# HETEROGENEOUS DELIVERY SYSTEMS

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## Abstract

**Keywords**: vehicle routing; optimal routes; combinatorial problem; optimization problem
**Domain**: computer science
**Section**: New (2020) thesis proposals

**Motivation**
The Vehicle Routing Problem (VRP) is a combinatorial optimization problem of great interest and it is focused on designing optimal routes that can be used by a fleet of vehicles in order to serve a set of customers. This problem was firstly proposed in [1] and since then its variations have never stopped appearing. One of them is the Capacitated VRP where a fleet of homogeneous vehicles is available and the only constraint is the capacity of each vehicle [2]. Another interesting variation is the VRP with Time Windows, where customers can be reached only in certain time intervals [3]. A variation of this problem that has gained much interest lately is the heterogeneous delivery system consisting in multiple vehicles, one or many drones and one or many depots. The drones have gained their popularity through the fact that they can fly almost anywhere (except restricted areas) in an almost straight line and with no traffic delay. Their capacity has increases from one year to another, making heavy packages delivery easier and with lower costs compared to the vehicle delivery.
The basic problem which consists in a fleet of vehicles and one drone is known by the name of Travelling Salesman Problem with a Drone (TSP-D), where the drone is attached to the truck, flies to a customer and meets the truck again at another location for charging the battery and load another package.

**Methodology of Research**
For my Ph.D. thesis I intend to focus on the TSP-D problem with multiple trucks and one drone and I intend to predict the solving time and cost for any instance of this problem by using algorithm selection. The TSP-D problem is a NP-hard problem, so the algorithms that give the best result regardless of the input distribution become intractable when dimension increases. Algorithm selection aims to identify the best algorithm for a problem instance, and implicitly the lowest cost. In order to obtain reliable data, several algorithms that solve the TSP-D problem are implemented and the results are compared with public data sets with well-known results. Specific features are identified and regression techniques are applied in order to predict the total cost and solving time for each solving method. The algorithm selection technique consists in choosing an algorithm from a portfolio for a specific instance. It is motivated by the fact that on many problems the algorithms behave differently, having good performance for some instances and poor performance for other instances. Identifying when to use a certain algorithm can improve the overall performance and the only requirement is to have a set of complementary algorithms.

**Results and Comparison with State-of-the-art**
I have implemented five solving methods for this problem using dynamic programming [4] and greedy [5] approaches, local searches [6] and Hill climbing applied for 150 iterations. In order to choose the best algorithm, instance features that can be expressed as numerical representations of an instance (ex.: number of nodes, truck speed etc.) are used. One of the approaches used in algorithm selection is regression. The performance of the algorithms can be predicted and the best algorithm can be selected by the best performance. The simple linear regression and ridge regression have been used to predict the cost and solving time. The measures I used to evaluate the prediction’s accuracy were RMSE (also called standard error) and R2 (also called correlation coefficient) [7]. The standard error varies between 11 and 40 depending on the solving method and the type of regression.

**Conclusions**
This paper presented a portfolio of algorithms that efficiently solve the Travelling Salesman Problem with a Drone and two regression methods that can predict the total cost or solving time of a tour for an instance using different solving methods. A set of well-known features have been used along with new features to improve the correlation coefficient and decrease the standard error. Further tests on larger data sets can be done in order to study and optimize the performance of the algorithms and the algorithm selection on different kind of instances.

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