ADVANCING INDUSTRIAL ENGINEERING IN NIGERIA THROUGH TEACHING, RESEARCH AND INNOVATION

A BOOK OF READING

Edited By

Ayodeji E. Oluleye
Victor O. Oladokun
Olusegun G. Akanbi

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(A Festchrift in honour of Professor O. E Charles-Owaba)

Professor O. E. Charles-Owaba

Advancing Industrial Engineering in Nigeria through Teaching, Research and Innovation.

ISBN : 978-078-515-9

Published by

Department of Industrial and Production Engineering
University of Ibadan.

Printed by:
Leading Edge Printers & Publisher
Ibadan

FOREWORD

It gives me great pleasure writing the foreword to this book. The book was written in recognition of the immense contributions of one of Nigeria's foremost industrial engineers, respected teacher, mentor, and lover of youth – Professor Oliver Charles-Owaba.

His commitment to the teaching and learning process, passionate pursuit of research and demonstration of excellence has prompted his colleagues and mentees to write this book titled – Advancing Industrial Engineering in Nigeria through Teaching, Research and Innovation (A Festschrift in honour of Professor O. E Charles-Owaba) as a mark of honour, respect and recognition for his personality and achievements.

Professor Charles-Owaba has written scores of articles and books while also consulting for a medley of organisations. He has served as external examiner to various programmes in the tertiary educational system. The topics presented in the book cover the areas of Production/Manufacturing Engineering, Ergonomics/Human Factors Engineering, Systems Engineering, Engineering Management, Operations Research and Policy. They present the review of the literature, extension of theories and real-life applications. These should find good use in the drive for national development.

Based on the above, and the collection of expertise in the various fields, the book is a fitting contribution to the corpus of knowledge in industrial engineering. It is indeed a befitting gift in honour of erudite Professor Charles-Owaba.

I strongly recommend this book to everyone who is interested in how work systems can be made more productive and profitable. It represents a resourceful compilation to honour a man who has spent the last forty years building up several generations of industrial engineers who are part of the process to put Nigeria in the rightful seat in the comity of nations. Congratulations to Professor Charles-Owaba, his colleagues and mentees for this festschrift.

Professor Godwin Ovuworie
Department of Production Engineering
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CHAPTER 12

The Traveling Salesman Problem: Algorithms, Sub-tours and Applications in Combinatorial Optimization

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Abstract

The importance of the traveling salesman problem (TSP) in combinatorial optimization and its application and adaptability to numerous real-life problems has led to the development of a wide range of algorithms. A major issue in the development of TSP algorithm involves how to handle the large number of subtour eliminating constraints which contribute to the exponential growth of computational time associated with TSP algorithms. In this chapter, basic concepts, development and many numerous research efforts of Professor O.E. Charles-Owaba on TSP were discussed; some of his works on the concept of the TSP set sequencing algorithm were highlighted.
Keywords: Traveling Salesman Problem, Subtour, Machine setup problem, Set Sequencing Algorithm, Combinatorial optimization, Sequence dependent setup, Charles-Owaba

1.0 Introduction

The need to determine the minimum total length of the route while visiting every point once in a given set gives rise to the traveling salesman problem (TSP). The TSP is an important and popular problem in combinatorial optimization that has attracted a lot of interests in operations research, mathematics, computer science, engineering and other research areas (Ezugwu & Adewumi, 2017; Kieu, 2019; Oladokun & Charles-Owaba, 2011). TSP can be stated as:

“Given N cities and the distance or cost between each pair of cities, a salesman starting in one city wishes to visit each of N-1 other cities once and only once and return to the starting point. In what order should he visit the cities to minimize the total distance travelled?" Mathematically, the problem can be stated as: Given a 'cost (distance) matrix' C = $\left(C_{ij}\right)$, where C_{ij} is the cost (distance) of traveling from city *i* to city *j* (i, j = 1, 2, . . ., *n*), find a permutation (i_1, i_2, i_1,….., i_n) of the integers from 1 through *n* that minimizes the quantity

$$C_{i_1 i_2} + C_{i_2 i_3} + . . . + C_{i_n i_1}.$$

Historically, the TSP has assumed many interesting names such as the laundry van problem, and the messenger problem. From a scheduling perspective, TSP is equivalent to the sequence-dependent single machine setup problem or simply referred to as machine setup problem (MSP). The TSP which was first formulated in the 1930s, came to prominence in the United States of America, in the 1950s, when solving a 33-city problem instance was used as a promotional contest by Soap Company for a price of $10,000.00.

2.0 Traveling Salesman Problem and Applications

The TSP as a combinatorial optimization problem has an associated decision problem that seeks to determine the cheapest cost route (i.e. route/distance) available to a salesman to visit a specified number of cities and return to the beginning city. This unique problem description of TSP has attracted numerous attention and research efforts from scientists across the globe. Apart from its theoretical importance, countless numbers of practical and interesting problems across several industries have been formulated as a TSP model within the context of optimization. The TSP is popular because of its practical relevance and application in many areas such as routing of vehicle, manufacturing and assembly of parts, manufacturing of electronic board manufacturing, scheduling of jobs in the production system, andgroup technology (GT) approach to manufacturing. The varied applications of the model remain the key motivating factor in the continued interests of many researchers in TSP. For example, in printed circuit boards (PCBs), the objective is to determine an optimal sequence for drilling circuit board holes considered as cities to be visited by drilling machine head (salesman) to reduce machine travel time or its associated cost (Grostchel, *et al*., 1991). In inventory order picking problem, a server or attendant (salesman) need to travel within the warehouse to collect a series of orders (cities) to minimise lead-time. Given the arrival of an order for a subset of items stored in a warehouse, an attendant/automated vehicle/server has to move strategically to collect these items before shipping it to customers. The objective here is to minimize the lead time of services to customers. Other applications include the sequencing of tasks on a weaving machine with set-up costs, the order spread elimination problem in cutting-stock model encountered in glass manufacturing, the problem of crystal orientation time reduction during the study of the atomic structure of crystals with x-ray diffractometers, efficient manpower utilization associated with the rostering of duties in public transport system (Bard *et al*, 1994; Foulds and Hamacher, 1980; Keuthen, 2003; Ohno *et al*, 1999; Rajkumar & Narendran, 1996; Al-Haboub & Shorik, 1993; Madsen, 1988; Ferreir, 1995). Also, there are research work that has emanated from the contributions of Professor Charles-Owaba to the traveling salesman problem. One is the simultaneous optimization of makespan (C_{max}) and the number of tardy jobs (NT) in a single machine problem with sequence-dependent setup time as described in Oladokun *et al* (2011). Another interesting application of TSP is in the music industry where the problem of generating harmonious song-list was modeled as a single machine setup problem with accompanying solution software (Oladokun *et al*., 2011).

2.1 The Single Machine Setup Problem

In a general-purpose work facility, the set-up time is an interval of time between the end of a job's processing and the beginning of the next available job. The machine setup can be sequence-dependent and sequence-independent. A schedule maps (or allocates) resources to tasks (or activities) over a specified period while a sequence involves the ordering of activities through machines or resources. The sequence-dependent machine setup problem minimizes a pre-defined cost or time objective of re-setting a facility by determining the optimal sequence required to perform a set of N operations. For a single machine commissioned to process job *i* and *j*, the scheduling problem of optimising the makespan, C_{max} (or completion time) with sequence-dependent machine setup times S_{ij} (j is processed immediately after i) is the single machine setup problem (MSP). In MSP, the sequence of X (stations) parts being processed by a single machine to minimize C_{max} can be likened to the traveling salesman problem. In scheduling, the modeling structure of the TSP is also referred to as sequence-dependent MSP. In many contexts, terms such as MSP and TSP are used interchangeably.

In a static single machine scheduling scenario with no sequence-dependent setup times, makespan minimization is a trivial problem because C_{max} is the same irrespective of the sequence adopted. However, in many practical scheduling problems with sequence-dependent setup times, makespan becomes a function of the job sequence. A classical example of such a single facility problem is found in the mixing of different paints produced repeatedly on one machine in fixed sequence per production cycle. The setup time corresponds to the cleaning time of the machine between colours changes; this depends on the time required for the colour to be removed, and the start of production for the next colour. Another example is the group technology (GT) approach to manufacturing systems design using TSP set-up time reduction principle, this exploits the sequence dependency of set-up times of some part families (Charles–Owaba & Lambert, 1988; Karabat & Akkan, 2006).

2.2. Other Variants of TSP

TSP can be categorised as symmetric and asymmetric. For the symmetric case, the distance (or equivalent cost) of travelling from the station (or city) i to station j is the same as travelling vice-versa (i.e. city j to city i) i.e. $C_{ij} = C_{ji}$. However, the asymmetric TSP is more generic in that $C_{ij} \neq C_{ji}$, and this portrays the real-life scenarios or problems such as when the to and fro trip fares are different for the pair of cities (Oladokun & Charles-Owaba, 2008). The TSP can also occur as cyclic when the salesman returns to the starting city or acyclic when the salesman stops at last city without 'return home' (Charles–Owaba, 2001). The Minimum Latency Problem (MLP) is another variation of the TSP, which aims to minimize the sum of arrival times at vertices, or the sum of clients waiting time to receive service and other many practical applications (Silva *et al*, 2012). The Time-Dependent TSP is a generalized TSP where the costs between pair of cities depend on their position in the sequence (Abeledo *et al*, 2013) while in the Time-Dependent TSP with Time Windows variant the time dependence is captured by considering variable average travel speeds Montero *et al* 2017). There is another variant in the context of maritime transportation called the TSP with Draft Limits (TSPDL) that is modelled to account for restrictions on the port infrastructures (Battarra *et al*, 2014).

3.0 Solving Travelling Salesman Problem

The TSP was infamous amongst scientists in early developmental years due to lack of scientific methodology for solving the problem. In TSP and other real-life instances of combinatorial problems, as soon as the number of cities increases, more computational resources will be required to solve the problem effectively and efficiently. Early solution approach includes a simple method of randomly chosen locations in the Euclidean plane as proposed in 1938 to a TSP application in farm survey, making a finite number of trials, with rules that may reduce the number of trials, and a modified assignment problem algorithm (Robinson, 1949). The TSP camouflage its computational complexity with a deceptively easy to grasp definition and remains a very attractive and productive platform for developing and testing many combinatorial optimization procedures.

The invention of the linear programming simplex algorithm ushered in a new world of possibilities when Dantzig *et al* (1954) formulated the TSP as an integer linear program and used the cutting plane method to find an optimal solution for a 49-city problem. There have been several adaptations of the LP algorithms for TSP, such as the use of dual LP algorithm for LP relaxations and max-flow algorithm for identifying violated sub tour inequalities of TSP model. There were applications of branch-and-bound algorithms that adopted an assignment problem (Eastman, 1958), the minimum spanning trees problem or similar relaxations as lower bounds. The branch-and-bound algorithm by Little *et al* (1963) was one of the most popular implicit enumeration approaches for the TSP. Other early exact algorithm approaches include dynamic programming algorithm (Bellman, 1960) and integer programming formulation solved with the Gomory's cutting-plane algorithm (Lambert, 1960). For small problem size, exact methods have proven to be effective. However, in TSP and other real-life instances of combinatorial problems, as soon as the number of cities increases, more computational resources will be required to solve the problem effectively and efficiently.Several heuristics have also been developed and applied to solve the TSP (Hossam *et al*, 2018; Almufti *et al*, 2019). Some of the widely known local optimization techniques and variants like simulated annealing, tabu search, neural networks, genetic algorithms and ant colony algorithm have adopted the TSP as a challenging playground for evolution and testing (Xu *et al*, 2018; Qaiduzzaman, et al., 2020; Rossman, 1958; Tian & Yang, 1993; Walshaw, 2002; Riera-Ledesma, 2005). The cheapest-insertion heuristic (Karg &Thompson 1964), and the Lin *k*-opt heuristic (Lin, 1965) were some of the earliest heuristic approaches to the TSP. A chronological review of the evolution of these algorithms and heuristics is contained in Oladokun and Charles-Owaba (2011).

3.1 Computational Complexity

A computational problem can be defined as a function *f* required to map each input *x* within a given domain to an output *f* (*x*) in a given range. Computational complexity considers the number of steps an algorithm needs to take to solve an instance of a problem (Oladokun, 2006; Oladokun & Owaba, 2011). Because the computer execution time required for solving a problem is a function of the number of computational steps, the performance of an algorithm is, therefore, measured as the maximum number of steps it requires for any instance of size N expressed as a function of N. A polynomial algorithm bounded by a polynomial function of instance size N is considered efficient, while an exponential algorithm bounded by an exponential function of instance size N is considered inefficient or computationally expensive (see Cook *et al*, 1998; Garey & Johnson, 1979; Johnson & Papadimitriou, 1985; Walshaw, 2001; Walshaw, 2002; Saadani *et al*, 2005). Hence, a problem is considered easy if there is a polynomial-time algorithm to solve it and hard otherwise (Cook *et al*, 1998; Marcotte *et al*, 2004; Gamboa *et al*, 2006). The TSP is classified as a hard combinatorial optimization problem with no polynomial-time optimizing algorithm (see Lawler *et al*, 1985; Applegate *et al*, 2004; Zhang, 2004). The TSP and its variants belong to a class of computationally complex problems called NP-complete. The class of P and NP problems can be solved by a non-deterministic polynomial (NP) time algorithm in polynomial time. This implies that if a polynomial-time algorithm is found for the TSP, it means all other NP-hard is solvable in polynomial time. This theoretical importance has been a key driver for the TSP research interests (Roberts & Flores, 1966; Fischetti & Toth, 1992; Dorigo & Gambardella, 1997; Applegate *et al*, 2004; Zhang 2004).

3.2 Algorithms and Heuristics

Like all other NP-hard discrete optimization problems, there are two classes of solution methods for the TSP problem: exact or optimization algorithms and heuristics also known as approximation algorithms. While exact algorithms are designed to contain a proof of optimality of the resulting solution; and have a mechanism to obtain the so called global optimal solution, they are computationally expensive and bounded by an exponential function of instance size N. TSP heuristics or approximation methods, on other hand, are designed to obtain a good solution without the confirmation of optimality and are mostly polynomial-time methods. Many heuristics are modified exact algorithms designed by jettisoning their optimality mechanisms as trade-off for achieving computational efficiency.

Since the TSP is a discrete optimization problem with a finite number of possible solutions, though this number is an exponential function of the problem size N, the complete enumeration is guaranteed to yield an optimal solution. However exponential growth renders this approach not practicable for even 2-digit size problems. For instance, an explicit enumeration algorithm running on the fastest computer would need about two days to find an optimal solution for a (N=20) problem size while for a (N=25) problem size the time grows to 400 centuries! Hence, practical algorithms are based on implicit enumeration which does not search through all solution space. Many existing algorithms are based on methods such as Integer Linear Programming method which formulate the TSP as a linear programming problem in zero-one variables and attempt to prove optimality using the concept of cutting planes. The TSP has been solved using dynamic programming formulation, branch and bound algorithm. While these algorithms are not efficient for practical problems they have been the basis for very good non-optimizing heuristics.

The Nearest Neighbour Algorithm is an example of such heuristics with easy to implement variations like multi-start approach Nearest Neighbour (see Johnson *et al*, 1997; Charles-Owaba & Oladokun, 1999; Hurkens & Woeginger, 2004). There are insertion methods (Karg &Thompson, 1964), the 2-opt and 3-opt heuristic which works as tour improvement methods using the deletion and replacement of 2 non-adjacent edges. The Lin-Kernighan k-opt method is a generalized implementation of the 2-opt tour improvement method (Lin & Kernighan, 1973; Chandra *et al*, 1999; Helsgaun, 2000).

There are also search heuristics such as genetic algorithm, simulated annealing, and tabu search. The genetic algorithm and many of its variations developed for the TSP are designed to mimic the biological evolution concepts that support the evolution of improved population of solutions. This improvement is achieved by mathematically mirroring evolution concepts such as survival of the fittest, crossover or reproduction, genetic mutation and migrations and similar evolution concepts (Charterjee *et al*. 1996; Johnson & McGeoh, 1997). The tabu search is another popular general heuristic procedure used for the TSP. Tabu search solves the problem of infinite cycling associated with improving search procedure by forbidding some moves, 'taboo moves', that will return to immediately previously visited point in the solution space (Radin, 1998; Kolohan & Liang, 2000). Simulated annealing is a search technique that controls cycling by mimicking the annealing process for improving the strength of steel (Tian & Yang, 1993; Johnson & McGeoh, 1997; Radin, 1998).

3.3 Feasibility and Sub tours in TSP Solutions

Feasibility due to subtour occurrence is a major issue in the formulation of the TSP or similar permutation sequence problem. Design of subtour constraints is a major challenge in model and algorithm development for the TSP. While it is easy to understand subtours, crafting subtour elimination constraints remains a difficult and challenging task (Radin, 1998; Oladokun and Charles-Owaba, 2011). Hence, theoretical principles for crafting these constraints within the context of algorithm development has been the thrust of many TSP works such as Crowder and Paderg(1980) which adopted a linear programming relaxation, Grötschel (1980) which used a cutting-plane algorithm with cuts involving sub tour inequalities, Hong (1972) used the Ford-Fulkerson max-flow algorithm for finding violated sub tour inequalities. In fact, the method for handling sub tour occurrences is what distinguishes one solution method from another and has influenced the various solution approaches. Meanwhile, the large number of sub tour elimination constraints, even for a modest number of points, makes the problem practically intractable.

The enormous number of computations required to solve such system of equations does not allow for the direct utilization of the ILP for TSP. However, researchers have adopted the idea of using the ILP to find good lower bound for the TSP. This lower bound procedure can then be used for assessing the effectiveness of heuristics solutions. For example, for the 380 cities record-breaking work of Crowder and Paderg (1980), a linear programming relaxation was adopted. An integer-programming solver was used to carry out a branch-and-bound search on the final linear programming relaxation. If the solution found using this search does not produce a tour, the subtour inequalities violated by the solution obtained is added back again using cutting-plane algorithm (Grötschel,1980). Subtours constraints require huge computational efforts. One approach to minimize these efforts in heuristics procedures is to adopt TSP formulation with simpler constraints such as formulating the TSP as quadratic assignment problem (QAP) and some adaptations of improving search methods on the QAP formulation. Oladokun and Charles-Owaba (2011) described some graph theoretic concepts for dealing with these sub tours constraints within the context of the set sequence algebra.

4.0 The Set Sequencing Algorithm (SSA)

Charles–Owaba (2001, 2002) proposed the set sequencing algorithm as a basis for the TSP solution. The set sequencing procedure describes a complete TSP sequence or tour as a set of N TSP matrix elements (links). The procedure then defines as the transformation of a known sequence (S_{i-1}) to a new sequence (S_i) by feasibly replacing a subset of its links (Lr) with an equal number (M) of candidate links (Lc) using a recursive function $Va(S_i) = Va(S_{i-1}) + \Delta(Lr, Lc, M)$. Where $Va(S_i)$ and $Va(S_{i-1})$ are the respective solution sequence values and $\Delta(Lr, Lc, M)$ is the exact amount $Va(S_i)$ is changed by the replacement operation. However, the original SSA had the challenge of feasibility; it sometimes results in infeasible solutions or subtours. The redesign of the SSA to develop a subtour-free set sequencing algorithm was the focus of a PhD thesis (Oladokun, 2006) supervised by Professor O.E Charles-Owaba in the Department of Industrial Engineering, University of Ibadan (see Oladokun & Charles-Owaba, 2011).

While implicit enumeration algorithms and heuristics view the machine setup problem in terms of the individual sequences and are designed to search through N factorial possible sequences (Charles-Owaba, 2001). The set sequencing concept addresses the machine setup problem differently, by searching for optimal elements among N(N-1) TSP matrix elements. A set of candidate links are used to replace some or all of the links of a given sequence to iteratively form improved sequences (Kwon *et al*, 2005). The SSA represents a major contribution of Professor O.E Charles-Owaba to the literature of the travelling salesman problem.

5.0 Conclusion

The traveling salesman problem has attracted quite a lot of interests for several decades evident by its wide practical applications such as routing, logistics, drilling, surveying, genetics, manufacturing, telecommunication, neuroscience, scheduling, to mention just a few. In scheduling, the traveling salesman problem or the sequence-dependent machine setup problem is an attempt to determine the minimum- total-length route while visiting every point once in a given set. In this chapter, the numerous research efforts of Professor Charles-Owaba to model and solve the different variants of the traveling salesman, such as the simultaneous optimization of makespan (C_{max}) and the number of tardy jobs (NT) in a single machine problem, group technology (GT) approach to manufacturing systems design using TSP set-up time reduction principle, and graph theoretic concepts for dealing with sub tours constraints within the context of the set sequence algebra were highlighted.

These research efforts were discussed by considering the single machine set-up problem (MSP) and other variants of TSP, the need to eliminate sub tour occurrences in the search for an optimal tour, which grows exponentially as the size of the problem grows. This difficulty brings to fore the concept of computational complexities, algorithms and heuristics available to solve TSP.

References

Abeledo, H., Fukasawa, R., Pessoa, A., & Uchoa, E. (2013). The time dependent traveling salesman problem: polyhedra and algorithm. *Mathematical Programming Computation* , *5* (1), 27-55

Al-Haboub-Mohamad, H.& Shokrik, Z. (1993). A Sequencing Problem in the Weaving Industry. *European Journal of Operational Research. 66* (1), 65-71.

Almufti, S.,Marqas, R., & Asaad, R. (2019). Comparative study between elephant herding optimization (EHO) and U-turning ant colony optimization (U-TACO) in solving symmetric traveling salesman problem (STSP). *Journal Of Advanced Computer Science & Technology* , *8* (2), 32

Applegate, D., Bixby, R.., Chvatal, V., Cook, W. & Helsghaun, K. (2004). The Sweden Cities TSP Solution' Available at www.tsp.gatech.edu//sweeden/cities/ cities.htm.

Bard, J.F., Clayton, R.W. and. Feo T. A. (1994). Machine Setup and Component Placement in Printed Circuit Board Assembly. *International Journal of Flexible Manufacturing Systems*. *6*, 5-31.

Battarra, M., Pessoa, A. A., Subramanian, A., & Uchoa, E. (2014). Exact algorithms for the traveling salesman problem with draft limits. *European Journal of Operational Research* , *235* (1), 115-128.

Bellman, R. (1960). Dynamic Programming Treatment of the TSP. *Journal of Association of computing Machinery*. 9,66.

Charles-Owaba, O.E & Oladokun, V.O (1999). A Set Sequencing Heuristic and the Computer Code for the TSP. *Proceedings of NIIE conference on Manufacturing Engineering*, *1*,135-146

Charles-Owaba, O. E. & Lambert, B.K. (1988). Sequence-Dependent Set-up Times and Similarity of Parts: A Mathematical Model. *Operation Research Special*. *20*(1).

Charles–Owaba, O. E. (2001). Optimality Conditions to the Acyclic Travelling Salesman Problem. *Operational Research Society of India*, *38*(5).

Charles–Owaba, O. E. (2002). Set-sequencing Algorithm to the Cyclic TSP. *Nigerian Journal of Engineering Management*, *3*(2), 47-64.

Charles-Owaba, O. E. & Oladokun V.O. (1999). A Set Sequencing Heuristic and the Computer Code For The TSP. *Proceedings of NIIE Conference on Manufacturing Engineering*, *1*, 135-146.

Chandra, B., Karloff H. & Tovey, C. (1999). New results for the old k-opt algorithm for the TSP. *SIAM Journal on Computing*, 28(6), 1998-2029.

Cook, W.J., Cunningham, W.H., Pulleyblank, R.W. & Schrijve, A. (1998). *Combinatorial Optimization* John &Sons, Inc New York

Crowder, H. & Padberg M.W (1980). Solving large-scale symmetric travelling salesman problems to optimality, *Management Science*, *26* 495-509.

Dantzig, G.B., Fulkerson D.R. & Johnson S.M.(1954). Solution of a Large-Scale Traveling-Salesman Problem. *Operations Research*, *2*, 393-410.

Dorigo, M. & Gambardella, L. M. (1997). Ant colony system: A cooperative learning approach to the traveling salesman problem. *IEEE Transactions on Evolutionary Computation*, *1* , 53-66.

Eastman, W.L. Linear programming with Pattern Constraints, Ph.D. Dissertation, Harvard 1958.

Ezugwu, A. E., & Adewumi, A. O. (2017). Discrete symbiotic organisms search algorithm for travelling salesman problem. *Expert Systems with Applications* , *87*, 70-78

Ferreir, J. V. (1995). A travelling salesman model for the sequencing of duties in bus crew rotas, *Journal of Operational Research Society*, *46* (4), 415-426.

Fischetti, M. & Toth, P. (1992). An Additive Bound Procedure for the Asymmetric Traveling Salesman Problem., *Mathematical Programming*, 53, 173-197.

Foulds, L. R. & Hamacher, H. W (1993). Optimal bin location and sequencing in printed circuit board assembly. *European Journal of Operational Research* (Netherlands). *66*(3), 279-290.

Gamboa D., Rego C. & Glover, F. (2006). Implementation Analysis of Efficient Heuristic Algorithms for the Traveling Salesman Problem, Computers and Operations Research. *33* (4), 1154-1172.

Garey, M. R. & Johnson, D. S. (1979). *Computers and Intractability: A Guide to the Theory of NP-completeness*, Freeman, San Fransisco.

Grötschel, M. (1980). On the Symmetric Travelling Salesman Problem: Solution of a 120-city problem. *Mathematical Programming Study*, *12*, 61-77.

Grötschel, M. (1991). On the Symmetric Travelling Salesman Problem: Solution of a 120-City Problem". Mathematical Programming Study, *12*, 61-77.

Helsgaun, K. (2000). An effective implementation of the Lin-Kernighan Traveling Salesman Heuristic. *European Journal of Operational Research*. 126, 106-130.

Hong, S. (1972). A Linear Programming Approach for the Traveling Salesman Problem, Ph.D. Thesis, The Johns Hopkins University. Hossam, A., Bouzidi, A., & Riffi, M. E. (2018).

Hossam, A., Bouzidi, A., & Riffi, M. E Elephants herding optimization for solving the travelling salesman problem. *International Conference on Advanced Intelligent Systems for Sustainable Development* (pp. 122-130). Springer, Cham

Hurkens, C.A. J. & Woeginger G. J. (2004). On the Nearest Neighbor Rule for the Traveling Salesman Problem. *Operations research Letters*, *32* (1), 1-4.

Johnson, D.S. & Papadimitriou, C. H. (1985). Computational Complexity in Lawler E. J, Lenstra J. K, Rinnoy Kan A.H.G, and Shmoys D.B. (eds). The Traveling Salesman Problem: *A Guided tour of combinatorial optimization*, 145-180. John Wiley & Sons.

Johnson, D.S. & McGeoh, L. A. (1997). The Traveling Salesman Problem: A Case Study in Local Optimization., In E. Aarts and J.K. Lenstra, editors, Local Search in Combinatorial Optimization, John Wiley and Sons, London, 215-310.

Karabat, S. & Akkan, C. (2006). Minimizing Sum of Completion Times on a Single Machine with Sequence-Dependent Family Setup times. *Journal of Operation Research Society*, *57*(3), 271-280.

Karg, R.L. & Thompson, G.L. (1964). A heuristic approach to solving travelling salesman problems. *Management Science*, 10, 225-248.

Keuthen, R. (2003). Heuristic Approaches for Routing Optimization. A PhD thesis at the University of Nottingham.

Kieu, T. D. (2019). The travelling salesman problem and adiabatic quantum computation: an algorithm. *Quantum Information Processing* , *18* (3), 90

Kolohan, F. & Liang, M. (2000). Optimization of hole making: A Tab search approach. *International Journal of Machine Tools and Manufacture*, 50, 1735-1753.

Kwon, S.. Kim H. & Kang, M. (2005). Determination of the Candidate Arc Set for the Asymmetric Traveling Salesman Problem, *Computers and Operations Research*, *32*(5), 1045-1057.

Lambert, F. (1960). The Traveling-Salesman Problem, *Cahiers du Centre de Recherche Opérationelle*. 2, 180-191.

Lawler, E.J., Lenstra J.K., Rinnoy Kan, A.H.G & Shmoys, D.B. (1985). *The Travelling Salesman Problem: A Guided Tour of Combinatorial Optimization*, John Wiley & Sons.

Lin, S. & Kernighan, B.W. (1973). An effective heuristic algorithm for the Traveling-Salesman Problem. *Operations Research*, *21*, 498-516.

Little, J.D.C., Murty, K.G., Sweeney, D.W., & Karel, C. (1963). An Algorithm for the Traveling Salesman Problem, *Operations Research*, *11*, 972-989.

Madsen, O.B.G. (1988). An Application of Travelling Salesman Routine to Solve Pattern Allocation Problem in the Glass Industry. *Journal of Operational Research Society*, *39*(3), 249-256.

Marcotte, P., Savard, G. & Semet, F. (2004). A BiLevel programming Approach to the Travelling Salesman Problem, *Operations Research Letters*,*32*(3), 240-248.

Montero, A., Méndez-Díaz, I., & Miranda-Bront, J. J. (2017). An integer programming approach for the time-dependent traveling salesman problem with time windows. *Computers & Operations Research* , *88*, 280-289.

Ohno, K., Jin, Z. and Elmaghraby, S. E. (1999). An optimal assembly mode of Multi-Type printed circuit boards. Computers & Industrial Engineering *36*, 451-471.

Oladokun, V.O. (2006). *The Development of a Subtour-Free Set Sequencing Algorithm and the Software for Solving the Machine Set-Up Problem*. Ph.D. thesis at the University of Ibadan: Ibadan, Nigeria.

Oladokun, V.O. & Charles-Owaba O.E. (2008). The Sequence Dependent Machine set Up Problem: A Brief Overview. Pacific Journal of Science and Technology, *9*(1), 36-44.

Oladokun, V.O & Charles-Owaba, O.E (2011). *The Sequence Dependent Single Machine Set-Up Time Problem: The Subtour – Free Set-Sequencing Algorithm Solution Approach*. LAP Lambert Academic Publishing GnbH & Co. KG, Dudweiler Landstr Deutschland.

Oladokun, V.O., Charles-Owaba,O.E. & Nnzeribe, T.M.C (2011) Harmonious Song-List Generation: An Application of the Sequence Dependent Machine Set Up Time Problem Model, *International Journal of Industrial Engineering and Technology*. *3* (3), 229-234.

Oladokun, V.O., Charles-Owaba, O.E. & Olaosebikan, F.O. (2011). A Bi-Criteria Algorithm for the Simultaneous Minimization of Makespan and Number of Tardy Jobs on a Single Machine with Sequence Dependent Set-up Time. *Research Journal of Applied Science, Engineering and Technology*, *3*(9), 1048-1051.

Padberg, M.W & Hong S. (1980). On the Symmetric Travelling Salesman Problem: A Computational Study. *Mathematical Programming Study*, 1, 78-107.

Qaiduzzaman, K. M., Khatun, S., Afsa, M., Sobhan, S., Hossain, M. E., Shaharum, S. M., et al. (2020). A Mutation Triggering Method for Genetic Algorithm to Solve Traveling Salesman Problem. In M. Mohd Razman, J. Mat Jizat, N. Mat Yahya, H. Myung, A. Zainal

Abidin, & M. Abdul Karim, *Embracing Industry 4.0* (pp. 159-170). Singapore: Springer

Radin, L.R. (1998).   Optimisation in Operations Research" Prentice Hall Inc. New Jersey USA.

Rajkumar, K. & Narendran, T. T. (1996). A Heuristic for Sequencing PCB Assembly to Minimize Set-up times. *Production Planning & Control*, *9*(5), 465–476.

Razman, J. Mat Jizat, N. Mat Yahya, H. Myung, A. Zainal Abidin, & M. Abdul Karim, *Embracing Industry 4.0* (pp. 159-170). Singapore: Springer

Riera-Ledesma, J. & Salazar-González, J.J. (2005). A Heuristic Approach for The Travelling Purchaser Problem, *European Journal of Operations Research*, *162*(1), 142-152.

Roberts, S.M. & Flores, B. (1966). An Engineering Approach to the Traveling Salesman Problem. *Management Science*, *13*, 269-288.

Robinson, B. (1949). On the Hamiltonian game (A Traveling Salesman Problem), *RAND Research Memorandum*

Rossman, M.J & Twery, R. J. (1958). A solution to the Traveling salesman problem. *Operations Research*, *6*, 687.

Saadani, N.E., Guinet A. & Moalla, M. (2005). A Travelling Salesman Approach to Solve the *F*/No-Idle/*C*max Problem. *European Journal of Operations Research*, *161*(1). 11-20.

Silva, M. M., Subramanian, A., Vidal, T., & Ochi, ,. L. (2012). A simple and effective metaheuristic for the minimum latency problem. *European Journal of Operational Research , 221* (3), 513-520.

Tian, P. & Yang, S. (1993). An Improved Simulated Annealing Algorithm with Generic Characteristics and Travelling Salesman Problem. *Journal of Information and Optimization Science*.14 (3). 241-254.

Walshaw, C. A. (2001). *Multilevel Lin-Kernighan-Helsgaun Algorithm for the Traveling Salesman Problem*. CMS press Centre for Numerical Modelling and Process Analysis. University of Greenwich, London.

Walshaw, C. A. (2002). Multilevel Approach to the Travelling Salesman Problem”. *Operations Research.50*(5), 862-877.

Xu, J., Pei, L., & Zhu, R. Z. (2018). Application of a genetic algorithm with random crossover and dynamic mutation on the travelling salesman problem. *Procedia computer science , 131*, 937-945

Zhang, W. (2004). Phase Transitions and Backbones of the Asymmetric Traveling Salesman Problem, *Journal of Artificial Intelligence Research, 21*. 471-497.