STUDY OF CAPACITATED VEHICLE ROUTING PROBLEM BASED ON PARTICLE SWARM OPTIMIZATION

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Special dedication and thanks to:

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ABSTRACT

Vehicle Routing Problem (VRP) is one of the common problems that happen in human life. There are many applications of VRP such as garbage disposal, mail delivery, school bus routing, airline schedule and many more. The main objective of VRP is to minimize the distance of the route starting from a depot, serves all of customers demand, and return back to depot. VRP is one of the optimization problems that belong to NP- hard (Non-deterministic Polynomial-time hard) problem and difficult to solve. VRP has also becomes one of the important topic to discuss and analyze. There are many types of VRP; this research is focusing on capacitated VRP (CVRP). CVRP is defined as the problem of determining optimal routes to be used by vehicles starting from one or more depots to serve all customers' demand, observing some constraints. Particle Swarm Optimization (PSO) method will be used to solve the VRP problems because there are lots of advantages of PSO. PSO is a population based stochastic optimization technique, inspired by social behavior of bird flocking or fish schooling. The experiment has been done to test this algorithm. Three variants of PSO have been used which are PSO with inertia weight, PSO without inertia weight, and PSO with constriction factor. The results show that the PSO with inertia weight strategy which include PSO with inertia weight and PSO with constriction factor have the best total distance. It can be concluded that PSO with inertia weight strategies have better performance because they take less iteration to arrive at the optimum value. The second comparison also showed that small range of inertia weight has the best total distance.

ABSTRAK

Masalah Laluan Kenderaan (VRP) adalah salah satu masalah biasa yang berlaku dalam kehidupan manusia. Terdapat banyak penggunaan VRP seperti pelupusan sampah, penghantaran mel, laluan bas sekolah, jadual penerbangan dan banyak lagi. Objektif utama VRP adalah untuk meminimumkan jarak laluan yang bermula daripada depot, memenuhi semua permintaan pelanggan, dan kembali semula ke depot. VRP merupakan salah satu masalah pengoptimuman yang mana kepunyaan masalah sukar-NP dan tidak mudah untuk diselesaikan. VRP juga telah menjadi salah satu topik yang penting untuk dibingcangkan dan dianalisis. Terdapat banyak jenis VRP; kajian ini memberi tumpuan kepada VRP berkapasiti (CVRP). CVRP ditakrifkan sebagai masalah penentuan laluan optimum yang akan digunakan oleh kenderaan bermula daripada satu atau lebih depot untuk memenuhi semua permintaan pelanggan, berdasarkan beberapa kekangan. Kaedah Teknik Kerumunan Zarah (PSO) akan digunakan untuk menyelesaikan masalah-masalah VRP kerana terdapat banyak kelebihan PSO. PSO adalah teknik pengoptimuman stokastik, yang diilhamkan oleh tingkah laku sosial kawanan burung atau kumpulan ikan. Eksperimen telah dilakukan untuk menguji algoritma ini. Tiga variasi PSO telah digunakan iaitu PSO dengan berat inersia, PSO tanpa berat inersia dan PSO dengan faktor penyempitan. Keputusan menunjukkan bahawa PSO dengan strategi berat inersia yang mana termasuk PSO dengan berat inersia dan PSO dengan faktor penyempitan menghasilkan jarak keseluruhan terbaik. Ia boleh disimpulkan bahawa PSO dengan strategi berat inersia berprestasi lebih baik kerana ia memerlukan lelaran yang kurang untuk sampai ke nilai yang optimum. Perbandingan kedua menunjukkan julat berat inersia yang kecil memberikan jarak keseluruhan yang terbaik.

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LIST OF SYMBOLS

n	-	Number of customers
m	-	Number of vehicles
c_{ij}	-	A non-negative cost from i to j
C	-	Capacity of vehicles
d_i	-	Demand of customer i
I	-	Number of particles
c_1 and c_2	-	Acceleration constants
ω	-	Inertia weight
x_{sn}	-	The current location of the particle
v_{sn}	-	The current velocity of the particle
p_s	-	The particle's personal best position (*pbest*)
g_n	-	The global best position (*gbest*)
r_1 and r_2	-	Random numbers
τ +1	-	Current iteration
τ	-	Previous iteration
tt	-	Maximum number of iteration
$\omega_{\max}$	-	Maximum of weighing factor
$\omega_{\min}$	-	Minimum of weighing factor
X	-	Constriction factor
d	-	Dimension of particle
cost $_{a2,a3}$	-	Distance between a_2 to a_3
D_j	-	The cost/distance of each vehicle j

LIST OF ABBREVIATIONS

CVRP	-	Capacitated Vehicle Routing Problem
VRP	-	Vehicle Routing Problem
PSO	-	Particle Swarm Optimization
SA	-	Simulated Annealing
FFT	-	Fast Fourier Transform
FEM	-	Finite Element Method
LS	-	Least Square
CAD	-	Computer-Aided
TSP	-	Travelling Salesperson Problem
BPP	-	Bin Packing Problem
COP	-	Combinatorial Optimization Problem
VRPTW	-	VRP with Time Windows
VRPB	-	VRP with Backhauls
MDVRP	-	Multi Depot VRP
OVRP	-	Open VRP
SVRP	-	Stochastic VRP
DCVRP	-	Distance-Constrained VRP
PVRP	-	Periodic VRP
SDVRP	-	Split Delivery VRP
VRPPD	-	VRP with Pick-Ups and Deliveries
HybPSO	-	Hybrid Particle Swarm Optimization
MPNS-GRASP	-	Multiple Phase Neighborhood Search - Greedy Randomized Adaptive Search Procedure
PR	-	Path Relinking
ENS	-	Expanding Neighborhood Search
SMCM	-	Sub Route Mapped Crossover Method
SEMM	-	Sub Route Exchange Mutation Method

PSODA	-	PSO Discrete Adapted
ALBH	-	Adapted Location Based Heuristic
OCGA	-	Optimised Crossover Genetic Algorithm
LRP	-	Location Routing Problem
SALRP	-	Simulated Annealing for the LRP
TS	-	Tabu Search
ACO	-	Ant Colony Optimization
FCPSO	-	Fast Convergence Particle Swarm Optimization
CPSO	-	Constriction factor approach of PSO
MOPSO	-	Multiobjective PSO

CHAPTER 1

INTRODUCTION

1.0 Introduction

In mathematics, optimization is the selection of the best element from some set of available alternatives. Optimization refers to the study of problems in which one seeks to minimize or maximize a real function by systematically choosing the values of real or integer variable within an allowed set. Optimization algorithms are search methods, where the goal is to find a solution to an optimization problem, such that a given quantity is optimized, possibly subject to a set of constraints (Engelbrecht, 2005).

Optimization is important in scientific research, management and industries because numerous real world problems can be essentially modeled as optimization task. An optimization algorithm is a procedure which is executed iteratively by comparing various solutions till an optimum or satisfactory solution is found. Optimization solution can be divided into two main classes which are local search algorithms and global search algorithms. Local search algorithms do not totally focus on search but it attempts to move from a current formation to a neighboring refining formation. An example of local search is hill climbing, which is an iterative algorithm which can start with a random solution and then tries to find a better solution by incrementally altering a solution of single element. In general, these algorithms are faster than other global search techniques and they can provide quite good solutions if the initialization step is adequate to the problem. Global search algorithms do not require an initial solution, and their goal

is to find the global optima of the cost function of a long time searching. But then again in reality, they are run and stop when stopping criterion is come across. Examples of this search include particle swarm optimization (PSO), simulated annealing (SA), and genetic algorithm (GA). Many global search techniques such as PSO can have their parameters adjusted to have them focus more on local search.

There are two distinct types of optimization algorithm which are deterministic algorithms and stochastic algorithms (Annicchiarico *et al.*, 2005). The deterministic methods however generally become quite involved and computationally time consuming as the problem becoming more complex (Khodier and Al-Aqeel, 2009). Deterministic method use specific rules for moving one solution to other and do not make use of random element. Besides that, stochastic methods use random elements to transform one candidate solution into a new solution. The stochastic algorithms are in nature with probabilistic translation rules. These are gaining popularity due to certain properties which deterministic algorithms do not have. Heuristic is an example of the algorithms which usually finds pretty good solutions, but there is no proof the solution could not get arbitrarily bad; it usually runs reasonably quickly, but there is no argument that this will always be the case (Goodman and Hedetniemi,1977).

Heuristic optimization methods or evolutionary computation including Particle Swarm Optimization(PSO), Ant Colony, Genetic Algorithm and many more. In general, all the applications areas that the other evolutionary application techniques are good at are the good application areas for PSO. The application areas for PSO are constrained optimization problems, min-max problems, multiobjective optimization problems and dynamic tracking (Shi, 2004). The deterministic methods include the analytical methods, for example Fast Fourier Transform (FFT), Finite Element Method (FEM) and Semi-Analytical Methods (e.g. least-square (LS) method, computer-aided (CAD) approach).

PSO is based on the interaction and the social communication of the group of particles and possesses a memory as every particle remembers the best position it has reached (Akjiratikal *et al*., 2007). PSO only involves a few parameters in the algorithm

so that it is easier to find the best combination of parameters value. Besides that, the simple concept of PSO makes it is easy to implement for solving many applications.

PSO has been applied in many areas, one of them is in vehicle routing problem (VRP) because the advantages of PSO such as rapid convergence towards an optimum, ease in encoding and decoding, fast, and easy to compute.

VRP commonly happens all around us in the sense that many consumers products such as food, drinks, gasoline and pharmaceuticals are delivered and distributed to retail outlets by a fleet of vehicles whose operations fits the vehicle routing model. According to that, VRP has been one of the great success stories of operation research and it has been studied widely (Braysy, 2001).

This project will focus on VRP with capacitated (CVRP) by applying Particle Swarm Optimization (PSO).

1.1 Background of the Problem.

Particle Swarm Optimization (PSO) is one of the famous heuristic optimization methods. As we know, PSO can solve many types of problem such as global optimization, artificial neural network training, fuzzy system control, engineering design optimization and logistics & supply chain management.

This research is to solve vehicle routing problem (VRP) using PSO. As the VRP has attracted most researchers over the last three decades, many literatures abstractions of routing problems can be found. VRP is a combinatorial optimization and integer programming seeking to service a number of customers with fleet of vehicles. VRP was first introduced by Dantzig and Ramser in 1959 to describe a real-world delivery problem of gasoline for service stations. The vehicle routing problem (VRP) aims to find

a set of routes at a minimal cost (finding the shortest path, minimizing the number of vehicles, etc) beginning and ending the route at the depot, so that the known demand of all nodes are fulfilled. Each node is visited only once, by only one vehicle, and each vehicle has a limited capacity. The most common types of constraints that are commonly used are capacity constraints, duration constraints and time window constraints.

The Vehicle Routing Problem (VRP) can be described as the problem of designing optimal delivery or collection routes from one or several depots to a number of geographically scattered cities or customers, subject to side constraints. VRP plays a central role in the fields of physical distribution and logistics (Laporte, 1992).

The Capacitated Vehicle Routing Problem (CVRP) was first formulated by Christofides *et al.* (1979), a fixed capacity of vehicle serves a set of customers from a common point called warehouse. A customer is visited by the vehicle only once, the vehicle capacity cannot exceed the maximum capacity, and the model deserves to find minimum distance of vehicle route or minimum time to serve the customers (Venkatesan *et al.,* 2011). CVRP is like VRP with the additional constraint that every vehicle must have uniform capacity of single commodity.

There are numbers of solution method for VRP which are exact, heuristics and metaheuristics. Heuristics and metaheuristics techniques are widely used because these methods are powerful problem solving tools. Thaillard *et al.* (2001), stated a few factors that contribute to the success of heuristics methods like ease of implementation, ability to consider specific constraints that arise in practical applications and the high quality of solution they produce.

There are several heuristic techniques that are widely used, this research will consider PSO to solve VRP because this evolutionary computation is simple as it requires short computational time and faster to converge than the Genetic Algorithm (GA) and Simulated Annealing (SA).

1.2 Problem Statement

Disposing of garbage is a basis problem in human life since all the human's activities produce it from houses, public facilities, factories, etc. Poorly managed waste disposal site, have bad effects on the environment and humans. In Malaysia, garbage collection has become a crucial problem since it is not managed effectively and efficiently. The garbage trucks must have to collect large pile of garbage in large areas. In order to overcome the problem, the garbage trucks must have to search for the shortest distance. In addition, it is time consuming and it can minimize energy consumption. Therefore, the trucks have to find the shortest distance to save time.

A number of different exact and heuristic methods have been studied to solve the VRP that is known to be NP-hard (Non-deterministic Polynomial-time hard). Although the exact methods give the optimal solution, their computation time considerably increases with the increasing size of the problem. Metaheuristic is another approach for solving a complex problem that may be too difficult or time-consuming for other techniques.

So, in this research PSO algorithm method is applied to minimize the route of garbage trucks. Thus, optimize both time and energy consumption. PSO has been chosen because PSO is simpler compared with exact algorithm and another metaheuristic algorithm because it only requires less computational bookkeeping and only a small number of lines codes. It is also very easy to understand and implement (Boeringer and Werner, 2004).

By doing this research, PSO algorithm can be used as one of the methods to solve the vehicle routing problem (VRP). At the same time, we can gauge the ability of PSO in solving the VRP. The research will concentrate on the usage of PSO methods in order to find the minimum distance for the VRP. In addition, the best possible solutions which satisfy the objectives and constraints in order to get optimal solution will find through this research.

1.3 Objectives of the Study

The objectives of this study are:

1. To solve the Capacitated Vehicle Routing Problem (CVRP).

2. To apply Particle Swarm Optimization (PSO) on CVRP.

3. To code PSO algorithm using Matlab.

4. To compare the PSO performances by using different parametric approaches and by using different inertia weight.

1.4 Significance of the Study

Generally, this research can give clear explanations about optimization method especially on solving PSO algorithms and to evaluate the performance of PSO algorithms for solving capacitated VRP. As we know, many real problems can be solved by PSO, through this research, we will find out the best possible solutions which satisfy the objectives and constraints to get the optimal solution. By doing this research, it will increase the cache of knowledge. Not only that, by doing this research, it will also increase the knowledge of the readers and the readers will get the addition idea about PSO. Besides that, this research will make reliable tool such as PSO available to solve vehicle routing problems.

1.5 Scope of the Study

The research will focus on capacitated vehicle routing problem. This study will concentrate on PSO algorithm as a tool to solve vehicle routing problem and use Matlab to code the algorithm. Computational experimentations were carried out on the following 50 number of customers serviced by 5 vehicles. We will assume only homogeneous vehicle type. The location point of customer is based on the Cartesian coordinate. The aim of the research is to minimize the distance as the objective of the problem. The performance of the algorithm is compared based on the solution quality and time step where the best solutions is obtained.

1.6 Organization of the Report

This study explores the performance of PSO algorithm in solving the vehicle routing problem (VRP). The data of the location of the customers and their demand will be used in this research. Chapter 1 presents the research framework. It starts with the introduction of heuristic methods, one of them is PSO. PSO is used to solve the VRP.

In Chapter 2, the literature review is presented. It consists of introduction on the VRP and also types of VRP. There are many types of VRP; we are focusing on capacitated VRP (CVRP). The mathematical formulation of CVRP discussed here. Lastly, reviews on VRP solution methods also will be presented here.

Chapter 3 presents the method to solve the VRP which is the PSO algorithm. Detailed description of the PSO and its various applications are given. Besides that, the flow of PSO algorithm is also presented.

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