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A New Approach for Solving the Disruption in Vehicle Routing Problem during Delivery

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Abstract

The purpose of this paper is to describe a new approach for solving the disruption in vehicle routing problem (DVRP) which deals with the disruptions that occur abruptly when executing the original plan. The paper then discusses further on the vehicle-breakdown problems, which is the most common and usually happening problem when delivering the goods and services to the customers. To handle these cases, we need to develop a new routing plans to reduce the negative impact and solution needs to be quickly produced to reduce the annual costs. Tabu Search algorithm is selected to solve these DVRP and is assessed with other meta-heuristics like ant colony optimization and genetic algorithms. The contribution of this paper is to determine a combination of meta-heuristics that produces new best-known solutions on the VRP benchmark problems. Numerical tests on a set of relevant benchmark problems have been produced and computational results from the experiments using the other meta-heuristic techniques are presented.

Keywords: vehicle routing problem, disruption, vehicle breakdown, meta-heuristics, tabu search.

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Новый подход в решении проблемы незапланированного изменения маршрута транспорта во время доставки

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Аннотация

Целью данной работы является описание нового подхода к решению проблемы нарушения маршрутизации транспортных средств (ПНМТС), который имеет дело с нарушениями, возникающими внезапно при выполнении первоначального плана. Затем в статье обсуждаются дальнейшие проблемы, связанные с поломкой транспортного средства, которые являются наиболее распространенной проблемой, возникающей при доставке товаров и услуг клиентам. Чтобы справиться с этим, нам нужно разработать новые планы маршрутизации, уменьшающие негативное воздействие, и решение должно быть найдено быстро, чтобы снизить ежегодные затраты. Алгоритм поиска с запретами выбирается для решения этих ПНМТС и оценивается с помощью других мета-эвристик, таких как муравьиная оптимизация и генетические алгоритмы. Основной вклад этой статьи заключается в определении комбинации метаэвристик, которая дает новые наиболее известные решения по эталонным задачам VRP. Были проведены численные тесты по набору соответствующих эталонных задач и представлены вычислительные результаты экспериментов с использованием других метаэвристических методов.

Ключевые слова: проблема маршрутизации транспортных средств, сбой, поломка транспортных средств, метаэвристика, поиск с запретами.

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Introduction

The purpose of this paper is to present a new approach for solving the disruption in vehicle routing problem (DVRP) during delivery. Disruption is the disturbance or problem which interrupts an activity or process. The main feature of disruption management is the ability to deal with a disturbance that is going to happen without knowing it in advance. There are many reasons for happening of disruptions which may occur abruptly when executing the original vehicle routing plan may be caused by vehicle-breakdown problems, delaying arrivals and departures from the depot, road accidents and traffic jams, etc. and aims to find a feasible solution to minimize the negative impact that was caused by disruptions. It also aims to minimizes the increase in travel time and minimizes the sum of annual costs. When dealing with disruptions a proper decision-making process should be made therefore with competent algorithms that can find a new plan as quickly as possible. The following are the factors that are involved in the disruption management.

1. There will be very limited time for the re-planning of the vehicle. This will be usually happening in many of the cases. For this situation, it is important to produce an optimized plan for recovery by using any algorithms.
2. The time needed to communicate with each other for the operational plan for those to implement it and to receive information back about disruption should also be considered into account.
3. Maybe the restriction in the new plan that was not in the original VRP plan. These may be the consequence of the disruption that has happened, as the road may be blocked due to the accident or unavailability of the vehicle, vehicle breakdown.
4. The undisrupted vehicle's original VRP plan may be helpful for the new plan as a starting point. When producing the newly developed plan, there is no need to find out a plan from scratch.
5. It may be appropriate to involve the new annual costs that are related to the deviations caused by the original VRP plan.

The formal definition of disruption management is found in Yu and Qi [1] *"At the beginning of the business cycle, an optimal or near-optimal operational plan is attained by using certain optimization methods and techniques. When such an optimization plan is executed, the disruptions may happen from time to time which leads to internal and external risk factors. As a result, the actual operational plan may not persist feasible or optimal. Therefore, we need to vigorously develop the original plan and obtain a new plan that reflects the constraints and objectives of the developing situation while minimizing the negative effect of the disruption ".*

In this paper, we suggested a formulation for the disrupted VRP that connects to a problem which is vehicle breakdown during delivery. To solve this disrupted VRP a meta-heuristic approaches like tabu search is selected and assessed with other meta-heuristics like ant colony optimization and genetic algorithm which are used to compare the results between each other. Numerical tests on a set of relevant benchmark problems have been produced and computational results from the experiments using the other meta-heuristic techniques are presented.

Related Work

This section deals with previous works pertaining to this area of research (i.e. disruption management in vehicle routing problems and meta-heuristic approaches for solving VRP). Vehicle Routing Problem (VRP) was first introduced by Dantzig and Ramser [2], in 1959 as a traveling salesman problem (TSP) and he described VRP is an integer programming and combinatorial optimization problem seeking to supply to the number of customers with a fleet of vehicles. VRP in [2] is an abstraction of a vehicle Scheduling problem in a real-world delivery system. The VRP problem is a logistics problem where a depot consists of more than one vehicle and distributed the goods to customers and delivery points. The problem lies behind each vehicle routing to cover all the delivery points such as cost, distance and time are set to the minimal extent [3].

Several papers are studied on disruption management and problems with vehicle routing problems. Li et al. [4], [23], described when a public transport vehicle breaks down on a scheduled plan, one or more vehicles are needed to reschedule the plan to serve and other service plans originally scheduled for the vehicle which is disabled. In that paper vehicle rescheduling problem is investigated to consider costs of scheduled disruption and operating costs and the cost of trips cancellation and a lagrangian relaxation-based insertion heuristic is developed. Snyder et al. in [5], have highlighted the need for planners to consider the risk of disruptions when designing supply chain networks and considered independent disruptions with equal marginal rates of disruption for each facility location.

The authors of [6], have described the meta-heuristic solution methods for rich vehicle routing problems. Addresses the periodic vehicle routing problem with time windows (PVRPTW) which generalizes the classical vehicle routing problem with time windows (CVRPTW). Performance of the suggested methodology compared to the literature with solutions requiring fewer vehicles and the cost of travel to perform efficiently.

The author of the article [7], is reviewed on the topic of deterministic vehicle routing problem. Also given a review of appropriate and exact solution techniques. Then appropriate solutions (Meta-heuristic) solutions are classified into simulated annealing, evolutionary algorithm, hybrid algorithm, genetic algorithm, tabu search, and ant colony optimization. Each of these techniques is briefly discussed.

The authors in the paper [8] have proposed a new approach to stochastic combinatorial optimization. The main characteristic of this model is distributed computation and the use of constructive greedy heuristic. They applied the suggested methodology to the classical Traveling Salesman Problem (TSP) and reported results. The author demonstrated the robustness of the approach and showed how the Ant System (AS) is applied to other optimization problems like an asymmetric traveling salesman, the quadrate assignment and the job-shop scheduling.

The authors in the paper [9] addresses the numerous applications in real life. He attempted to find an optimal route result for VRP of his university shuttle bus problem by using a genetic algorithm. Author achieved an optimal solution that reduces the consuming of time and distance for the paths which leads to the speedy transportation of students to their locations, to reduce the costs of transportation such as fuel utilization and additionally the vehicle costs, to implement the Capacitated Vehicle Routing Problem (CVRP) model for optimizing shuttle bus problem. Baker in paper [10], the study considers the application of genetic algorithm (GA) to the basic VRP. The computational results are given for pure GA and results are given using a hybrid of this GA with neighborhood search methods. The author showed GA is competitive with tabu search and simulated annealing in terms of cost and time.

Jia and Li in the paper [11] have discussed the importance of disruption management. In this paper, the author designs and realized a new tabu search by introducing mutation and mixed local searching approaches for overcoming the weakness of the current TS. The author also has done the comparison of improved tabu search with other algorithms, and the performance of improved TS is shown.

The author in the paper [12], have introduced a parallel iterated tabu search heuristic for solving four different routing problems they are: the classical VRP, multi-depot VRP, the periodic VRP, and the site dependent VRP. Besides, applies to the time window constrained variant of these problems. By using the iterated local search framework, the heuristic method combines tabu search with a simple perturbation mechanism to ensure a broad exploration of the search space. And described a parallel implementation of the heuristic to take advantage of multiple-core processors.

The authors of [13], have solved vehicle routing problem with discrete spit deliveries and pickups is a variant of the VRP with split deliveries and pickups, in which the customer demands are discrete in terms of orders. The author proposed a mathematical model and a tabu search algorithm with specially designed order combinations and item creation operations. The order combination operation is designed to avoid unnecessary costs of travel, while the creation of item operation effectively speeds up the search and improve the searchability of the algorithm.

AlgorithmS

In this section we summarize the followed algorithm in this paper. It describes the various components of this work such as tools, benchmarks or datasets used, and how the selected algorithm is tuned and assessed in relation with other algorithms and tested between each other. We also present the pseudo codes of the selected and used algorithms.

A. Tools Used

The implementation of the algorithm has been done in "JAVA 8 by using Eclipse IDE" in windows laptop. ANOVA in Microsoft Excel is a built-in statistical test that is used to analyze the variances. The 'data analysis' tool in excel which is used to test the different data sets against each other to identify the best solution.

B. Benchmarks or datasets Used

The benchmarks are one of the major sources to aid this paper. The datasets which are required for testing our approach and comparing with other approaches is obtained from domain CVRPLIB (Capacitated Vehicle Routing Problem Library)[1] [14]. By using these benchmarks, we can obtain the best-known solutions. The datasets contain the following basic information as input:

- A graphical coordinate representing the position of the delivery points and position of the depot.
- The number of vehicles used and the size of the problem (number of delivery points).

C. Selected Algorithms

We present the selected tabu search (TS) algorithm which is used as a reference algorithm and tuned to get the near-optimal solutions and assessed in relation with ant colony optimization (ACO) and genetic algorithm (GA) which we base our work in this paper.

1) Tabu Search Algorithm (TS)

Tabu Search is one of the successful meta-heuristics for the application to combinatorial optimization and is a dynamic neighborhood search method. The main feature of TS is always moved to the best available neighborhood solution point, even if it is worse than the current solution [20].

The below algorithm provides a pseudo-code implementation for minimizing the time, and cost function of the TS algorithm. The listing shows the simple TS algorithm with short term memory, without intermediate and long-term memory management.

```
Input : tabuList_size
Output : S_best
S ← S_0
S_best ← S
tabuList ← ∅
while ( ¬ stoppingCondition( ))
    customerList ← ∅
    for(S_customer ∈ S_bestNeighborhood)
        if(¬ containsTabuElements(S_customer , tabuList))
            customerList ← S_customer
        end
    end
    S_customer ← LocateBestCustomer(customerList)
    if(cost(S_customer) ≤ cost(S_best))
    if(time(S_customer) ≤ time(S_best))
        S_best ← S_customer
        tabuList ← featureDifferences(S_customer , S_best)
        while(size(tabuList) > maxTabuListSize)
            ExpireFeatures(tabuList)
        end
    end
end
return(S_best)
```

Pseudo-code of TS for cost function [15].

1) Ant Colony Optimization (ACO)

Ant colony optimization is one of the new distributed metaheuristic applications for combinatorial optimization of VRP problems [21]. The following code shows the ACO meta-heuristic algorithm.

```
Input : CO problem of an instance n
Output: S_best, customer to optimal solution for n
while (¬ met termination condition) repeat while
    ScheduleActivites
        AntBasedSolutionConstruction( )
        PheromoneUpdate( )
        DaemonActions( )
    end ScheduleActivities
    S_best ← best solution in the population of solutions
end while
```

Pseudo-code of Ant Colony Optimization [16].

[1] CVRPLIB - All Instances [Electronic resource]. Available at: http://vrp.atd-lab.inf.puc-rio.br/index.php/en (accessed 18.07.2020). (In Eng.)

1) Genetic Algorithm (GA)

Genetic Algorithm is most widely and very likely to be known meta-heuristic algorithms, today receiving exceptional attention all over the world [24]. Below are the general steps of the genetic algorithm.

```
Genetic Algorithm {
  Generate initial population P_o
  Evaluate population P_o
  while(¬ satisfied, stopping GA criteria) Repeat {
     For 1 to (number of events) {
          Select N_t chromosomes for events
          Find chromosome with lowest fitness
          Remove chromosome with lowest fitness
          Crossover (Create new chromosome)
          Evaluate new chromosome
        }
        Mutation
        Evaluate (mutated chromosomes)
     }
}
```

Pseudo-code of Genetic Algorithm [17].

Experimental results

Several experiments are conducted to check the performance of tuned TS algorithm. The conducted experiments are concisely chosen from the public domain as you can see clearly below to ease hereafter referencing, see Fig.1.

The results of the implementation and experimentation can be clearly visualized through Figures. The results are compared between each other and also compared with five other related solution algorithms. In order to determine how the performance of the selected algorithm is working better when compared to other algorithms by using different approaches, but also will know which one gives better results for optimal or near-optimal solutions. CVRPLIB instances or datasets are used.

These datasets or benchmarks could be a good choice when not knowing the size of the problem and/or when having a limited samples in the data set (which holds true for our case in this paper).

The first paper shows the set of benchmarks that are collected from the solution that was proposed by Augerat et al. in 1995 paper [18]. The author has solved CVRP problems and got very good results and have been tested instances from six different classes and sets. The data sets are made up of 27 instances. From the paper, two sets of instances are gathered which are set A and Set B and the results of set A are shown in below table 1 and table 2.

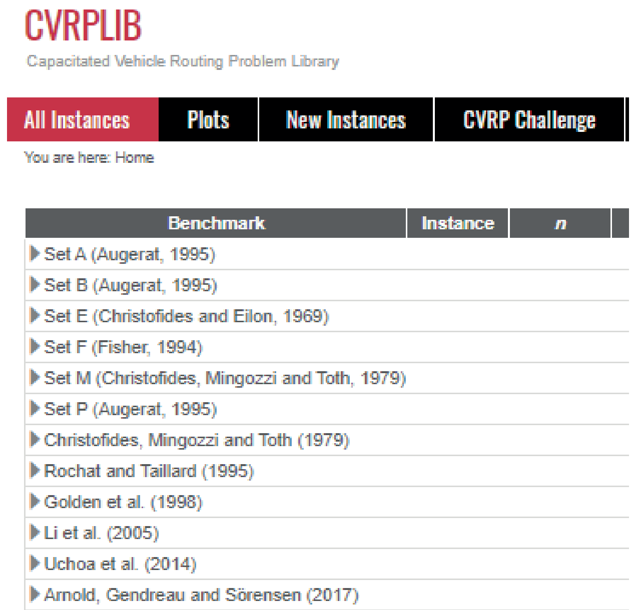


Fig. 1. The datasets used in this study2

Table 1. **Comparing the performance of the algorithms with Augerat et al. Set A.**

Benchmarks	ACO	GA	TS	Augerat et al.
A-n32-k5	810	678	671	784
A-n33-k6	837	751	736	742
A-n34-k5	741	715	683	778
A-n36-k5	830	789	723	799
A-n37-k6	859	795	786	949
A-n38-k5	808	744	687	730
A-n39-k5	837	774	703	822
A-n46-k7	940	862	851	914
A-n55-k8	1176	1072	1062	1073
A-n62-k8	1291	1076	1051	1288
A-n69-k9	1462	1218	1200	1259
A-n80-k10	1526	1284	1259	1763

The first paper extends the solution algorithm with set B, And the comparison results of set B are shown in below table 2.

Table 2. **Comparing the performance of the algorithms with Augerat et al. Set B.**

Benchmarks	ACO	GA	TS	Augerat et al.
B-n35-k5	788	716	665	955
B-n38-k6	893	808	785	805
B-n41-k6	930	810	807	829
B-n50-k8	1063	976	964	1312
B-n57-k9	1207	1087	1076	1598
B-n63-k10	1436	1168	1167	1496
B-n66-k9	1319	1274	1256	1316
B-n68-k9	1446	1151	1121	1272

[2] Ibid.

The Second paper shows the set of benchmarks that are collected from the solutions that were proposed by Christofides et al. in 1969 paper [19]. The author in this paper used exact and heuristics for solving the vehicle-dispatching problem. I have gathered the benchmarks of this paper and compared it with the selected algorithm which showed in the below table 3.

T a b l e 3. **Comparing the performance of the algorithms with Christofides et al. Set E.**

Benchmarks	ACO	GA	TS	Christofides et al.
E-n30-k3	671	535	530	534
E-n33-k4	730	663	637	835

From the above two papers, we can clearly see that the performance of TS algorithm gives the optimal solutions when compared to other algorithms.

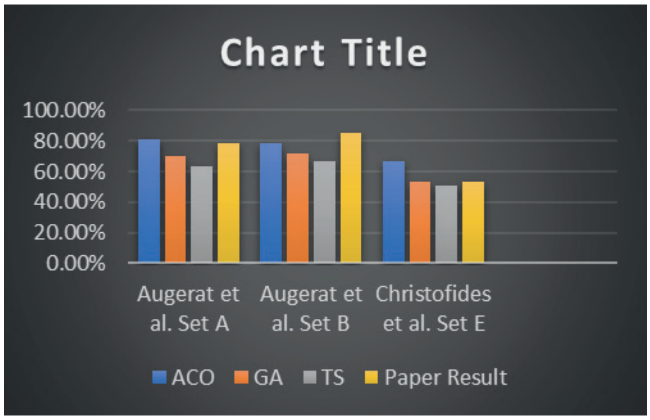
Discussion

The performance analysis on the dataset of tabu search algorithm is 7%, which is better than some of the other existing algorithms, for example the authors of [19], [20] reported their algorithm produced almost optimal solutions.
To perform the statistical analysis " ANOVA – two factor without replication " has been used as it is suitable for the data used for this paper. The word itself represents the analysis of variance. ANOVA in Microsoft Excel is a built-in statistical test that is used to analyze the variances. It is part of the 'data analysis' tool in excel and which can help us to test the different data sets against each other to identify the best solution. Particularly, I have used two factor without replication because the type of comparison is done by using the data which depends on the number of samples and number of factors. From the results obtained by the experiment, we have conducted a statistical analysis of each of these cases individually. We have considered the only column-wise because to see the differences in the comparison of each algorithm in every case. Not considered row-wise because we don't want to see the differences in the comparison of the performance of an algorithm with each problem size.

T a b l e 4. **Statistical analysis of algorithms with two-factor without replication for dataset Christofides et al.**

Anova: Two-Factor Without Replication						
SUMMARY	*Count*	*Sum*	*Average*	*Variance*		
E-n30-k3	4	2270	567.5	4765.667		
E-n33-k4	4	2865	716.25	7802.25		
ACO	2	1401	700.5	1740.5		
GA	2	1198	599	8192		
TS	2	1167	583.5	5724.5		
Christofides et al.	2	1369	684.5	45300.5		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	44253.13	1	44253.13	7.947581	0.066786	10.12796
Columns	20999.38	3	6999.792	1.257118	0.427637	9.276628
Error	16704.38	3	5568.125			
Total	81956.88	7				

The two hypotheses formed are as follows:
Null Hypothesis: The performance of all the algorithms are identical.
Alternative Hypothesis: Tabu search algorithm performs better than ant colony optimization and genetic algorithms. From the above table 4, we can see that the source of variation the F value and F crit values are not equal and F > F crit. The value of alpha (α) has a value, the null hypothesis is rejected with 95% confidence (α = 0.05). If the P-value < alpha value then it means the performance of algorithms has critical differences. We can observe that F > F crit and α > P-value.
As per ANOVA tool used in this paper and after comparing with the datasets, we believe that tabu search performs better than other two ACO and GA meta-heuristic algorithms in all cases.



F i g. 2. Summarized the percentage of datasets that are compared with selected algorithms

Conclusion and future work

In this paper, we have described DVRP. In situations where the delivery times at the customers are important, such as after some disruption or vehicle break down happens unexpectedly, good routing methodologies must be selected to attend those in need in a very quick and proper manner. Vehicle routing problems and their type of variations engage the optimization of routes for numerous vehicles so to meet all the objectives and to reduce the number of vehicles used, travel distance and cost [25].

Statistical analysis was used to analyze the data obtained through the experiments. CVRPLIB benchmarks are used to calculate and to compare the performance of our selected algorithm to check if we were successful in improving TS algorithm. Based on the results from statistical analysis, we were able to conclude that TS algorithm performed better than ACO and GA with 95% of confidence.

In this paper, we have analyzed the performance of the algorithms with other heuristics. Three types of meta-heuristics algorithms were considered, tabu search, ant colony optimization and genetic algorithm. When analyzing the performance of algorithms, the selected TS algorithm for solving disruption in VRP obtains promising results on tested instances, which shows the stability of the algorithm. They were tested on different benchmark instances that were gathered from CVRPLIB. The results of the experiment illustrate the efficiency and effectiveness of the selected algorithm, for which we provide better results than the existing best-known results for datasets.

There are many relative domains that need to be considered in a future study, disruption problem in vehicle routing problems may cause further from traffic jams, accidents, road blocking, environmental conditions, etc... which needs to be investigated in future work. Also, the possibilities of implementing the meta-heuristic algorithms and measures further metrics for solving the related routing problems by considering the objectives like capacity, changes of request to customers, time windows, usage number of vehicles. Finally, the algorithms should be tested with very large-scale benchmark instances. An algorithm with proper parameters and strategies can be developed by using meta-heuristics or with mixed heuristic and exact solutions for solving complex routing problems. There is still a long way to go on the track to connect the vehicle routing problems with sustainable issues. We hope this research may lead to new opportunities and circumstances for sustainable management of logistics industries and will encourage more researchers and make interests in choosing topic DVRP.

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