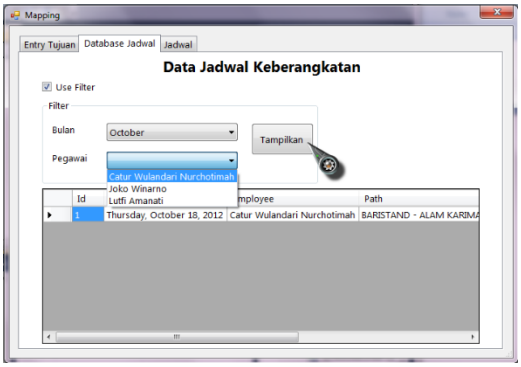

Figure 7. The Submenu Entry Direction Appearance.

2. The Schedule of Submenu

   The steps to obtain the departure schedule:

   i. Click **Generate**
   ii. Click Path
   iii. Choose **Date Survey** to start the sampling
   iv. Choose **Employee**
   v. Click **Add** then **Save**
   vi. Enter into Schedule Database

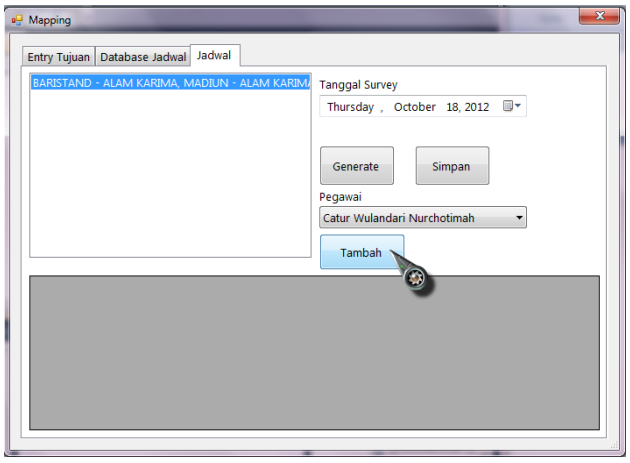

Figure 8. The Schedule of Submenu Appearance.

3. The Schedule of Submenu Database

   The steps to obtain the schedule that appropriate with the month or the employee that required:

   i. Click Use Filter

ii. Choose Month or Employee

iii. Click Show

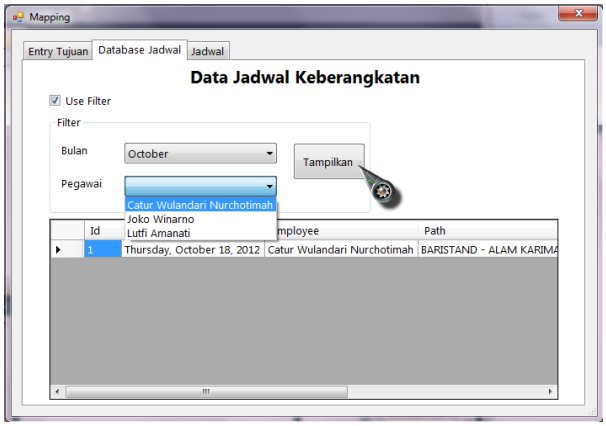

Figure 9. The Database Schedule of Submenu Appearance.

f. Back Up Data into Microsoft Office Excel

The steps to backup data into Microsoft Office Excel are:

1. Open the Microsoft Office Excel program
2. Click **Data**
3. Click **Get External Data**
4. Click **From Other Sources**
5. Click **From XML Data Import**
6. Type the name file that imported and click **Open** then **OK**
7. **Save** data

The ACO Algorithm procedure for solving the Si Dull VRP problem is implemented using the Visual Basic (VB) programming language, namely the solution search process starts from the ant solution to get the first solution from the VRP distribution path. The first mileage distribution route is the best. After that, choose the right path using probability values. The next search is the process of evaporating the pheromone and then updating it to increase or decrease the previous pheromone value. We obtain the pheromone model in the next iteration. The solution search process is carried out continuously until the maximum iteration or certain computing time limit. The Ant Colony Optimization (ACO) application program for the Vehicle Routing Problem (VRP) is implemented in the Visual Basic programming language. The ACO process to solve the VRP are as follows: first, set the parameters and initial, then each ant fulfills the finished taboolist, next calculates the objective function of each ant, saves the best solution, and updates the pheromone. Next, check the cycle, if it has not been fulfilled then empty the taboolist and return to fulfilling the taboolist. If not, next is the process of generating an initial population, then select individuals, obtain a new population, and check the cycle. If it is still not met then return to selecting a new population. If not, the process is stopped and a VRP solution is obtained. Thus, a shortest line is formed (graph).

3.7. Example

The sampling schedule will be coordinated by the regulatory body based on incoming correspondence at PT. Angputra Global Organik Pasuruan, PT. Surya Bumi Kartika Kediri, Perusahaan Alam Karima Ngawi, CV. Tani Makmur Magetan, PT. Subur Wangi Sentosa Magetan, PT. Wahana Organik Muliajaya Situbondo, and PT. Mustika Berkah Abadi Surabaya. The methodology employed to determine the sampling schedule is outlined as follows:

a. Compiling a list of companies to be subjected to sampling.

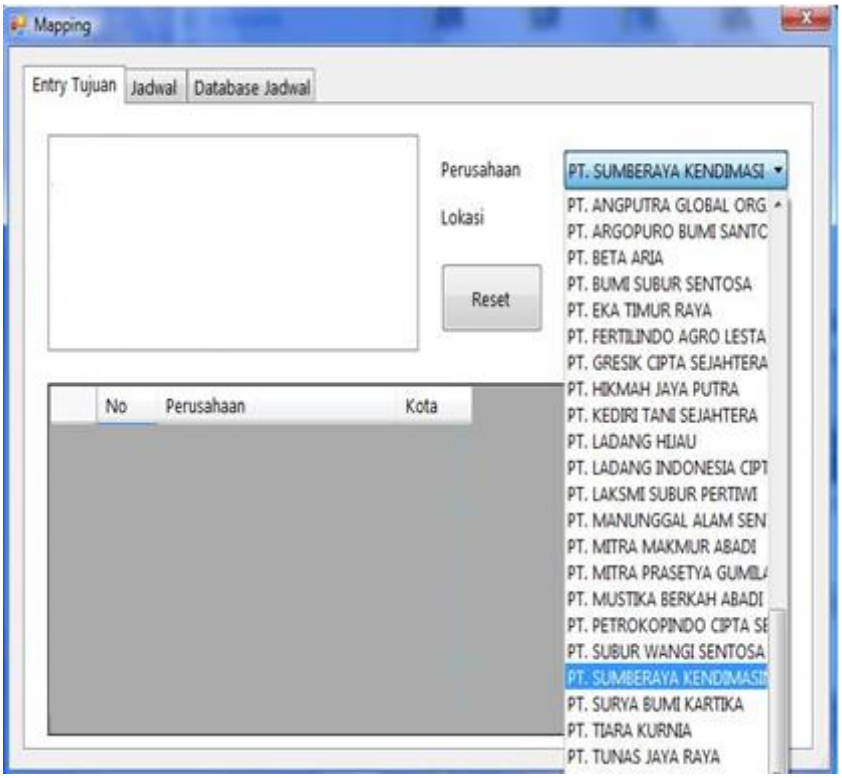

Figure 10. Compiling a list of Companies Subject to Sampling in the Entry Schedule

b. Determining the sampling dates every two days and the personnel responsible for sample collection.

With clarification:

Mode 1. Sampling is conducted every two days

Mode 2. Each staff member performs sampling every three days.

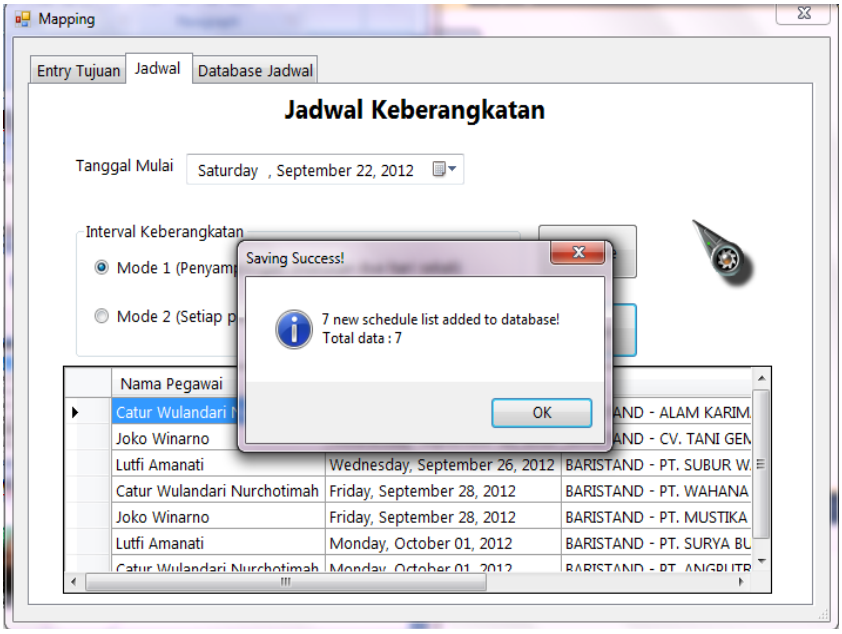

Figure 11. Creating a Schedule in Accordance with the Specified Mode

Based on Figure 11, it is clear that sampling is carried out every two days. There is one officer who takes samples of goods/products from Baristand Surabaya employees who carries out product sampling per company from 7 companies based on the Standard Operating Procedure for their services in a day, namely: Alam Karima Ngawi Company by Catur Wulandari Nurchotimah, CV. Tani Makmur Magetan by Joko Winarno, PT. Subur Wangi Sentosa by Lutfi Amanati, PT. Mustika Berkah Abadi Surabaya by Joko

Winarno, PT. Muliajaya Organic Rides by Catur Wulandari Nurchotimah, PT. Surya Bumi Kartika Kediri by Lutfi Amanati, and PT. Angputra Global Organic Pasuruan by Catur Wulandari Nurchotimah.

c. Recording the sampling schedule.

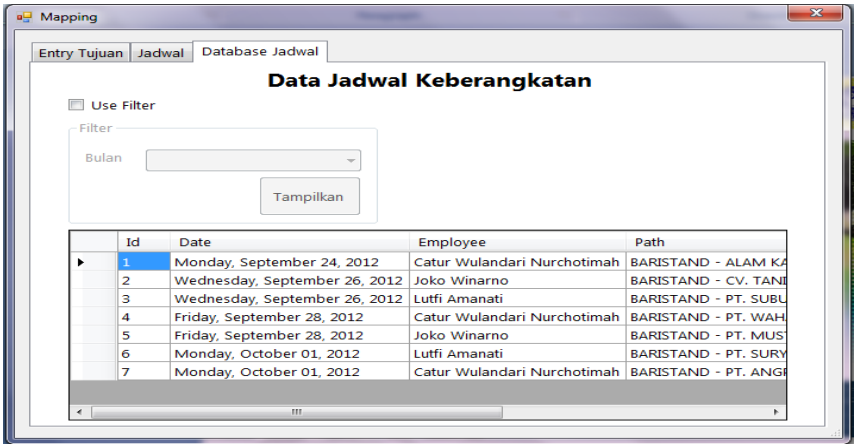

Figure 12. Formation of the Departure Schedule

Based on **Figure 12**, What must be considered is the distance traveled by the sampling vehicle. If it exceeds 200km of the total delivery distance given, then the sampling vehicle must return to the initial depot and the vehicle will continue the journey the following day.

In this case example, it is known that there are 7 companies that Baristand Surabaya will visit.

In a two-day interval, there are four clusters of sampling departure schedules:

1. Alam Karima Ngawi Company on Monday, September 24, 2012.
2. CV. Tani Makmur Magetan – PT. Subur Wangi Sentosa Magetan on Wednesday, September 26, 2012.
3. PT. Mustika Berkah Abadi Surabaya – PT. Wahana Organik Muliajaya Situbondo on Friday, September 28, 2012.
4. PT. Surya Bumi Kartika Kediri – PT. Angputra Global Organik Pasuruan on Monday, October 1, 2012.

4. CONCLUSIONS

The initial manual and distance-unconsidered sample collection process conducted by the Industrial Research and Standardization Center of Surabaya has been significantly improved through the application of the Si Dull scheduling software. The integration of the Ant Colony Optimization (ACO) algorithm, coupled with the utilization of Visual Basic programming language, marks a crucial advancement. This sophisticated combination of Si Dull and the ACO algorithm not only enhances the efficiency of the manual sampling process but also addresses the intricate Vehicle Routing Problem (VRP). The VRP entails determining optimal routes for vehicles engaged in sample collection, considering specific capacities and constraints. Visual Basic plays a pivotal role in crafting the Si Dull application, providing a robust programming framework to optimize route configurations and minimize travel distances. This integration demonstrates a holistic approach to improve the overall sample collection methodology employed by the institute, synergizing algorithmic sophistication with practical software development using Visual Basic.

AKNOWLEDGEMENT

This research was supported by Industrial Research and Standardization Center of Surabaya.

REFERENCES

[1] M. Kumar, M. L. Mittal, G. Soni, and D. Joshi, "A hybrid TLBO-TS algorithm for integrated selection and scheduling of projects," *Comput Ind Eng*, vol. 119, pp. 121–130, May 2018, doi: 10.1016/j.cie.2018.03.029.

[2] T. O. Omotehinwa, "Examining the developments in scheduling algorithms research: A bibliometric approach," *Heliyon*, vol. 8, no. 5, p. e09510, May 2022, doi: 10.1016/J.HELIYON.2022.E09510.

[3] Z. Wang and P. Wen, "Optimization of a Low-Carbon Two-Echelon Heterogeneous-Fleet Vehicle Routing for Cold Chain Logistics under Mixed Time Window," *Sustainability*, vol. 12, no. 5, p. 1967, Mar. 2020, doi: 10.3390/su12051967.

[4] S. E. CÖMERT, H. R. YAZGAN, İ. SERTVURAN, and H. ŞENGÜL, "A new approach for solution of vehicle routing problem with hard time window: an application in a supermarket chain," *Sādhanā*, vol. 42, no. 12, pp. 2067–2080, Dec. 2017, doi: 10.1007/s12046-017-0754-1.

[5] A. K. Beheshti, S. R. Hejazi, and M. Alinaghian, "The vehicle routing problem with multiple prioritized time windows: A case study," *Comput Ind Eng*, vol. 90, pp. 402–413, Dec. 2015, doi: 10.1016/j.cie.2015.10.005.

[6] P. Sitek, J. Wikarek, K. Rutczyńska-Wdowiak, G. Bocewicz, and Z. Banaszak, "Optimization of capacitated vehicle routing problem with alternative delivery, pick-up and time windows: A modified hybrid approach," *Neurocomputing*, vol. 423, pp. 670–678, Jan. 2021, doi: 10.1016/j.neucom.2020.02.126.

[7] H. Fahmi, M. Zarlis, E. B. Nababan, and P. Sihombing, "Ant Colony Optimization (ACO) Algorithm for Determining The Nearest Route Search in Distribution of Light Food Production," *J Phys Conf Ser*, vol. 1566, no. 1, p. 012045, Jun. 2020, doi: 10.1088/1742-6596/1566/1/012045.

[8] I. Chaouch, O. B. Driss, and K. Ghedira, "A Modified Ant Colony Optimization algorithm for the Distributed Job shop Scheduling Problem," *Procedia Comput Sci*, vol. 112, pp. 296–305, 2017, doi: 10.1016/j.procs.2017.08.267.

[9] H. Idris, A. E. Ezugwu, S. B. Junaidu, and A. O. Adewumi, "An improved ant colony optimization algorithm with fault tolerance for job scheduling in grid computing systems," *PLoS One*, vol. 12, no. 5, p. e0177567, May 2017, doi: 10.1371/journal.pone.0177567.

[10] X. Zhang, X. Shen, and Z. Yu, "A Novel Hybrid Ant Colony Optimization for a Multicast Routing Problem," *Algorithms*, vol. 12, no. 1, p. 18, Jan. 2019, doi: 10.3390/a12010018.

[11] M. Yousefi, M. Yousefi, D. Hooshyar, and J. Ataide de Souza Oliveira, "An evolutionary approach for solving the job shop scheduling problem in a service industry," *International Journal of Advances in Intelligent Informatics*, vol. 1, no. 1, p. 1, Mar. 2015, doi: 10.26555/ijain.v1i1.5.

[12] W. Gao, "Improved Ant Colony Clustering Algorithm and Its Performance Study," *Comput Intell Neurosci*, vol. 2016, pp. 1–14, 2016, doi: 10.1155/2016/4835932.

[13] B. Pascariu, M. Samà, P. Pellegrini, A. D'Ariano, D. Pacciarelli, and J. Rodriguez, "Train routing selection problem: Ant colony optimization versus integer linear programming," *IFAC-PapersOnLine*, vol. 54, no. 2, pp. 167–172, 2021, doi: 10.1016/j.ifacol.2021.06.060.

[14] S. R. M. MAKING, B. P. SILALAHI, and F. BUKHARI, "Multi Depot Vehicle Routing Problem dengan Pengemudi Sesekali," *Jurnal Matematika dan Aplikasinya*, vol. 17, no. 1, 2018.

[15] C. Sitompul and O. M. Horas, "A Vehicle Routing Problem with Time Windows Subject to the Constraint of Vehicles and Good's Dimensions," *International Journal of Technology*, vol. 12, no. 4, p. 865, Oct. 2021, doi: 10.14716/ijtech.v12i4.4294.