CHAPTER II

LITERATURE REVIEW

2.1 Previous Research

PT. Aksara Solopos is one of Newspaper Company in the Surakarta city that produces a well known newspaper Solopos. The company provides newest update of national, Surakarta city, and surrounds region news. This type of business requires distribution activity in every day. The newspaper as the finish product has to be delivered to the all customers in the early morning time. One main concern in the distribution activity is about assigning of vehicles or some vehicles to deliver the products. PT. Aksara Solopos, has two types of vehicles that distribute newspaper for Surakarta region. The two types of vehicles have different capacity, fixed cost, and variable cost. The current routes are created based on the estimation of the drivers and didn't consider the cost (fixed and variable). Considering that situation, assigning which customers must be served by which vehicle is becomes important thing because it is related with the satisfying the customers with minimize the money spent by company. So that in order to get those objectives, the company requires good routing for distribution vehicles.

The problem exist in the PT. Aksara Solopos is related with Vehicle Routing Problem (VRP) with particular name is Heterogeneous Fixed Fleet Vehicle Routing Problem (HFFVRP). Heterogeneous Fixed Fleet corresponds to the heterogenic vehicles (capacity, fixed cost, and variable cost) in the limited number (two vehicles in a fleet). As stated in the chapter one about the difficulties of HFFVRP, all researches has conducted using heuristic. The HFFVRP research begun from the suggestion of Taillard (1999) that heuristic column generation method is applicable to HFFVRP. Then Tarantilis, *et. al.* (2003) began their research to solve HFFVRP using List Based Threshold Accepting (LBTA). Tarantilis *et. al.* (2004) continued their research to solve HFFVRP using Back Tracking Adaptive Threshold Accepting (BATA) algorithm. Gencer, *et. al.* (2006) solved HFFVRP by Passenger Pickup Algorithm that has principle to make clustering of customers first then routing the vehicle for the customers clustered. Feiyue, *et. al.* (2007) solved HFFVRP by Record to Record Travel algorithm. Jalel and Habib (2010) have solved HFFVRP by using Hybrid Tabu Search algorithm. Tuntuncu (2010) used Greedy Randomized Adaptive Memory Programming Search (GRAMPS) to solve HFFVRP. Xiangyong, *et. al.* (2010) combined Multistart Adaptive Memory Programming (MAMP) and path relinking algorithm to solve HFFVRP. Kewei *et. al.* (2010) used Parallel Improving Tabu Search algorithm and provide a mathematical model of HFFVRP. Brandao (2011) using Tabu Search algorithm to solve the HFFVRP.

This research will use a classical heuristic Holmes and Parker algorithm (1976) that an extension of Clarke and Wright algorithm (1964) to solve the problem faced by the company. Holmes and Parker (1976) tested this algorithm to the Heterogeneous Fleet Vehicle Routing Problem (HVRP) type. This research uses the Holmes and Parker algorithm to solve HFFVRP which is variants of VRP. The different between HVRP and HFFVRP are in the number of vehicle available unlimited and limited (Tarantilis *et. al.*, 2003). HVRP is more appropriate for strategic decision to purchase or hire the vehicles required by the company, while HFFVRP the vehicles are already in the company.

2.2 Theoretical Background

2.2.1 Vehicle Routing Problem

Vehicle Routing Problem (VRP) becomes one of the optimization problems in Operational Research that has practical role in the distribution activity. The distribution activity concerns with the service, in a given time period, for a set of customers by a set of vehicles, which are located in one or more depots, operated by a set of crews (drivers), and perform their movements by using an appropriate road network (Toth and Vigo, 2002). The Vehicle Routing Problem lies at the heart of distribution management. It is faced each day by thousands of companies and organizations engaged in the delivery and collection of goods or people (Cordeau *et. al.*, 2007). Much progress has been made since the publication of the first article on the "truck dispatching" problem by Dantzig and Ramser (1959). The Classical Vehicle Routing Problem (VRP) is one of the most popular problems in combinatorial optimization, and its study has given rise to several exact and heuristic solution techniques of general applicability. Toth and Vigo (2002) gives a brief introduction for the basic things from Vehicle Routing Problem (VRP). This problem has several basic important things that will always exist in any kinds of VRP types. Here below the explanations of VRP.

In particular, the solution of a VRP calls for the determination of a set of routes that each performed by a single vehicle that starts and ends at its own depot, such that all the requirements of the customers are fulfilled, all the operational constraints are satisfied, and the global transportation cost is minimized. There are several main characteristic or components of VRP which are road network, customers, depots, vehicles, and drivers, the different operational constraints that can be imposed on the construction of the routes, and the possible objectives to be achieved in the optimization process.

The road network, used for the transportation of goods, is described through a graph, whose arcs represent the road sections and vertices may correspond to the depot, terminal, and customer locations. The arcs can be directed or undirected, depending on whether they can be traversed in only one direction (for instance, because of the presence of one-way streets, typical of urban or motorway networks) or in both directions, respectively. Each arc is associated with a cost, which generally represents its length, and a travel time, which is possibly dependent on the vehicle type or on the period during which the arc is traversed. The arc representation in distance d can be in symmetric $d_{ij} = d_{ji}$ or asymmetric $d_{ij} \neq d_{ji}$. The distance also can be measured in Euclidean or in real urban transport.

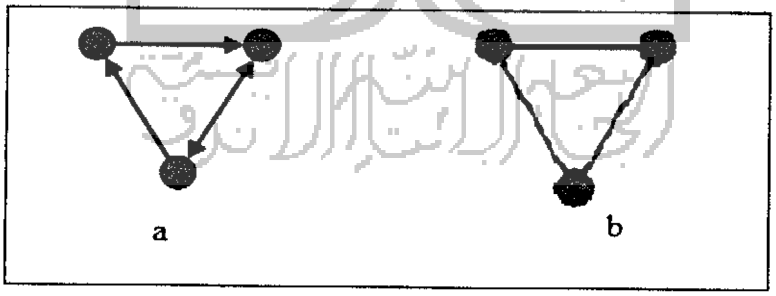

Figure 2.1 Directed Graphs (a) and Undirected Graphs (b)

The customers also have several characteristics. Each customer has own demand and possibly in different number that must be collected (waste collection) or delivered (newspaper). The demand itself can be in deterministic and stochastic, depend in the cases faced. The routes performed to serve customers start and end at one or more depots, located at the vertices of the road graph. Each depot is characterized by the number and types of vehicles associated with it and by the global amount of goods it can deal with.

Transportation of goods is performed by using a fleet of vehicles whose composition and size can be fixed or can be defined according to the requirements of the customers. Usually the vehicle is starting at a depot and returning can be to the initial depot or terminal (other depot or home). Vehicle has capacity and usually represent by maximum weight and volume that the vehicle can load. The capacity of vehicle can be homogeny or heterogenic and also the number can be limited or unlimited. Also there is a special vehicle that has special capability depends on the goods carried (refrigerator inside). The vehicle also has two works like loading and unloading the goods. There are several costs that occur in operating vehicle such variable cost (per distance unit, per time unit, per route, etc.) and fixed cost (insurance, maintenance, driver wages, etc).

The routes has to satisfy several of operational constraints. The constraints can be coming from the nature of the transported goods, on the quality of the service level, and on the characteristics of the customers and the vehicles. Some general operational constraints like along each route, the current load of the assigned vehicle cannot exceed the vehicle capacity; the customers served in a route can only the delivery (unloading goods) or the collection of goods, or both possibilities can exist; and customers can be served only within their time windows and the working periods of the drivers associated with the vehicles visiting them. Precedence constraints can be imposed on the order in which the customers served in a route are visited. One type of precedence constraint requires that a given customer be served in the same route serving a given subset of other customers and that the customer must be visited before (or after) the customers belonging to the associated subset. This is the case, for instance, of the so-called pickup and delivery problems, wherein the routes can perform both the collection and the delivery of goods, and the goods collected from the pickup customers must be carried to the corresponding delivery customers by the same vehicle.

Vehicle Routing Problem also has several objectives that want to be accomplished, such as:

a. minimization of the global transportation cost, dependent on the global distance traveled (or on the global travel time) and on the fixed costs associated with the used vehicles (and with the corresponding drivers).
b. minimization of the number of vehicles (or drivers) required to serve all the customers.
c. balancing of the routes, for travel time and vehicle load.
d. minimization of the penalties associated with partial service of the customers.

2.2.2 Heterogeneous Fleet Vehicle Routing Problem

Heterogeneous Fleet Vehicle Routing Problem (HVRP) is a variant of VRP that has heterogeneous vehicle in a fleet. The vehicles inside the HVRP have different capacity and also the cost (either fixed and variable cost or only variable cost). This HVRP also has several variants; two of them are Heterogeneous Mixed Fleet Vehicle Routing Problem (HMFVRP) and Heterogeneous Fixed Fleet Vehicle Routing Problem (HFFVRP).

A. Heterogeneous Mixed Fleet Vehicle Routing Problem

Heterogeneous Mixed Fleet Vehicle Routing Problem; Shuguang *et. al.*, (2009) explained that Heterogeneous Mixed Fleet Vehicle Routing Problem (HMFVRP) has to decide how many vehicles of each type to use given a mix of vehicle types differing in capacity and costs. The fleet is heterogeneous and the available number of vehicles for each type remains unlimited. The objectives are to find both the fleet composition and the vehicle routing that minimize the summation of variable cost and fixed cost. Some times the HFMVRP is only named as HVRP.

B. Heterogeneous Fixed Fleet Vehicle Routing Problem

Heterogeneous Fixed Fleet Vehicle Routing Problem; Heterogeneous Fixed Fleet Vehicle Routing Problem (HFFVRP) is the variant of VRP, extension of HVRP. HFFVRP has same characteristic with HMFVRP (HVRP) which is the used of the vehicle is heterogenic. The differences are in the objective and the size of vehicle fleet. Brandao (2010) explained that HFFVRP consists of defining a set of routes and the vehicles assigned to them so that the following constraints; use no more vehicles than those available, satisfy customers' demand, visit each customer exactly once, a vehicle route starts and finishes at the depot, and do not exceed the capacity of the vehicle. The objective of HFFVRP is to design a set of vehicle route to distribute the goods in order to satisfy the customer needs and also to minimize the sum of the fixed cost and variable cost with subject to the previous constraints. For HMFVRP the objective are to determine the fleet composition and also make a set of route that minimizes the total cost. Another difference is the number of vehicle in a fleet for HFFVRP is limited while HMFVRP is unlimited. For the mathematical formulation of HFFVRP will be given in the chapter III. This research is focused on HFFVRP. To solve the HFFVRP, this research will use an algorithm coming from the classical heuristic called as Holmes and Parker algorithm. To be more understands of the method that used in this research to solve HFFVRP, here below the explanation.

2.2.3 Clarke and Wright Algorithm

Route construction methods were among the first heuristics for the VRP and still form the core of many software implementations for various routing applications. These algorithms typically start from an empty solution and iteratively build routes by inserting one or more customers at each iteration, until all customers are routed. Construction algorithms are further subdivided into sequential and parallel, depending on the number of eligible routes for the insertion of a customer. Sequential methods expand only one route at a time, whereas parallel methods consider more than one route simultaneously. Route construction algorithms are fully specified by their three main ingredients, namely an initialization criterion, a selection criterion specifying which customers are chosen for insertion at the current iteration, and an insertion criterion to decide where to locate the chosen customers into the current routes (Cordeau *et. al.*, 2007).

Clarke and Wright algorithm was developed by Clarke and Wright (1964). Clarke and Wright algorithm classified as classical heuristic. This algorithm is a constructive algorithm that gradually builds a feasible solution while keeping on eye on solution cost. Clarke and Wright was introduced a concept called as savings. Savings s becomes the main point of the algorithm work.

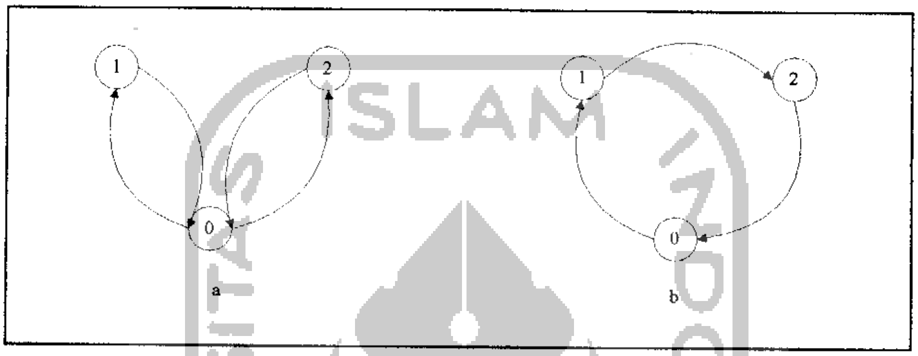

Figure 2.2 Savings Concept

Figure 2.3 shows the different of condition without savings (a) and with savings (b). Saving is the reduction of distance if the vehicle doing the loop 0-1-2-0 without return again to the depot 0-1-0-2-0. Saving between depot 0 and two customers i and j is formulated below;

$s_{i,j}$ = Saving value of customer i and j

$$s_{i,j} = d_{i,0} + d_{0,j} - d_{i,j} \qquad i \neq j, \ \forall i,j = 1,2,3,\dots,n \tag{2.1}$$

The algorithm can work in two versions which are sequential and parallel version. The algorithm works as follows:

Step 1 (savings computation). Compute the savings as in the equation (2.1). Create n vehicle routes $(0, i, 0)$ for $i = 1,\dots,n$. order the savings in a non increasing fashion.

Step 2 (parallel version). Starting from the top of saving list, execute the following. Given a saving s_{ij}, determine whether there exist two routes, one containing arc or edge $(0, j)$ and the other containing arc or edge $(i, 0)$, that can feasibly merged. If so, combine these two routes by deleting $(0, j)$ and $(i, 0)$ and introducing (i, j).

Step 2 (sequential version). Consider in turn each route $(0, i, \ldots, j, 0)$. Determine the first saving s_{ki} or s_{jl} that can feasibly be used to merge the current route with another route containing arc or edge $(k, 0)$ or containing arc or edge $(0, i)$. Implement the merge and repeat this operation to current route. If no feasible merge exist, consider the next route and reapply the same operations. Stop when no route merge is feasible.

2.2.4 Holmes and Parker Algorithm

Holmes and Parker algorithm was developed by Holmes and Parker (1976). This algorithm is using the Clarke and Wright algorithm with parallel version as the foundation in generating routes. There are several additional concepts in this algorithm from Clarke and Wright algorithm which are suppression schemas. With these schema, the solutions that produced by Clarke and Wright algorithm can be explored deeper and a new better solution can be found. The suppression means the prohibition of an ordered pair to involve in the current iteration. The suppression schemas are temporary suppression and permanent suppression. The temporary suppression is applied to an ordered pair i, j (with specific rule) to the current best solution for the next iteration so then a new solution is produced. When the new solution result is better than the current best solution, the ordered pair i, j is suppressed permanently to avoid the ordered pair i, j chosen again for the next iteration. To apply the Holmes and Parker algorithm into HFFVRP, there are some additional modifications. In the step 4.4.1, the additional rule added so that the solution will not violate constraint (3.2). Then in the step 4.5 the Total Cost *TC* calculated based on the objective function of HFFVRP (3.1). The additional rule is added in the step 4.4.3 that limits the total distance of each vehicle to the distance maximum (use the current vehicle routes distance). This research using Holmes and Parker algorithm because the Clarke and Wright algorithm can be used to create a solution for HFFVRP as stated by Taratilis *et. al.* (2003). As the beginning of Holmes and Parker algorithm, the initialization is required for the basic of the algorithm works. The steps of Holmes and Parker algorithm shown below:

A. Initialization

In initialization step, there are several steps used to generate the distance matrix then saving matrix.

Step 1: Distance matrix

1.1 Construct an initial distance matrix D, such that $D = [d_{ij}]$; $i, j = 0,1,2,..,n$ where 0 represent depot and $1,2,\ldots,n$ is customer. When $i = j$, let $d_{ij} = 0$.

1.2 Determine the demand of each point c_i, the number of vehicle of type t is N_t and the capacity of each is C_t.

Step 2; Construct the saving matrix $[s_{i,j}]$

1.1 Compute saving s_{ij} as in the equation (2.1);

if $s_{i,j} < 0$, set $s_{i,j} = 0$. Set $s_{i,j} = 0$ for all $i = j$.

1.2 Let $s_{i,0} = s_{0,j} = -1$, $\forall i,j = 1,2,3\ldots,n$. note that $s_{i,j} = -1$ indicates the presence of (i,j) in a current solution.

B. Iteration

The iteration begins to create an initial solution without any suppression schema. After the initial solution generated, the suppression schema is begun.

Step 3: Determine a candidate pair

3.1 Find the ordered pair i,j with the greatest feasible saving such that $s_{i,j} = max\ [s_{i,j}]$ where (i,j) is defined over all ordered pairs such that $s_{i,0}$ and $s_{0,j} \neq 0$. Go to step 4.

3.2 If $s_{i,j} = 0$, go to step 4.6.

Step 4: Join the point i and j on a route

4.1 If neither of the points is on a route, construct a new route z and compute the required demand c_z such that

$$c_z = c_i + c_j \qquad (2.2)$$

Then go to step 4.4

4.2 If one point is currently assigned to a route, say $z\ (i,j)$, attempt to join the new pair $(j,k\ )$ with unassigned point (k) to z. compute total demand c_z where

$$c_z \rightarrow c_z + c_k \tag{2.3}$$

Then go to step 4.4

4.3 If both point are currently assigned to routes, say u (i,j) firstly selected, then v (k,l) after u selected, attempt to join both routes into one route, z. Compute the total demand c_z where

$$c_z = c_u + c_v \tag{2.4}$$

Then go to step 4.4

4.4 Join (merging) key concept has several principals.

4.4.1 First, check the routes whether two same points are in the same route or not. As an example the ordered pair selected i,j and j,k from the descending from the largest saving as $s_{i,j}$; $s_{j,k}$ respectively. If there is an ordered pair that has smaller saving value than two ordered pairs before, and it is suggested (feasible to be selected) such as k,i with saving $s_{k,i}$, this merged cannot be performed because it is not allowed to visit the point or node more than one time by one type of vehicle which is in the example is point i. Then, like the example $s_{k,i}$ is set to be 0. Then go to step 4.4.2. This step is added to Holmes and Parker algorithm, so that the result generated will not violate the constraint (3.2)

4.4.2 Second, Check the capacity restrictions. For the condition 4.1, select the vehicle with the smallest capacity first C_t such that $C_t \geq c_z$, if no such C_t exist, set $s_{ij} = 0$ and proceed to step 3. For the condition in step 4.2, if the capacity of the vehicle is not enough, then the merged cannot be conducted and set the $s_{jk} = 0$ and proceed to step 3. For the condition step 4.3, If the c_z is exceed the capacity of vehicle C_t, separate the *u (i,j)* and *v (k,l)* then select the next vehicle for the last ordered pair *v (k,l)* that has smaller capacity (if exist) or same capacity or larger capacity and proceed to step 3. The priority of vehicles used is the lowest capacity first. Then go to the step 4.4.3.

4.4.3 Third, check the distance restrictions. The routes that created can not exceed the maximum distance stated. In order to make easy the distance are converted to the cost which can be calculated from multiplying the distance with each vehicle variable cost.

4.5 Update the savings matrix after an ordered pair selected such that $s_{i,j} = -1$, $s_{j,i} = 0$ and si,0 = $s_{0,j} = 0$. Repeat the iteration from step 3 until the condition of step 3.2 happen.

4.6 Save all pair with its saving value $s_{i,j}$ that already join for every vehicle. Then compute the total cost *TC* of all routes as in the equation (3.1). Then go to step 5.

Step 5: Save the best solution

5.1 If this is the first solution (initial solution), save the cost *TC'*, such that *TC'* = *TC*. Maintain all routes and the order in which points were joined. Go to step 6.

5.2 If this is not the first solution and $TC \geq TC'$, set $TC' = TC$, the suppression number increase, for first suppression L=1; second suppression L=2 and so on, and then set $s_{i,j}= 0$ in the saving matrix. Note that (i,j) is the pair just suppressed (suppressed temporally) and further that (i,j) remains suppressed (suppressed permanently) in all subsequent solution. Go to step 5.4.

5.3 If $TC < TC'$, let $L+1$ Go to step 5.4.

5.4 Maintain the routes formed and the order in which point were joined. Proceed to the step 6.

Step 6: Suppress specified pairs

6.1 If there is still feasible ordered pair in the current best solution that has not been suppressed exist, suppress (suppressed temporally) the ordered pair that joined next in the current best solution, say (i', j') such that $s_{i'j'} = 0$ in the saving matrix and begin iteration with return to step 3.

6.2 If there is no more joined pair in the current best solution that can be suppressed, terminate the algorithm.

This algorithm assisted by the tree diagram to know the next suppression pair and the summary of the solution.

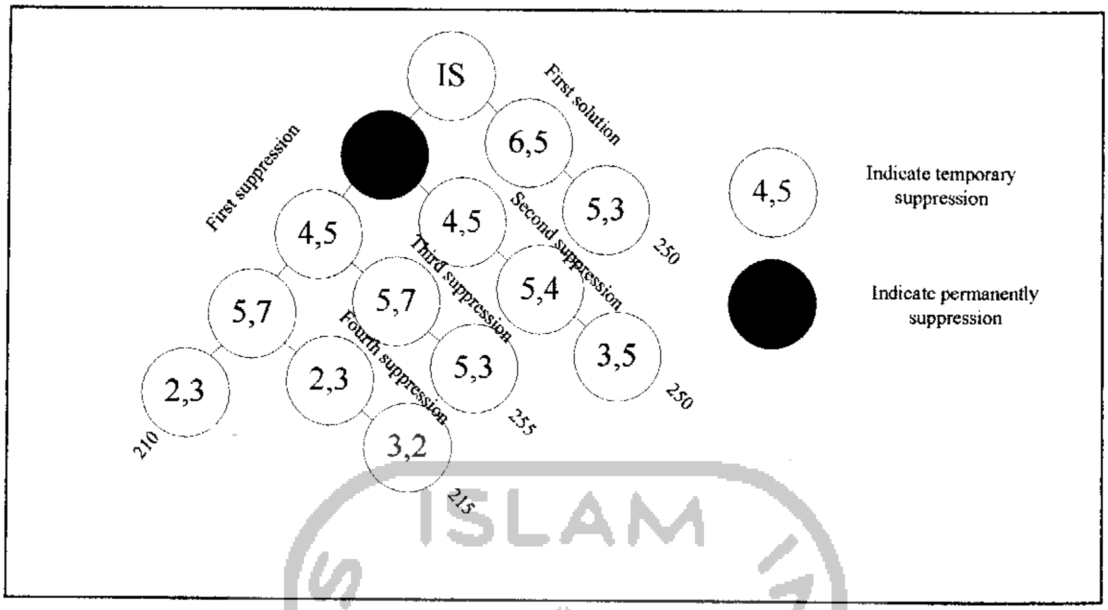

Figure 2.3 Tree Diagram