



**Crow Search Algorithm for Solving Travelling
Salesman Problem with Time Segregation for
Perishable Products**

by

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LIST OF ABBREVIATIONS

AP	Awareness Probability
ACO	Ant Colony Optimization
CSA	Crow Search Algorithm
CVRP	Capacitated Vehicle Routing Problem
DBA	Discrete Bat Algorithm
DPSO	Discrete Particle Swarm Optimization
DSOS	Discrete Symbiotic Organisms Search Algorithm
FL	Flight Length
FP	Flock Population
GWOA	Greedy Whale Optimization Algorithm
RNG	Random Number Generated
PD	Percentage Difference between new solution to the optimal solution
SA	Simulated Annealing
SSABCA	Swap Sequence-based Artificial Bee Colony algorithm
TSP	Travelling Salesman Problem
VRP	Vehicle Routing Problem

LIST OF SYMBOLS

$c_{i,j}$	The travel cost of salesman which include distance travel from node i to node j .
$cp^{i,j}$	Crow's position at i and j position.
$d_{i,j}$	Demand at node i and j .
$m^{i,j}$	Memory allocation of crow at i and j position.
p_m	Time period that needed by the salesman to finish the routing in minutes.
q	The capacity of individual to carry load or demand.
T_{total}	Total time taken for salesman to finish the routing operation.
t_{ij}	Travel time from node i to j .
t_{bp}	Time taken for the product to perish.

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Metaheuristik Pencarian Gagal untuk Penyelesaian Masalah Jurujual Kembara dengan Pemisahan Masa bagi Produk Mudah Rosak

ABSTRAK

Masalah Jurujual Kembara (MJK) melibatkan jurujual untuk melakukan perjalanan ke setiap bandar hanya sekali dan kembali ke tempat asal. MJK boleh digunakan bagi menyelesaikan pelbagai masalah yang melibatkan laluan terutamanya penghantaran produk mudah rosak. Dalam penyelidikan ini, satu algoritma yang dikenali sebagai Algoritma Pencarian Gagal (APG) dibangunkan bagi menyelesaikan masalah MJK bagi produk mudah rosak. Namun begitu, kebanyakan model matematik tidak mengambil kira aspek masa untuk menyelesaikan masalah melibatkan penghantaran produk mudah rosak. Penggunaan APG bagi menyelesaikan MJK menjadi satu cabaran kerana kurang penyelidikan yang menggunakan APG dari segi penetapan parameter. Penyelidikan ini menggabungkan operator tambahan untuk menyelesaikan MJK bagi produk mudah rosak dari segi pengiraan kos perjalanan dan kekangan masa yang ditambah terhadap model. Selain itu, prestasi APG yang baru disahkan menggunakan set data piawai dan simulasi kajian kes. Metodologi penyelidikan ini dimulakan dengan menambah kekangan pemisahan masa terhadap model matematik MJK. Kemudian, pelaksanaan APG dengan kombinasi Pergerakan Kejiranan diperkenalkan untuk mencari penyelesaian. Prestasi dan keupayaan APG dikodkan menggunakan MATLAB dan diuji dengan 20 set data daripada TSPLIB. Seterusnya, APG yang baru dibandingkan dengan keputusan set data piawai yang terkini dan algoritma klasik. Keputusannya menunjukkan hasil yang menyakinkan dengan 15 dataset TSPLIB kurang daripada 10% menghampiri penyelesaian optimal. APG juga menunjukkan prestasi yang bagus berbanding algoritma klasik di mana semua keputusan mendekati penyelesaian optimal. Sebagai tambahan, apabila disimulasikan untuk kajian kes, APG berkemampuan untuk menjana penyelesaian. Kesan kekangan masa menunjukkan hasil yang positif dalam kes-kes simulasi iaitu produk sampai kepada pelanggan dalam masa ditetapkan. Oleh yang demikian, APG mempunyai potensi untuk diterokai untuk penyelidikan masa hadapan dalam pelbagai bidang seperti Masalah Laluan Kenderaan, Masalah Laluan Teraruh dan lain-lain.

Crow Search Algorithm for Solving Travelling Salesman Problem for Perishable Products

ABSTRACT

The Travelling Salesman Problem (TSP) involves a salesman travelling to each city and returning to the origin. TSP is used for various types of routing problems; one of them is delivery of perishable products. In this research, a promising metaheuristics algorithm known as the Crow Search Algorithm (CSA) is applied for solving TSP for perishable products. However, most mathematical models do not consider the time constraint aspect of solving problems related to the transshipment of perishable products. Implementation of CSA for the aim of solving TSP appeared to be a difficult task due to a lack in tuning the CSA's parameters. In addition, CSA is not fully applied in the area of routing problems' research. This research developed a new CSA with combination of additional operators to solve TSP for perishable products in terms of calculating the travel cost and adding time constraint to the model. Besides that, the new CSA performance is verified using benchmark datasets and a simulated case study. The methodology of this research starts by adding a time segregation constraint to the mathematical model of TSP. Then, the implementation of CSA with combination of Neighborhood Moves is introduced to find the solution. The performance and capability of the CSA is coded using MATLAB and tested with 20 instances from TSPLIB. Next, the new CSA is compared with other established results using benchmark datasets which recent and classical algorithms. The findings show promising result by producing 15 instances of TSPLIB less than 10% from the optimal solution. CSA also performed well than classical algorithm where all the results approached the optimal solution. Additionally, when simulated for the case study, CSA is competence to generate the solutions. The impact of time constraint shown positive result in simulated cases that the product reached customer in timely manner. Therefore, CSA has the potential to be explored for future research in various areas such as in vehicle routing problem, capacitated arc routing problem and other variants.

CHAPTER 1 : INTRODUCTION

1.1 Overview

Travelling Salesman Problem (TSP) is a class of network graph theory that draws many attentions in research and applications. The problem involves a set of nodes and a set of links that are connecting between the nodes. The complexity to find a path with minimum cost increased tremendously as the number of cities increased. Researchers have proposed various methods involving exact, heuristic and metaheuristic methods to find the solution's path that gives the optimal solution. Modern methods such as metaheuristics have recently shown promising potential to find the solution in a shorter time and avoid from stuck at the local minima. The algorithm needs modifying according to the constraints in the problem.

It is now becoming a mature field since it becomes a foundation for mobile navigation application such as Google Maps and Waze. Due to that, it is vital to have an adequate operation management of the routing problem as it helps to reduce the cost and a step ahead of time in term of planning before executing some operations based on intended goal. Therefore, it is paramount important to choose the best route in term of cost and distance because it will affect the delivery process. As such, the company needs to choose the best route in order to ensure the goods such as perishable products will reach the customers between the range of estimated time.

1.2 Research Background

This section focuses on research relating to the study of the travelling salesman problem. Serious discussions and analysis of “Travelling Salesman” emerged during the 1960s with Karg and Thompson (1964). The problem involves the total distance that needs to be covered by a salesman in visiting the entire city once before returning home. A problem is called a Euclidean problem as it involves calculating points from the Euclidean plane. The problem falls into the symmetric case, as the distance travelled from point A to point B is equal to from point B to point A. In an asymmetric case, the path from point A to point B differs for both directions. Papadimitriou (1977) considers TSP as NP-Complete by taking into account two cases of *Euclidean* TSP, which are the coordinate system and the general case. Both of the cases consider solving TSP on a plane.

As graphs are considered as fundamental combinatorial structures, most of the problems in combinatorial optimization are described naturally using graph theory (Korte & Vygen, 2000). For example, in TSP, let $G = (V, E)$ be a graph (directed or undirected) where vertices or a set city for a salesman to travel and the set edges or path. The weight of each edge is referred as ‘distance’ and it can be replaced with another measure of effects such as time and cost in defining the weight that will lead to adding many variations of TSP (Hoos & Stützle, 2007). In planar problems, the distance between each vertex on $P_i = (X_i, Y_i)$ is calculated using the *Euclidean distance*, which refers to the cost matrix between two points (Laporte, 2010).

The main objective of TSP is to find the minimum distance with minimum total travel cost of salesman for a network (Wong, Low, & Chong, 2010). Meanwhile, important constraints, such as each city or node, can be visited only once before returning to the starting point. Other variants of the TSP problem serve certain purposes and are discussed in the next chapter.

Besides, the potential applications of TSP have been widely described in the literature. For example, Cho (2010) stated that TSP is also used to solve problems such as drilling printed circuit boards, overhauling gas turbine engines, X-Ray crystallography, computer wiring, the order-picking problem in warehouses, vehicle routing, and mask plotting in PCB production. Another application of TSP is in delivering dairy products as for their case study to develop a systematic route plan that is more rational and efficient for the distribution of products offered (Palhares & AraUjo, 2018).

Christofides, Mingozzi, & Toth (1981) consider TSP, time-constrained TSP and VRP in their research. They define routing problems as a problem that requires solutions for finding a path represented by a connected graph and a traversable graph. In the graph, the connection between arcs or edges is called a vertex. Meanwhile, the first node is called depot (origin). In the classical TSP model, each set has one depot. However, it can vary in other cases that have multiple depots. Paths are created by combining vertices that are related to each other from the depot.

Next, Eksioglu, Vural, & Reisman (2009) define VRP as a problem involving a graph problem. Each node in the graph represents the non-negative demand contained in the customer, except for node 0, which is the depot. The VRP is said to be a symmetric

VRP if the distance travelled from A to B is equal to the distance travelled from B to A. The VRP includes selecting a set of k paths on the network so that each of the vehicle routes produces the lowest travel cost, such that each path needs to visit the depot, each node is visited exactly once, and the sum of demand at the node does not exceed vehicle capacity. The TSP produces a single travel path through all the nodes, while VRP produces numerous travel paths with a limitation on vehicle capacity as in Figure 1.1.

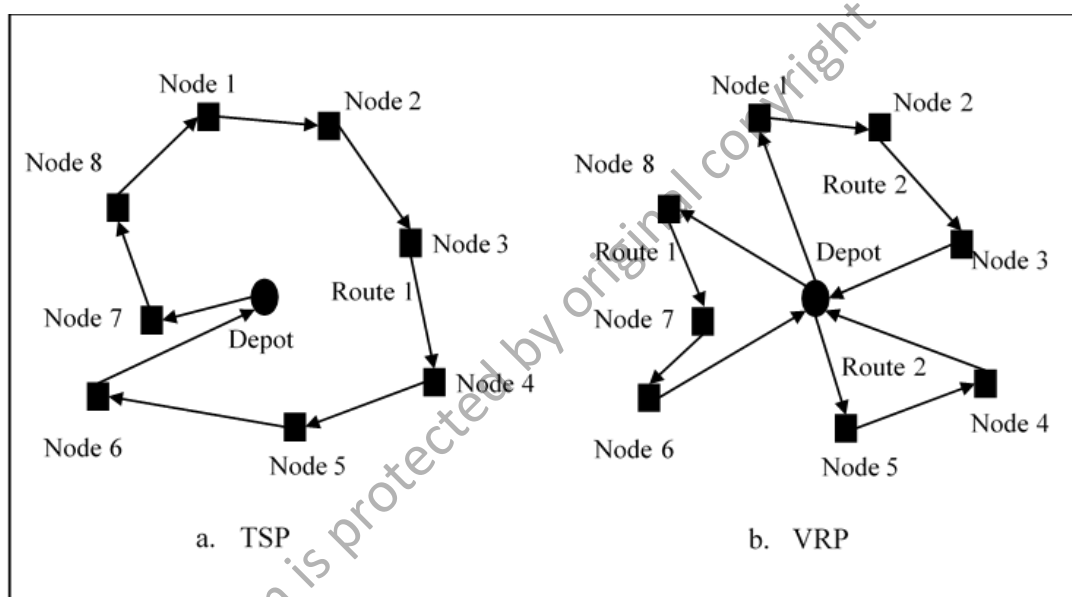


Figure 1.1 Route selection for TSP and VRP

The term *NP-hard* problems originated around 1974 when it is considered that the problem could be solved in polynomial time (Knuth, 1974). In the *NP-hard* problem, the number of combinations increase exponentially with the size of the problem of interest. It is incredibly computationally complex and impractical to look for every possible combination (Ouaarab, Ahiod, & Yang, 2014). Table 1.1 describes a definition that considers the problem as *NP-hard*.

Table 1.1 NP-hard problem

Author	Research Titles	Type of Problem	Explanation
Juneja et al. (2019)	Travelling Salesman Problem Optimization Using Genetic Algorithm	<i>NP</i> -Hard Problem	No existing algorithm capable of finding its solution in polynomial time.
Strange et al. (2019)	Discrete Flower Pollination Algorithm for Solving the Symmetric Travelling Salesman Problem	<i>NP</i> -Hard Problem	Could not be solved in polynomial time.
Gupta et al. (2018)	Greedy WOA for Travelling Salesman Problem	<i>NP</i> -Hard Problem	Having a non-polynomial complexity, which means that the computational time increases exponentially by increasing the number of cities.
Chiang & Hsu, (2014)	A knowledge-based evolutionary algorithm for the multi-objective vehicle routing problem with time windows	<i>NP</i> -Hard Problem	Consider Vehicle Routing Problem (VRP) are combination of two NP - hard problem that includes TSP and bin packing problem.

Most of the problems with combinatorial optimization are *NP*-hard, and it is difficult to find the optimal or even suboptimal solution. Factors that affect the search of the optimal solution are the size of the problem, the dynamic working environment, the lack of accuracy in data collection, the difficulty in formulating certain constraints and sometimes the massive number of real problems that are not effectively optimized by mathematical approaches (Saji & Riffi, 2016).

One of the methods for solving *NP*-hard problems is by using heuristics, as heuristics are non-deterministic, adaptive, and competitive to find the solution (Colomi et al., 1996). Later, metaheuristics, also known as modern heuristics, are introduced to solve various *NP*-hard problems. Metaheuristics is defined as a repetitive process over

iterations that guides a heuristic by intelligently combining different concepts to explore the solution inside the search space to find the near-optimal solution (Osman & Laporte, 1996).

Nowadays, people can purchase any product that they would like to buy by browsing through their smartphones without visiting a physical store. It is considered very time-efficient. Goods purchased by buyers need to be delivered within a clear-cut period of time to meet the needs of the consumer, even if the products may take longer time to arrive as compared to buying them from physical stores. The customer's products must be delivered in good condition as well as on time to meet the customer's requirements. In this case, as with proper planning, the seller and the platform's owner need to choose the courier service that can provide the best service to their customers. Therefore, it is vital to choose the best route in terms of cost and distance that the company will choose in shortening the travel time.

Important aspects need to be considered in managing the transshipment of perishable products, especially as the goods deteriorate over time (Wu, Nie, Xu, & Yan, 2018). Liang, Liu, Lim, & Zhang (2020) discussed time, temperature, and humidity on the VRP model but not on the TSP with time segregation. Previous research on perishable products typically only investigated the time dependent when sending the goods. What has been missing so far is a time segregation constraint in the TSP model for the transshipment of perishable products.

Besides, there are perishable products in the market such as food; for instance, bread, dairy, cakes, vegetables and fish that have expiration dates. Moreover, the

freshness of the products will decrease within some periods. Some of the products such as bread and milk are produced in factories and later will be transhipped to consumers using trucks, van, and motorcycles. Thus, proper planning before sending the perishable products will ensure that the goods will reach customers on time.

Many different algorithms, including exact methods, heuristic algorithms, and metaheuristics, have been proposed by researchers to solve the routing problems. However, researchers have recently expressed an increased interest in metaheuristic algorithms for solving the problem because they can escape from local optima and thus are more efficient. Furthermore, CSA has shown promising results in solving a wide range of other optimization problems (Meraihi, Benmessaoud, Amar, & Cherif, 2020). Thus, CSA by Askarzadeh (2016a) is proposed in this study to solve the problem.

1.3 Problem Statement

Despite the wealth of literature available in the field of routing problems, there is a lack of perishable products for solving TSP. As the current mathematical models for the routing problem are incomplete (Iswari, 2016), some aspects hinder the delivery of the goods as planned. A feasible route needs to be chosen as it will affect the total travel cost in TSP. Based on recent research on the routing of perishable products (Song & Ko, 2016; Liang et al., 2020; Hajad et al., 2020), is found that the existing mathematical model for perishable product-based TSP are inadequate and incomplete. This is because the problem does not consider time segregation for delivery of the products. If the path is not planned correctly, the products will be rotten and damaged quickly due to the time taken.

Crow Search Algorithm (CSA) was introduced by Askarzadeh (2016a), which is based on the simple movement of the crow in order to find and hide food. Recently, CSA has solved various areas and fields of optimization problems, including computer science and engineering problems. However, CSA has limitations according to the No Free Lunch theorem (Meraihi et al., 2020), which states that an optimization algorithm cannot perform successfully on all optimization problems. As from previous research, there is no study being conducted for the tuning of CSA parameters that involves flock population and awareness probability to solve the problem (Hussien et al., 2020). The solution generated by CSA may get stuck in the local optima if there is poor tuning of parameters.

From the explanation, TSP is chosen to represent the model of delivery of perishable product problems. Then, the proposed models are designed to seek the solution of the case in perishable items. Unfortunately, very few studies exist on the CSA solving optimization algorithm, and their findings show that CSA has big potential but still lacks of research in the case of the routing problem (Meraihi et al., 2020). In conclusion, its mathematical model needs to be improved to solve the real cases and CSA is selected as it shows the possibility for finding the solution.

1.4 Research Objectives

This study developed crow search algorithm for solving a class of NP-hard problem namely as TSP for perishable products:

- i. To model a TSP for perishable products with time segregation constraint.
- ii. To develop a new CSA with additional operators for solving the proposed TSP.
- iii. To verify the performance of the new CSA tested on TSP benchmark datasets and simulated case study with other approaches.