ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering
Tome V (Year 2012). FASCICULE 1 [January–March]. ISSN 2067-3809

[1.] Yasel COSTA, [2.] René ABREU, [3.] Norge COELLO, [4.] Elke GLISTAU

SOLVING THE DECISION-MAKING PROCESS IN ROUTE PLANNING RELATED WITH REPAIR OF ELECTRICAL BREAKDOWNS

[1-3.] DEPARTMENT OF INDUSTRIAL ENGINEERING, CENTRAL UNIVERSITY "MARTA ABREU" OF LAS VILLAS, SANTA CLARA, CUBA
[4.] OTTO VON GUERICKE UNIVERSITY, GERMANY

ABSTRACT: *The Vehicle Routing Problem (VRP) has been widely study by different authors, often specialist from Operation Research and Logistic fields. However, in the real context of decision making, new variants of VRP are found. These variants also show peculiar conditions which require a new approach for the existing methods. According to literature there are two types of optimization methods for solving VRP, exact and approximate methods. Sometimes, decision makers are subject of uncertainty about which method (exact or approximate) should be used according with the problem dimension, and also their characteristics. For these reasons, this paper proposes Discriminant Analysis for solving uncertainly about which optimization methods can be used with high quality results, due to the results of Discriminant Analysis we introduce a modified Ant Algorithm for route planning in the repair of electrical breakdowns. The meta-heuristic performance has been compared with a Branch and Bound strategic. Computational results confirm the effectiveness of the algorithm proposed.*
KEYWORDS: *discriminant analysis; uncertainty*

INTRODUCTION

In the industry and services sector, transport costs represent a significant portion of the goods or services provided. Proper distribution planning can mean considerable savings. These potential savings largely support the use of Operation Research techniques as planning supporting, since it is estimated that transport costs represent between 10% and 20% of the final cost of goods. In that sense, several variants of Vehicle Routing Problems have received a lot attention in the recent years, such as, theoretical and practical groups (e.g. [4]). This kind of problem is a well-known NP-Hard combinatorial optimization problem which is encountered frequently in decision making process, beside in logistics system. Exact methods have been used with feasible results [2] for solving different variants of VRP, although the Traveling Salesman Problem (TSP) has received a great deal of attention. However, most of these approaches have been developed for small to medium problems with at most a few customers to be performed by a small fleet of trucks. In the last decade, approximate methods have made significant progress in the optimization of VRP families, specifically meta-heuristics [3]; [1]. Many real world problems have been solved by feasible use of approximate methods, often problem with obvious big dimension. For these problems, most exact methods proposed in the literature are unfeasible due to computational time and available time for decision making in the operative context. Nevertheless, uncertainty behavior appears when the decision makers have to desire which kind of methods should be used in those problems with none palpable dimension. For that reason this paper proposes a multivariate analysis in order to decrease the uncertainty about using exact or approximate methods in VRP, with an emphasis on route planning related with repair of electrical breakdowns. Moreover, due to the results of multivariate analysis and other peculiar conditions a hybrid algorithm of Sweep Heuristic (SH) and Ant Colony System (ACS) is presented. The paper is structured as follows: In Section 2 is formulated the real problem mentioned, Discriminant Analysis for uncertainty in decision making is showed at Section 3. Hybrid algorithm of SH-ACS is defined at Section 4. Computational results and the algorithm performance can be found in Section 5. Conclusions and future researches are outlined in Section 6.

PROBLEM DEFINITION

The route planning for repair of electrical breakdowns is in principle a variant of m-TSP, but with dynamic approach. The problem consists in a tour planning from dispatch (D) multiple vehicles, with homogeneous characteristics, for repairing different types of breakdowns. The breakdowns have different priorities: first priority in electrical networks between 220 and 33 KV; second priority for those of 4 KV; and the third in electrical networks under 4 KV (the most frequent). The problem also present dynamic approach, when the tours for repairing are already planning, new breakdowns occur. The problem complexity increase when new breakdowns have to be inserted according to their priorities, but this approach will be considered in feature research. Different types of integer programming formulations are proposed for the m-TSP. We use one of them considering the priorities for breakdowns. The decision variable can be defined as follows:

$$X_{ij} = \begin{cases} 1 & \text{if arc}(i,j)\text{ is used on the tour} \\ 0 & \text{otherwise} \end{cases}$$

The objective function "(1)" and the constraints can be given as follows:

$$\text{minimize} \sum_{i=D}^{n}\sum_{j=D}^{n} C_{ij} \quad X_{ij} \qquad (1)$$

s.t.

$$\sum_{j=1}^{n} X_{Dj} = m \qquad (2)$$

$$\sum_{i=1}^{n} X_{iD} = m \qquad (3)$$

$$\sum_{i=D}^{n} X_{ij} = 1, \quad j = 1,\ldots,n \qquad (4)$$

$$\sum_{j=D}^{n} X_{ij} = 1, \quad i = 1,\ldots,n \qquad (5)$$

$$\sum_{i\in S}\sum_{j\in S} X_{ij} = |S| \quad 1, \ \forall S \subseteq V\setminus\{1\}, S \neq \varphi \qquad (6)$$

$$X_{Dj} = 1, \ \forall j : (\text{first}) \text{ and } (\text{second}) \text{ priority} \qquad (7)$$

Where "(2)" and "(3)" ensure that exactly "m" vehicles depart from and return back to node D (the Dispatch). The constraints "(4)" and "(5)" allow to the vehicles visit once different breakdowns. Expression "(6)" is for the classical sub-tour elimination and "(7)" is a hard constraint which ensure that fleet of vehicles should to visit breakdowns with first and second priority starting from dispatch.

DISCRIMINANT ANALYSIS FOR UNCERTAINTY IN DECISION-MAKING

From scientific literature is well-know the classical group of methods (exact or approximate) for solving any variant of VRP. Sometimes the decision making for solving VRP is carried out under uncertainty. For small and medium VRP exact methods have shown good performance according to solution quality and computational time. Similarly, approximate methods can to solve VRP with big dimensions and also medium dimension with hard constraints due to the real context of decision making in VRP. Therefore, there is uncertainty to establish relevant optimization methods regarding dimension boundaries. This paper proposes Discriminant Analysis in order to know which group of methods will be relevant considering the problem dimension with multivariate approach. In the Table 1, dependent and independent are shown. These variables were extracted of literature, specifically of [5].

Knowledge base was created regarding these variables, 122 cases from literature about best practices in VRP solution, using both optimization methods. In the knowledge base, 28 belong to exact category and 93 to approximate. Considering the customer demand, 99 are classified as deterministic and 22 stochastic, based on time constraints, there were 69 with time windows and 52 otherwise. In 76 cases was considered one-objective and homogeneous fleet.

Table 1. Classification variables

Variables	Type	Instances
Relevant method	Dependent	▪ Exact ▪ Approximate
Number of nodes	Independent	▪ Discrete number
Fleet size	Independent	▪ Discrete number
Fleet type	Independent	▪ Homogeneous ▪ Heterogeneous
Number of objective	Independent	▪ One-objective ▪ Multi-objective
Time constraints	Independent	▪ With time windows ▪ Without time windows
Customer demand	Independent	▪ Deterministic ▪ Stochastic

The Discriminant Analysis is given by "(8)"; beside independent variables appear in the same order that Table 1.

$$D = b_1 \cdot X_1 + b_2 \cdot X_2 + b_3 \cdot X_3 + b_4 \cdot X_4 + b_5 \cdot X_5 + b_6 \cdot X_6 \qquad (8)$$

Base on the proposal for decrease uncertainty in decision making, we introduced the problem of route planning for repair of electrical breakdowns in knowledge base and thus Discriminant Analysis for classification process. The Table 2 figures main characteristics of the problem regarding defined variables. We use as statistical package the SPSS, obtaining results in Figure 1. Statistical test indicates that approximate methods are relevant for solving the problem defined in Section 2.

Table 2. Variables of defined problem

Route planning for repair electrical breakdowns
Number of nodes: 56 (breakdowns) Time constraints: Without time windows Fleet size: 3 vehicles Fleet type: Homogeneous Number of objectives: One-objective Time for repair: Stochastic

Casewise Statistics

Case Number	Actual Group	Highest Group: Predicted Group	Highest Group: P(D>d | G=g) p	Highest Group: P(D>d | G=g) df	Highest Group: P(G=g | D=d)	Highest Group: Squared Mahalanobis Distance to Centroid	Second Highest Group: Group	Second Highest Group: P(G=g | D=d)	Second Highest Group: Squared Mahalanobis Distance to Centroid	Discriminant Scores: Function 1
112	1	1	.421	1	750	.647	2	.250	2.844	1.009
113	1	1	.815	1	545	.055	2	.455	.419	-.030
114	2	1(**)	.187	1	825	1.741	2	.175	4.844	1.523
115	1	2(**)	.785	1	.652	.074	1	.348	1.332	-.950
116	2	2	.473	1	.735	.514	1	.265	2.555	-1.395
117	2	2	.483	1	.733	.493	1	.267	2.507	-1.379
118	2	2	.458	1	.739	.551	1	.261	2.636	-1.420
119	1	1	.420	1	.750	.652	2	.250	2.852	1.011
120	1	1	.420	1	.750	.652	2	.250	2.852	1.011
121	1	1	.420	1	.750	.652	2	.250	2.852	1.011
122	ungrouped	2	.513	1	.724	.428	1	.276	2.359	-1.332

** Misclassified case

Figure 1. Discriminant Analysis results using SPSS

HYBRIC ALGORITHM OF SH-ACS

This paper proposes a feasible strategy according with the results of application of Discriminant Analysis in Section 3. The strategy consists of make breakdown clusters, with Sweep Heuristic, considering geographic position of each breakdown, also a feasible and consistent distribution of vehicle available time. Finally, for each cluster of breakdowns Ant Colony System is proposed.

The group of breakdowns formed in each cluster is given by Algorithm 1, which considers segmentation according to the fleet size allocating each vehicle for each cluster built. Also the allocation of available time is considered.

Algorithm 1: Sweep Heuristic
Step 1: Initiation -Order increasingly breakdowns according to an angle "ϑ" according with [6] -If two breakdowns have the same "ϑ", decide regarding polar coordinate "ρ" Step 2: Selection -If all nodes (breakdowns) belong to the same cluster C_k execute Step 3, else: If each breakdown "A_i" satisfies the available time: $C_k := C_k \bigcup \{A_k\}$; else: Do k:= k + 1 and create a new cluster with $C_k := \{A_k\}$ Step 3: Optimization -For each C_k solve TSPAnhörenUmschrift

Algorithm 2: General procedure for Ant colony System

1. Initiation phase
Initialize parameter for Ant Colony System: (q_o); (α); (β); (ρ)
Get the initial solution (ψ^{nn}) based on nearest neighbor heuristic
$\psi^{gb} \leftarrow \psi^{nn}$: where ψ^{gb} is the best global solution
$L_{gb} \leftarrow L_{nn}$: Total length of the best route
Initialize initial pheromone (τ_0)
$\forall (i,j) \rightarrow \tau_{(i,j)} = \tau_0$: where $\tau_0 = (n \cdot L_{nn})^{-1}$
2. Cycle executed by each ant "k"
Do until Termination criterion = True
For each Ant "k"
Route construction (ψ^k) using (**new ant algorithm**)
If $L_k \le L_{gb}$ **Then**
$L_{gb} = L_k$: $\psi^{gb} = \psi^k$
End If
End For
Loop
3. Updating global pheromone
$\tau_{(i,j)}(\text{current}) = (1-\alpha)\cdot\tau_{(i,j)}(\text{previous}) + \frac{\alpha}{L_{gb}} \quad \forall (i,j) \in \psi^{gb}$

q_o: Relative importance (Intensify vs. Diversify) mechanisms α : Global pheromone evaporation β : Relative importance Pheromone vs. Heuristic ρ : Local pheromone evaporation

The Ant Colony System is bio-inspired in the real ant behavior (Dorigo & Stützle, 2004). The real ants always find the shortest between their nest and food sources, due to indirect exchange of information through pheromone trail. While shorter is the path, greater number of ants passes through it, and therefore, greater amount of pheromone is deposited. This pheromone trail influences when ants deciding which path should be taken. In the Algorithm 2 is presented a general procedure followed for achieve high quality solution in route planning.

The probabilistic construction followed for each artificial ant is formulated in Algorithm 3, also a new heuristic (η_{ij}) is proposed as desirability for adding a node (breakdown) to a tour. Beside, a priority index (P_j) is fixed depending of the breakdown type: (0.6) when "j" is a first priority breakdown; (0.3) when "j" is a second priority breakdown; and (0.1) for the third priority. For route construction two stochastic mechanisms are defined in the "(9)" and "(10)".

$$\text{Intensify}(i,j) = \begin{cases} \arg\max\left\{\tau(i,j)\cdot[\eta(i,j)]^{\beta}\right\} & \text{if} \quad \text{Rnd} \le q_o \\ \text{Diversify}(i,j) & \text{otherwise} \end{cases} \tag{9}$$

$$\text{Diversify}(i,j) = \begin{cases} \dfrac{[\tau(i,j)]\cdot[\eta(i,j)]^{\beta}}{\sum_{j\in J_k(i)}[\tau(i,j)]\cdot[\eta(i,j)]} & \text{if} \quad \text{Diversify} \in J_k(i) \\ 0 & \text{otherwise} \end{cases} \tag{10}$$

Algorithm 3: New Ant
1. Initiation **Locate** the ant "k" ant node dispatch (D) **Initialize** Current Time$_k \leftarrow$ 0 **2. Cycle for doing a tour by each ant "k"** **For** ant (k) located at node (i) (start at Dispatch), it determines the set of nodes (N_i^k). If node (i) is not the Dispatch, include it in the set **For each** $i \notin N_i^k$ $\text{Dist}_{ij} = \text{Max}(1, \text{Travel}_{ij})$ $\eta_{ij} = \frac{1}{\text{Dist}_{ij}} \cdot \frac{RT_j}{AT} \cdot P_j$ $RT_j = \begin{cases} U(45,60) & \text{if} \ \langle j \rangle \text{is first priority breakdown} \\ U(25,35) & \text{if} \ \langle j \rangle \text{is second priority breakdown} \\ U(10,20) & \text{if} \ \langle j \rangle \text{is third priority breakdown} \end{cases}$ Stochastic selection for next node (i) using η_{ij} **Update** the route: $\psi^k \leftarrow \psi^k + (j)$ **Update** the total length: $L_k \leftarrow L_k + \text{Travel}_{ij}$ **Update** local pheromone: $\tau_{(i,j)}(\text{current}) = (1-\rho)\cdot\tau_{(i,j)}(\text{previous}) + \rho\cdot\tau_0$ **End For**

COMPUTATIONAL RESULTS

In this section some computational results are presented in order to evaluate the performance of the algorithm described in Section 4. Algorithm runs have been carried out on a personal computer equipped with an Intel Pentium dual-core processor 1.6 GHz and 1 GB of ram memory. The SH-ACS was coded Java 1.5.0. The configuration of the SH-ACS has been defined as follows: 10 artificial ants were used, 50 iterations were executed for each run, the parameters q_o, β, α, ρ were 0.75, 1, 0.1, 0.3 respectively. The algorithm is tested into 10 different runs. In Table 3, the best found solutions are reported for two strategies: SH-ACS and exact method called Branch and Bound.

Starting from figures of Table 3 we obtained non significant differences between these algorithms, due to results of Wilconxon coefficient as statistic test. The Branch and Bound strategic computed the runs about 25 minutes as average, existing significant differences compared to a few seconds of SH-ACS. For these reason results of multivariate analysis described in Section 3 are validated, approximate methods, such as SH-ACS is relevant solution for the real problem formulated in Section 2.

Table 3. Numerical results for SH-ACS compared to branch and bound

Algorithm runs	SH-ACS	Branch and Bound
1	154	149
2	175	149
3	171	149
4	171	149
5	154	149
6	175	149
7	154	149
8	186	149
9	171	149
10	186	149
Average	169.7	149

CONCLUSIONS

In this paper, Discriminant Analysis is presented for assisting decision making for decreasing uncertainty before optimization process in VRP; also a hybrid algorithm SH-ACS is formulated. Moreover, the performance of SH-ACS in the real problem defined outcomes relevant. According with numerical and statistic test, we can conclude that SH-ACS can solve the real problem defined more effectively than Branch and Bound strategic.

FUTURE RESEARCH

Future researches would focus to modify SH-ACS considering unexpected breakdown, also define an Ant Algorithm to obtain integrated solution, vehicles allocation and route planning at the same time. Beside we have to consider sensitivity analysis of the fixed parameters in the algorithm.

ACKNOWLEDGMENT

This research was supported by Cuban CED (Center of Electricity Distribution) and also by the Department of Artificial Intelligence of Central University "Marta Abreu" of Las Villas. This support is gratefully acknowledged.

REFERENCES

[1] ALBA, E. & DORRONSORO, B. (2006). *Computing nine new bestsofar solutions for Capacitated VRP with a cellular Genetic Algorithm. Information Processing Letters. Vol. 98. Pages 225230*

[2] BARD, J.F., KONTORAVDIS, G. & YU, G.A. (2002). *A branch and cut procedure for the vehicle routing problem with time windows. Transportation Science. No 36. Pages 250– 269.*

[3] DORIGO, M. & STÜTZLE, T. (2004). *Ant Colony Optimization. Cambridge, MA: MITPress/Bradford Books.*

[4] LAPORTE, G. (1992). *"The Vehicle Routing Problem: An Overview of Exact and Approximate Algorithms," European Journal of Operational Research 59, 345–358.*

[5] TOTH, P., VIGO, D.: *An Overview of Vehicle Routing Problems. Monographs on Discrete Mathematics and Applications. In: The Vehicle Routing Problem. SIAM (2000) 1-26.*

[6] WREN, A., HOLLIDAY, A.: *Computer Scheduling of vehicles form one or more depots to a number of delivery points. Operational Research Quarterly 23 (1972) 333-334*