

# Report on article The Travelling Salesman Problem: A Linear Programming Formulation

Radosław Hofman, Poznań 2008

**Abstract**—This article describes counter example prepared in order to prove that linear formulation of TSP problem proposed in [7] is incorrect (it applies also to QAP problem formulation in [8]). Article refers not only to model itself, but also to ability of extension of proposed model to be correct.

**Index Terms**—complexity class, linear programming, P vs NP, large instances.

## I. INTRODUCTION

Unknown relation between P and NP [3] complexity classes remains to be one of significant non solved problems in complexity theory. P complexity class consists of problems solvable by Deterministic Turing Machine (DTM) in polynomially bounded time, while NP complexity class consists of problem solvable by Non Deterministic Turing Machine (NDTM) in polynomially bounded time. This means that DTM can verify solution of every NP problem in polynomially bounded time even if polynomial algorithm for finding this solution is unknown [16].

Significant subclass of NP problems is known as NP-complete class. Problems from this class have ability to represent any other problems from whole NP complexity class. In 1970 S. Cook presented in [2] first reduction from any NP problem to Boolean Satisfiability Problem, and two years after R. Karp proved that 21 other problems are in NP-complete class showing many-one polynomial time reductions to these problems [14]. If then anyone shows algorithm solving any NP-complete problem in polynomially bounded time then any of NP problems may be solved in no more then  $O(n^c)$  steps, where  $n$  stands for instance size and  $c$  is some constant value [16].

In 2006 there appeared articles claiming to have proven that  $P=NP$  formulating TSP and QAP problem in terms of linear programming ([4], [10], [5] and other). Author of this article have prepared counter example [11] for one of these article discussing inability for LP approach to solve large instances of NP-complete problems [12].

Some suggestions from [11] were taken into proposed model and counter example is not valid for new version of these models. In this article we present extended version proving flaws in extended model.

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## II. MODEL LIMITATIONS

### A. 3D space

Model consists of variables representing usage of flow between nodes  $i$  and  $j$  at some stage  $r$ . Example is presented below:

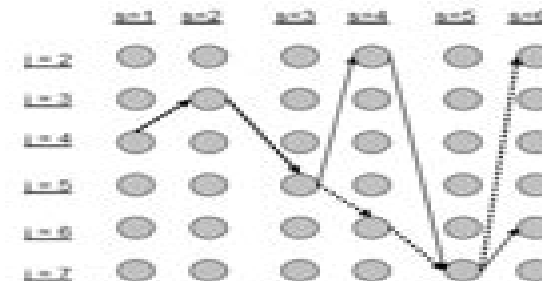


Figure 1. Example flow

Using these 3D variables (there are  $O(n^3)$  variables where  $n$  is number of nodes) for linear formulation could not prevent of solutions where:

- flow splits to clusters
- within clusters flow reaches same nodes several times
- summary flow at each node is preserved

Example of flow beyond restrictions for 3D variables is presented at fig. 2.

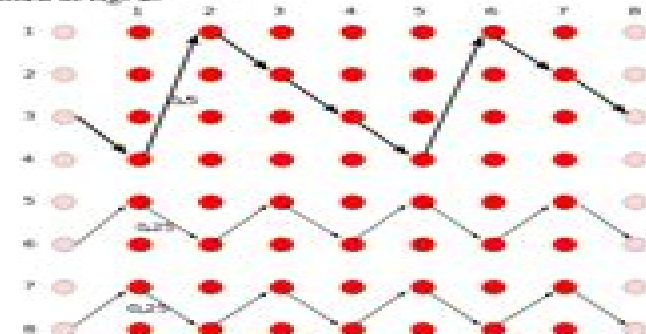


Figure 2. Flows in LP model based on 3D variables

# The Traveling Salesman Problem A Linear Programming

**Gerhard Reinelt**



## **The Traveling Salesman Problem A Linear Programming:**

*A Linear Programming Approach for the Traveling Salesman Problem* Saman Hong,1972      **The Traveling Salesman Problem** David L. Applegate,2006 Presents the findings on one of the most intensely investigated subjects in computational mathematics the travelling salesman problem This book describes the method and computer code used to solve a range of large scale problems and demonstrates the interplay of applied mathematics with increasingly powerful computing platforms

**On a Linear-programming-combinatorial Approach to the Traveling-salesman Problem: Notes on Linear Programming and Extensions-part 49** George Bernard Dantzig,1959 A demonstration that the linear programming combinatorial approach wherein simplex multipliers are used in a combinatorial analysis of undominated tours at some stage of the linear programming approach affords a practical way of solving traveling salesman problems      **The Traveling Salesman Problem and the Subtour Linear Programming** [],2017      [The Traveling Salesman Problem and Its Variations](#) G. Gutin,A.P. Punnen,2006-05-02 A brilliant treatment of a knotty problem in computing This volume contains chapters written by reputable researchers and provides the state of the art in theory and algorithms for the traveling salesman problem TSP The book covers all important areas of study on TSP including polyhedral theory for symmetric and asymmetric TSP branch and bound and branch and cut algorithms probabilistic aspects of TSP and includes a thorough computational analysis of heuristic and metaheuristic algorithms      **On a Linear Programming-combinatorial Approach to the Traveling Salesman Problem** George Bernard Dantzig,D. R. Fulkerson,S. M. Johnson,RAND CORP SANTA MONICA CALIF.,1958      *Traveling Salesman Problem* Donald Davendra,2010-12-30 This book is a collection of current research in the application of evolutionary algorithms and other optimal algorithms to solving the TSP problem It brings together researchers with applications in Artificial Immune Systems Genetic Algorithms Neural Networks and Differential Evolution Algorithm Hybrid systems like Fuzzy Maps Chaotic Maps and Parallelized TSP are also presented Most importantly this book presents both theoretical as well as practical applications of TSP which will be a vital tool for researchers and graduate entry students in the field of applied Mathematics Computing Science and Engineering      [The Traveling Salesman](#) Gerhard Reinelt,2003-08-02 Still today I am receiving requests for reprints of the book but unfortunately it is out of print Therefore since the book still seems to receive some attention I p posed to Springer Verlag to provide a free online edition I am very happy that Springer agreed Except for the correction of some typographical errors the online edition is just a copy of the printed version no updates have been made In particular Table 13 1 gives the status of TSPLIB at the time of publishing the book For accessing TSPLIB the link <http://www.iwr.uni-heidelberg.de/iwr/comopt/software/TSPLIB95> should be used instead of following the procedure described in Chapter 13 Heidelberg January 2001 Gerhard Reinelt Preface More than fteen years ago I was faced with the following problem in an assignment for a class in computer science A brewery had to deliver beer to ve stores and the task was to write a computer program for determining the shortest route for the truck driver to visit all

stores and return to the brewery All my attempts to find a reasonable algorithm failed I could not help enumerating all possible routes and then select the best one

Advances in Combinatorial Optimization, 2015 Combinatorial optimization CO is a topic in applied mathematics decision science and computer science that consists of finding the best solution from a non exhaustive search CO is related to disciplines such as computational complexity theory and algorithm theory and has important applications in fields such as operations research management science artificial intelligence machine learning and software engineering Advances in Combinatorial Optimization presents a generalized framework for formulating hard combinatorial optimization problems COPs as polynomial sized linear programs Though developed based on the traveling salesman problem TSP the framework allows for the formulating of many of the well known NP Complete COPs directly without the need to reduce them to other COPs as linear programs and demonstrates the same for three other problems e.g the vertex coloring problem VCP This work also represents a proof of the equality of the complexity classes P polynomial time and NP nondeterministic polynomial time and makes a contribution to the theory and application of extended formulations EFs On a whole Advances in Combinatorial Optimization offers new modeling and solution perspectives which will be useful to professionals graduate students and researchers who are either involved in routing scheduling and sequencing decision making in particular or in dealing with the theory of computing in general

*The Traveling Salesman Problem* D.B. Shmoys, J.K. Lenstra, A.H.G. Rinnooy Kan, E.L. Lawler, 1985 The Traveling Salesman Problem is central to the area of Combinatorial Optimization and it is through this problem that many of the most important developments in the area have been made This book focuses on essential ideas through them it illustrates all the concepts and techniques of combinatorial optimization concisely but comprehensively The extensive reference list and numerous exercises direct the reader towards related fields and give results Each of the twelve chapters in this volume is concerned with a specific aspect of the Traveling Salesman Problem and is written by an authority on that aspect It is hoped that the book will serve as a state of the art survey of the Traveling Salesman problem which will encourage further investigations and that it will also be useful for its comprehensive coverage of the techniques of combinatorial optimization

Encyclopedia of Optimization Christodoulos A. Floudas, Panos M. Pardalos, 2008-09-04 The goal of the Encyclopedia of Optimization is to introduce the reader to a complete set of topics that show the spectrum of research the richness of ideas and the breadth of applications that has come from this field The second edition builds on the success of the former edition with more than 150 completely new entries designed to ensure that the reference addresses recent areas where optimization theories and techniques have advanced Particularly heavy attention resulted in health science and transportation with entries such as Algorithms for Genomics Optimization and Radiotherapy Treatment Design and Crew Scheduling

**Constraints and Solutions of the Travelling Salesman Problem when Handled as a Linear Programming Problem** Peter M. Ellis, 1969

Integer Programming Harvey M. Salkin, 1975

**The Traveling Salesman Problem** E.L. Lawler, J.K. Lenstra, A.H.G. Rinnooy Kan, D.B. Shmoys, 1985 The

Traveling Salesman Problem is central to the area of Combinatorial Optimization and it is through this problem that many of the most important developments in the area have been made This book focuses on essential ideas through them it illustrates all the concepts and techniques of combinatorial optimization concisely but comprehensively The extensive reference list and numerous exercises direct the reader towards related fields and give results Each of the twelve chapters in this volume is concerned with a specific aspect of the Traveling Salesman Problem and is written by an authority on that aspect It is hoped that the book will serve as a state of the art survey of the Traveling Salesman problem which will encourage further investigations and that it will also be useful for its comprehensive coverage of the techniques of combinatorial optimization

**In Pursuit of the Traveling Salesman** William J. Cook, 2014-11-09 The story of one of the greatest unsolved problems in mathematics What is the shortest possible route for a traveling salesman seeking to visit each city on a list exactly once and return to his city of origin It sounds simple enough yet the traveling salesman problem is one of the most intensely studied puzzles in applied mathematics and it has defied solution to this day In this book William Cook takes readers on a mathematical excursion picking up the salesman's trail in the 1800s when Irish mathematician W R Hamilton first defined the problem and venturing to the furthest limits of today's state of the art attempts to solve it He also explores its many important applications from genome sequencing and designing computer processors to arranging music and hunting for planets In Pursuit of the Traveling Salesman travels to the very threshold of our understanding about the nature of complexity and challenges you yourself to discover the solution to this captivating mathematical problem **Approximation Algorithms for Traveling Salesman Problems Based on Linear Programming Relaxations** Hyung Chan An, 2012 The traveling salesman problem TSP is the problem of finding a shortest Hamiltonian circuit or path in a given weighted graph This problem has been studied in numerous variants and linear programming has played an important role in the design of approximation algorithms for these problems In this thesis we study two versions of the traveling salesman problem and present approximation algorithms for them based on the Held Karp relaxation We first investigate the s t path TSP Hoogeveen showed that the natural variant of Christofides algorithm is a  $5/3$  approximation algorithm for this problem this asymptotically tight bound had remained the best approximation ratio known until now We surpass this 20 year old barrier by presenting a deterministic  $1.5$  approximation algorithm for the s t path TSP for an arbitrary metric The techniques devised in this context can also be applied to other optimization problems including the prize collecting s t path problem and the unit weight graphical metric s t path TSP The integrality gaps of the LP relaxations for all three problems are studied Then we consider the bottleneck asymmetric TSP where the objective is minimizing the bottleneck or maximum length edge cost rather than the total edge cost We present the first nontrivial approximation algorithm for this problem by giving a novel algorithmic technique to shortcut Eulerian circuits while bounding the lengths of the shortcuts needed Building on this framework and the result of Asadpour Goemans Madry Oveis Gharan and Saberi we achieve an  $O(\log n \log \log n)$

approximation algorithm We also explore the possibility of improvement upon this result through a comparison to the symmetric counterpart of the problem      *Linear Programming and Related Techniques* C. van de Panne,1971      **Linear Programming Formulation of the Multi-Depot Multiple Traveling Salesman Problem with Differentiated Travel Costs** Moustapha Diaby,2010      *Linear Programming* James P. Ignizio,Tom M. Cavalier,1994 For senior graduate level courses in Linear Programming A comprehensive modern introduction to the philosophies and procedures used in the modeling solution and analysis of linear programming problems      *A Linear Programming Relaxation with Cycles for the Asymmetric Traveling Salesman Problem* Dorothee Henke,2018

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