Journal of Nature Studies 13 (2): 13-24
ISSN: 1655-3179

DETERMINING THE OPTIMAL ROUTE OF VEHICLES DELIVERING RELIEF GOODS TO THE CALAMITY-PRONE AREAS IN REGION IV-A

Mark Lexter D. De Lara[1*], Vanessa Joy B. Burgos[1, 2]
Ann Margaret M. Silva[1, 2] and Allen L. Nazareno[1]
[1]Institute of Mathematical Sciences and Physics, College of Arts and Sciences,
University of the Philippines Los Baños
[2] Canon Information Technologies Philippines, Inc.
*Corresponding author: mrklxtrdlr@yahoo.com

ABSTRACT - This paper presents an integer linear programming model that determines the optimal route of vehicles delivering relief goods to the calamity-prone areas in Region IV-A, Philippines. This optimization problem is categorized as a capacitated vehicle routing problem. Data for typhoon Gener from the Department of Social Welfare and Development (DSWD) were considered in this study. Clarke-Wright's Savings Algorithm was used to generate the specific routes of each vehicle from the warehouses to the affected areas. The algorithm gave the optimal routes to be covered and the minimum total travel time to be taken by the delivery vehicles. The solution to this problem can be used by DSWD in efficiently distributing the relief goods to different areas in Region IV-A and consequently optimizing the use of government's resources.

Keywords: integer linear programming, vehicle routing problem, Clarke- Wright's algorithm, relief distribution, disaster management

INTRODUCTION

The Philippines, located above the equator in Southeast Asia, between latitude 4°23" and 21°25" North and longitude 116° and 127° East (Marsman, 2007), has a tropical and maritime climate. It has a relatively high temperature, high humidity and abundant rainfall (PAGASA, 2012). On the right side of the country is the vast Pacific Ocean where the typhoons are coming from. These typhoons greatly influence the Philippine climate. Around 20 typhoons visit the country each year, and damage properties and kill lives (Lacorte, 2012).

The Department of Social Welfare and Development (DSWD, as one of the executive department of the Philippine government, helps the local government to repack and distribute relief goods to evacuation centers. Scarcity of resources is a major issue in such situations. The number of vehicles used in delivering goods is limited. The vehicles need to go back and forth to the affected city to satisfy all the demand. The department thus, needs an efficient distribution system. Developing such system is crucial in any organization dealing with multiple distribution points. Several constraints must be taken into consideration. For the past decades, mathematicians had worked on improving the distribution of goods or services or commonly known as vehicle routing problem.

To cite this paper: De Lara, M. L. , Burgos, V. J., Silva, A. M. and Nazareno, A. 2014. Determining the Optimal Route of Vehicles Delivering Relief Goods to the Calamity-Prone Areas in Region IV-A. *Journal of Nature Studies.* 13 (2): 13-24

Vehicle Routing Problem (VRP) or the Truck-Dispatching Problem is about distributing goods between depots and customers (Golden, 1975). Its objective is to determine the optimal set of routes each vehicle must take so that a given number of customers are all served. VRP originated from Travelling Salesman Problem (TSP). The TSP is the simplest and most famous routing problem known to researchers. Itcalls on determining the shortest tour in a given set of cities so that each city is visited exactly once (Taha, 2008). Both the exact and heuristic methods are applied and were being explored to solve the VRP (Gambardella et al., 1999; Gendreau et al., 1994; Golden et al., 2008; Laporte et al., 2000; Osman, 1993) . One of the variations of the VRP which was adopted in this study was the Capacitated Vehicle Routing Problem (CVRP), . a special type of VRP wherein there is a restriction on the carrying capacity of the vehicles (Toth & Vigo, 2002).

Due to the urgent need of relief goods, an optimal route for the delivery vehicles is needed. These relief goods must satisfy the demand of each area. The study determines the optimal route of the delivery vehicles inV calamity-affected areas in the provinces of Region IV-A, specifically Batangas, Cavite, Laguna and Rizal.

METHODOLOGY

A. Data Gathering

MJ Mollenido, head of the Operations Team of DSWD-Region IV-A, served as the key informant for the needed data. He provided the following information:

- number of vehicles the department use in delivery and the respective capacities;
- transportation costs and the travel time;
- number of warehouses where the relief goods are coming from and the places served by these warehouses;
- vehicles' carrying capacity; and
- population density and the number of families affected.

Google Maps was used to determine the distances between places in the region. The corresponding estimated travel time between two places was computed using the distance suggested by Google Maps. The succeeding figures show the map and the corresponding network representation created for each province. The nodes represent the municipalities or cities and the edges represent the connection between each pair of nodes. It is assumed that the trucks used the shortest path connecting the two cities. In this study, alternative routes were not considered. The objective is for each truck to drop relief goods at one city and then move to the next city in its tour. Node 0 is the source node. The weight on each edge is the travel time expressed in minutes.

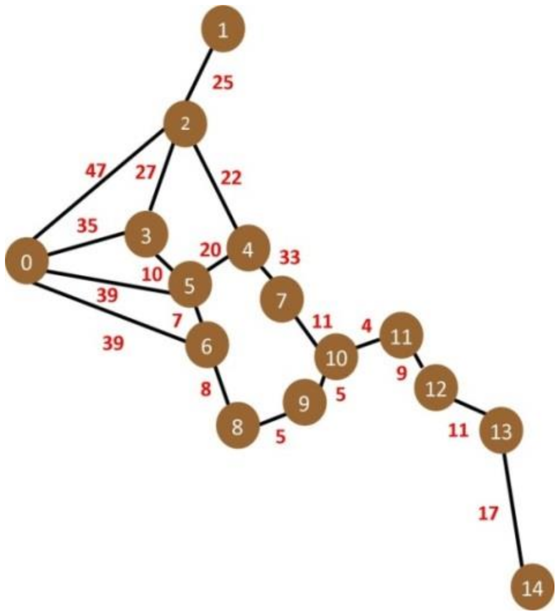

Figure 1. Network Representation of Rizal Province

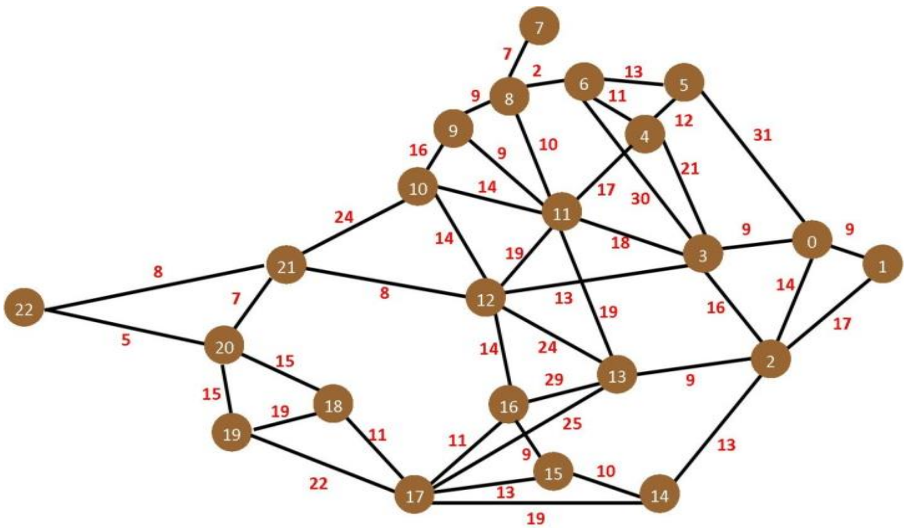

Figure 2. Network representation of Cavite Province

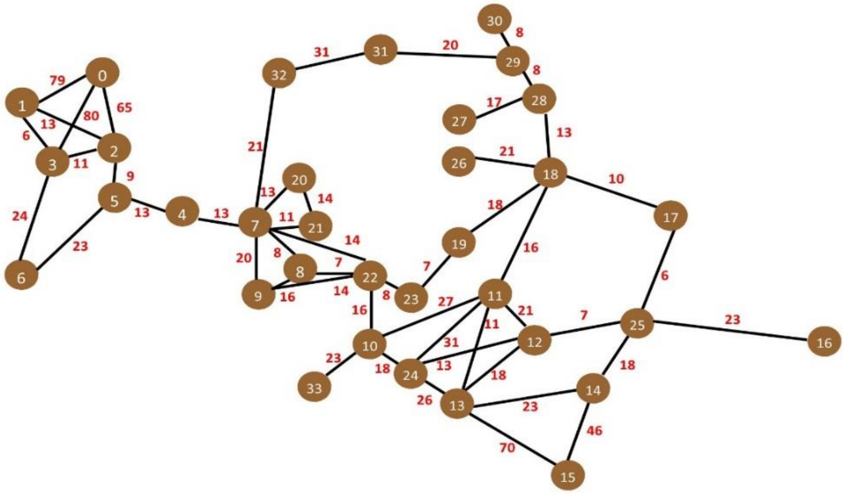

Figure 3. Network representation of Batangas Province

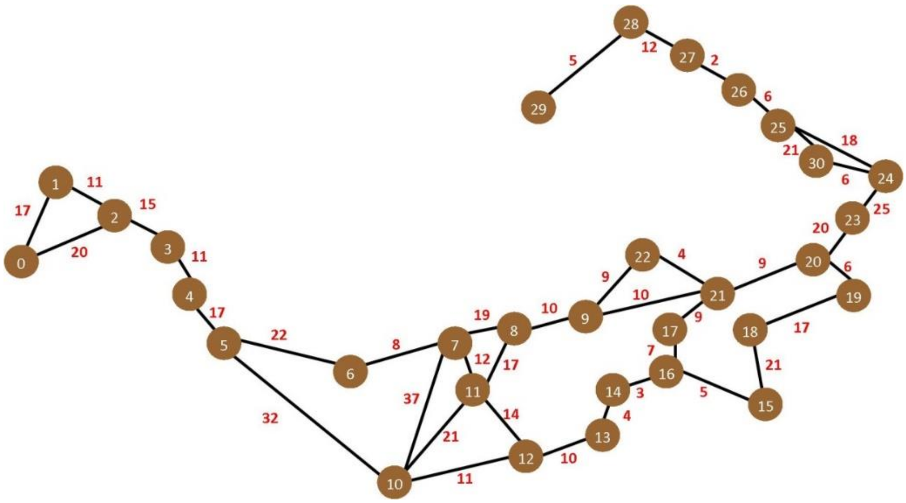

Figure 4. Network representation of Laguna Province

Table 1. Node Labels for the Province of Rizal, Cavite, Batangas and Laguna

Rizal	
Area	**Node**
National Resource Operation Center (Pasay City)	0
Rodriquez	1
San Mateo	2
Cainta	3
Antipolo	4
Taytay	5
Angono	6
Teresa	7
Binangonan	8
Cardona	9
Morong	10
Baras	11
Pililla	12
Tanay	13
Jala-Jala	14

Batangas			
Area	**Node**	**Area**	**Node**
GMA Cavite	0	Padre Garcia	17
Nasugbu	1	Lipa City	18
Tuy	2	Cuenca	19
Lian	3	Agoncillo	20
Calaca	4	San Nicolas	21
Balayan	5	Sta. Teresita	22
Calatagan	6	Alitagtag	23
Lemery	7	San Pascual	24
Taal	8	Rosario	25
San Luis	9	Mataas na Kahoy	26
Bauan	10	Balete	27
San Jose	11	Malvar	28
Ibaan	12	Tanauan	29
Batangas City	13	Sto. Tomas	30
Taysan	14	Talisay	31
Lobo	15	Laurel	32
San Juan	16	Mabini	33

Cavite			
Area	**Node**	**Area**	**Node**
GMA Cavite	0	Trece Martires City	12
Carmona	1	Amadeo	13
Silang	2	Tagaytay City	14
Dasmarinas	3	Mendez	15
Imus	4	Indang	16
Bacoor	5	Alfonso	17
Kawit	6	Gen. E. Aguinaldo	18
Cavite City	7	Magallanes	19
Noveleta	8	Maragondon	20
Rosario	9	Naic	21
Tanza	10	Ternate	22
Gen. Trias	11		

Laguna			
Area	**Node**	**Area**	**Node**
GMA Cavite	0	Liliw	16
San Pedro	1	Magdalena	17
Binan City	2	Luisiana	18
Sta. Rosa City	3	Cavinti	19
Cabuyao City	4	Lumban	20
Calamba City	5	Pagsanjan	21
Los Baños	6	Sta. Cruz	22
Bay	7	Kalayaan	23
Victoria	8	Paete	24
Pila	9	Pangil	25
Alaminos	10	Siniloan	26
Calauan	11	Famy	27
San Pablo City	12	Sta. Maria	28
Rizal	13	Mabitac	29
Nagcarlan	14	Pakil	30
Majayjay	15		

B. Model Formulation

An integer linear programming model of the capacitated VRP was formulated to optimize the route to be taken by the vehicles delivering the relief goods in the affected areas in Region IV-A. The general model given below was applied to the provinces in the region.

$$Minimize\ z = \sum_{i=0}^{NC} \sum_{j=1}^{NC} \sum_{k=1}^{NV} a_j t_{ij} l_{ijk} \qquad (1)$$

The objective is to determine the unique routes that minimizes the total accumulated travel time of all the vehicles that will be dispatched to distribute relief goods in the province.

$$\sum_{i=0}^{NC} \sum_{k=1}^{NV} l_{ijk} = 1, j = 2, \ldots, NC \qquad (2)$$

$$\sum_{i=0}^{NC} l_{ick} - \sum_{j=1}^{NC} l_{cjk} = 0, k = 1, \ldots, NV, \quad c = 1, \ldots, NC \qquad (3)$$

Constraints (2) and (3) guarantee that the solution assigns each vehicle a unique route. Constraint (3) also assures the continuity of each route.

$$c_k - \sum_{i=0}^{NC} (Q_i \sum_{j=1}^{NC} l_{ijk}) \geq 0, k = 1, \ldots, NV \qquad (4)$$

The capacity of trucks constraint is given by constraint (4).

$$\sum_{j=1}^{NC} l_{0jk} \leq 1, \quad k = 1, \ldots, NV \qquad (5)$$

Constraint (5) makes certain that truck availability is not exceeded.

Lastly, constraint (6) indicates that the decision variables are binary.

$$l_{ijk} \in \{0,1\} \text{ for all i,j,k} \qquad (6)$$

where

$NC =$ number of cities or municipalities

$NV =$ number of vehicles

$t_{ij} =$ travel time from city i to city j

$c_k =$ capacity of each vehicle k

$Q_i =$ demand at city i

$$l_{ijk} = \begin{cases} 1 \text{ if arc}(i, j) \text{ is traversed by truck } k \\ 0 \text{ otherwise.} \end{cases}$$

To ensure feasibility, constraint (7) or Miller-Tucker-Zemlin formulation was imposed (Kara and Bektas, 2003).

$$\sum_{i \in S}^{NC} \sum_{j \notin S}^{NV} l_{ijk} \geq 1, \forall k = 1, \ldots, NV, \quad |S| \geq 2 \qquad (7)$$

C. Heuristic Solution

The integer linear programming model was solved using Clarke-Wright's Savings (CWS) Heuristic (Lysgaard, 1997). Microsoft Excel 2010 was used to calculate the savings of each province. The savings were then arranged in descending order.

The CWS algorithm is the first savings-based algorithm (also called merging-algorithm). Initially, this algorithm assumes that each customer is served by its own vehicle. Next, two customers are to be served by the same vehicle as long as their capacity constraints are not violated. To determine the order in which customers are combined into a certain vehicle, the savings for a pair of customers is calculated.

The savings s_{ij} for a pair of customers V_i and V_j is defined as the savings in terms of distance that would be realized if these two customers would be served right after each other by the same vehicle instead of each by their own vehicle.

$$s_{ij} = c_{0i} + c_{0j} - c_{ij}$$

This quantity s_{ij} is larger than or equal to zero (0) because of triangle inequality. The algorithm takes the savings list, which is sorted in descending order, and processes the customer pairs on the savings list if they satisfy the conditions for the feasibility of including path (i,j) in a route assuming that operation does not violate capacity constraints. The algorithm has two variants: parallel and sequential variants. The difference between the two is that the parallel version builds multiple routes at a time, whereas the sequential version builds one route at a time. In the parallel version, after the savings list has been processed, unassigned customers are assigned to their own vehicle, exceeding the total amount of available vehicles. The parallel variant of CWS Algorithm was implemented in this study.

RESULTS AND DISCUSSION

The following tables show the solutions or policies that we propose to be implemented by DSWD-Region IV-A. These were obtained after applying the CWS Algorithm.

The tables display number of unique routes that must be taken by the vehicles dispatched in each province. Each vehicle takes a certain route to serve specific cities in the province. The number of returns is the number of times the vehicle goes back and forth to deliver relief goods depending on the demand of the city. The total relief goods distributed by each vehicle and the total travel time of each vehicle are also indicated in the tables.

Table 2. Summary of Results for Rizal Province

Route No.	No. of Returns	Route	Nodes Served	Total Relief Goods Distributed (yds^3)	Travel Time (hours)
1	4	0-5-0	5	108	2.6
2	1	0-6-8-9-8-6-0	6,9	27	1.73
3	1	0-5-6-8-9-8-6-0	5,8,9	25.31	1.85
4	2	0-6-8-9-10-9-8-6-0	10	41.29	1.9
5	1	0-6-8-9-10-11-12-11-10-9-8-6-0	11,12	23.34	2.33
6	1	0-6-8-9-10-11-12-13-12-11-10-9-8-6-0	12,13	27	2.7
7	3	0-3-5-4-7-4-5-0	3,4,7	63.13	3.17
8	10	0-2-1-2-0	1,2	246.78	12

Table 3. Summary of Results for Cavite Province

Route No.	No. of Returns	Route	Nodes Served	Total Relief Goods Distributed (yds^3)	Travel Time (hours)
1	1	0-3-11-12-21-20-22-21-12-10-11-3-0	0,3,10,1120,21,22	27	2.28
2	1	0-3-11-8-9-10-11-3-0	8,9,10	27	1.72
3	2	0-3-11-8-7-8-11-4-3-0	7	54	2.93
4	1	0-3-11-8-7-8-9-10-11-4-3-0	7,10,4	27	2.28
5	3	0-5-0	5	81	1.55
6	1	0-5-4-3-0	5,4	25.38	1.22
7	2	0-3-6-3-0	6	45.51	1.3

Table 4. Summary of Results for Batangas Province

Route No.	No. of Returns	Route	Node Served	Total Relief Goods Distributed (yds^3)	Travel Time (hours)
1	1	0-2-5-4-7-8-22-10-24-13-15-13-24-10-33-10-22-23-19-18-28-29-31-32-7-20-21-7-8-9-7-4-5-2-0	7, 8, 9, 10, 13, 15, 19, 20, 21, 22, 28, 29, 31, 32, 33	20.22	11.5
2	1	0-2-5-4-5-6-3-1-0	1, 2, 3, 4, 5, 6	18.03	3.87

Table 5. Summary of Results for Laguna Province

Route No.	No. of Returns	Route	Node Served	Total Relief Goods Distributed (yds^3)	Travel Time (hours)
1	1	0-2-3-4-5-6-7-8-9-21-20-23-24-30-25-26-27-26-25-24-23-20-21-9-8-7-6-5-4-3-2-0	30, 25, 26, 27	22.87	7.22
2	4	0-2-3-4-5-6-7-8-9-22-9-8-7-6-5-4-3-2-0	22, 9	103.58	17.47
3	1	0-2-3-4-5-6-7-8-9-21-20-23-24-25-26-27-28-29-28-27-26-25-24-23-20-21-9-8-7-6-5-4-3-2-0	28, 29	10.38	7.47
4	1	0-2-3-4-5-6-7-8-9-21-20-23-24-23-20-21-9-8-7-6-5-4-3-2-0	20, 23, 24	17.48	6.2
5	2	0-2-3-4-5-6-7-6-5-4-3-2-0	6, 7	52.76	6.2
6	7	0-2-3-4-5-10-12-11-8-7-6-5-4-3-2-0	5, 10, 12, 11, 8	186.7	16.75
7	11	0-2-3-2-0	2, 3	259.25	10.33
8	1	0-1-0	1	15.84	0.57
9	1	0-2-3-4-3-2-0	4	19.79	1.53

To interpret the tables, consider Table 5, the summary of results for Laguna Province. It indicates that there are nine (9) different routes that must be covered to supply the demand for all the nodes. Column 2 shows the number of times the specific route must be taken. For example, consider the second route, one or more vehicles must be assigned to this route and must serve nodes 22 and 9. The vehicle/s must follow the route 0-2-3-4-5-6-7-8-9-22-9-8-7-6-5-4-3-2-0. Recall that a vehicle always come from the relief goods depot and return to the depot, that is why the route starts from node 0 and go back to node 0. To satisfy the demand in the city, the route must be covered four (4)times. If the government has enough vehicles, then 4 vehicles at once can be assigned to this route. However, if there is only one vehicle available, then that vehicle can cover the task and return four (4) times. The sum of all the values in the last column is 73.73, which is the total accumulated travel time of one truck which returns four (4) times to satisfy the demand of the province of Laguna. Following this scheme will result to the low cost of transporting the relief goods while satisfying the demand of the province.

The near optimal total accumulated travel time to satisfy the needs of the provinces of Rizal, Cavite, Batangas and Laguna were 28.28, 13.28, 15.37 and 73.73 hours respectively.

SUMMARY AND CONCLUSION

Every year our country experiences the adverse impacts of typhoons. Providing immediate response and assistance to the typhoon’s affected areas has been the major problem of the local government. With the limited number of vehicles available for delivering goods, improving the distribution system is a big challenge. Hence, developing an efficient distribution system is essential to alleviate the effects of this nature-driven catastrophe.

This paper presents a methodology to come up with a near optimal route system of delivering relief goods in Region IV-A. The general integer linear programming model was formulated for Cavite, Laguna, Batangas and Rizal provinces and solved using Clarke-Wright’s Savings Algorithm. With the use of the algorithm, the optimal route with the minimum total travel time to be taken by the delivery vehicles in distributing the relief goods to each province in Region IV-A was determined.

RECOMMENDATIONS

The study assumed a deterministic demand. Conducting a study with stochastic approach for the demand is highly suggested because the effect of a calamity is unpredictable. The study can be extended by considering barangays as nodes instead of towns. This will involve more nodes and more computations but it may give better solution and better representation of the true relief distribution scenario. Other constraints like presence of heavy traffic in some roads and existence of blocked roads may also be considered. These more complicated problems may need the use of goal programming to address the conflicting objectives.

The study was an initial attempt to improve a particular aspect in disaster risk reduction and management. It can serve as stepping stone to solve more complicated problems and to come up with better strategies.

STATEMENT OF AUTHORSHIP

The first author initiated the concept of the study and was the lead writer of the paper. The second and the third author gathered the data, implemented all the computations and helped in the writing process. The fourth author gave some insights about the study and helped in the review and revision of the final paper.

REFERENCES

Ahmed, Z.H. (2004). Genetic Algorithm for the Traveling Salesman Problem using Sequential Constructive Crossover Operator. International Journal of Biometrics & Bioinformatics (IJBB) 3 (6). 96-100

Bager, Z., Meybodi M.R., & Abbaszadeh M.(July 11-13, 2007). "A Hybrid Method for Solving Traveling Salesman Problem".Proceedings of the 6th IEEE/ACIS International Conference on Computer and Information Science (ICIS 2007), IEEE Computer Society, Melbourne, Australia . 394-399 pp.

Cordeau,J.F., Gendreau, M., Laporte, G. Potvin,J.Y. & Semet, F2002). “A guide to vehicle routing heuristic”, The Journal of the Operational Research Society, ,Palgrave Macmillan Journals53(5): 512-522.

Erdoğan, G., Cordeau, J. F., & Laporte, G. (2010). The attractive traveling salesman problem. *European Journal of Operational Research*, *203*(1), 59-69.

Gambardella, L. M., Taillard, É., & Agazzi, G. (1999). Macs-vrptw: A multiple colony system for vehicle routing problems with time windows. In New ideas in optimization.

Gendreau, M., Hertz, A., & Laporte, G. (1994). A tabu search heuristic for the vehicle routing problem. Management science 40(10): 1276-1290.

Golden, B. L., Raghavan, S., & Wasil, E. A. (2008). *The Vehicle Routing Problem: Latest Advances and New Challenges: latest advances and new challenges* (Vol. 43). Springer.

Hornik, K., & Grün, B. (2007). TSP-Infrastructure for the traveling salesperson problem. *Journal of Statistical Software*, *23*(2), 1-21.

Helvig, C.S. and Robins, G. (2003). The moving-target traveling salesman problem. Lecture Notes in Comp. Sci.,. 1461 (1998): 453–464.

Herrera, C.D. and Palaje, M.J.M. (2011). Determining the Optimal Routes of Field Agents of Sterix Inc., Special Problem, Division of Mathematics, Institute of Mathematical Sciences and Physics, U.P. Los Baños.

Kara, I., & Bektas, T. (2003). Integer linear programming formulation of the generalized vehicle routing problem. In *EURO/INFORMS Joint International Meeting, Istanbul, July* 6-10, 2003.

Lacorte, G. (2012.). ‘So, that’s what a typhoon is like’. Philippine Daily Inquirer. Retrieved on December 5, 2012 from www.newsinfo.inquirer.net/318527/so-thats-what-a-typhoon-is-like

Laporte, G., Gendreau, M., Potvin, J. Y., & Semet, F. (2000). Classical and modern heuristics for the vehicle routing problem. International transactions in operational research, 7 (4-5): 285-300.

Lysgaard, J. (1997). Clarke & Wright’s Savings Algorithm. Department of Management Science and Logistics, The Aarhus School of Business.

Marsman Drysdale Travel, Inc. (2007). Philippine information. Retrieved on December 5, 2012 from http://www.marsman-tours.com.ph/philinfo.htm.

Osman, I. H. (1993). Metastrategy simulated annealing and tabu search algorithms for the vehicle routing problem. Annals of operations research 41(4): 421-451.

PAGASA. (2012). Climate of the Philippines. Retrieved on December 5, 2012 from http://kidlat.pagasa.dost. gov.ph/cab/climate.htm

Pizlo, Z., Stefanov, E., Saalweachter, J., Li, Z., Haxhimusa, Y., & Kropatsch, W. G. (2006). Traveling salesman problem: A foveating pyramid model. *The Journal of Problem Solving*, *1*(1), Article 8. 83-101.

Rand, G.K. (2009). The life and times of Savings Method for Vehicle Routing Problems. Orion 25 (2): 125-145.

Ralphs, T. K., Kopman, L., Pulleyblank, W. R., & Trotter, L. E. (2003). On the capacitated vehicle routing problem. *Mathematical programming*, *94*(2-3), 343-359.

Toth and Vigo (20**02)**. The Vehicle Routing Problem. United States of America: Society of Industrial and Applied Mathematics.

JOURNAL OF NATURE STUDIES
(formerly Nature's Bulletin)
ISSN: 1655-3179