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Issue Article

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BRIEF REVIEW OF 20th CENTURY IN DEVELOPMENT AND ACCESSIBILITY OF TRAVELLING SALESMAN PROBLEM AND TSPLIB

Abstract: *This paper provides a brief review of the 20th century in development and accessibility of the Traveling Salesman Problem (TSP) and TSPLIB. The TSP is a well-known NP-hard problem that has been studied extensively in the field of computer science and operations research. The problem involves finding the shortest possible route that a salesman can take to visit a given set of cities exactly once and return to the starting city. TSPLIB is a benchmark library that contains a collection of TSP instances that researchers and practitioners can use to test the performance of TSP algorithms. In this paper, we discuss the historical background of the TSP and its relevance to various fields, including logistics, transportation, and computer science. We then review the development of TSPLIB and the various improvements and additions made to it over the years. Finally, we provide a brief overview of some of the significant advancements in TSP algorithms that have occurred over the last century and their impact on the field. Overall, this paper provides a comprehensive overview of the TSP and TSPLIB's history and their impact on the development of algorithms for solving combinatorial optimization problems.*

Key words: *TSP, TSPLIB, logistics, review, publications, academic articles.*

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Introduction

The Travelling Salesman Problem (TSP) is a classic optimization problem in computer science and operations research. It involves finding the shortest possible route that visits a set of cities and returns to the starting point. Despite its seemingly simple description, the TSP is known to be NP-hard, which means that no known algorithm can solve it in polynomial time. This has led to the development of numerous heuristic and approximation algorithms that attempt to find good solutions in a reasonable amount of time.

The TSP were treated as mathematical problems in the 19th cemtury by the Irish and British mathematicians. Sir William Rowan Hamilton and Thomas Penyngton Kirkman were first to treat TSP as puzzle of Hamilton Cycle, where conditions to completions were similar and stated as follows: “Hamiltonian cycle is a cycle that visits each vertex exactly once” [1]. Hamilton and Kirkman were not the first to publish the information about TSP, although origins are unclear, problem and tour examples were mentioned in 1832 year handbook without any mathematical treatment [2]. The general form of the TSP first appeared in study of Harvard mathematicians in 1930s, especially Karl Menger who defined the problem and considered comparing brute-force algorithm to the nearest neighbors algorithm, proving NN non-optimal [3]. First academic to consider applying TSP to real-world problems was Merril M. Flood who was looking to solve a school bus routing problem.

Due to rising popularity of TSP, some researchers started to run tests on publicly available datasets of problems to compare effectiveness of developed algorithms and suggestions. One of the most popular library of datasets of problems for TSP have been documented and published in 1991, named TSPLIB [4]. TSPLIB is a widely used library of instances for the TSP, a classic optimization problem in computer science. The library contains a collection of benchmark instances that are commonly used for testing and comparing algorithms designed to solve the TSP. TSPLIB instances are categorized based on their size, structure, and characteristics, and they have been used extensively in academic research and industrial applications. The library includes both symmetric and asymmetric instances, which represent cases where the distance between two cities is the same in both directions or not, respectively. TSPLIB is a valuable resource for anyone interested in exploring the TSP or developing new algorithms to solve it, and it has contributed significantly to the progress made in this field over the years.

1. TSP publications

The formalization of the Traveling Salesman Problem (TSP) as a mathematical problem in the 19th century marked a turning point in the study of optimization problems. The study of the TSP led to the development of other important concepts and techniques in mathematics and computer science, such as graph theory, linear programming, and dynamic programming. These ideas have found applications in a wide range of fields, including operations research, economics, and engineering.

Despite the progress made in solving the TSP, the problem remains a challenging one, and researchers are still working on developing new algorithms and techniques to improve the efficiency and effectiveness of TSP solutions. The ongoing research on the TSP is an important part of the broader effort to solve complex optimization problems and improve the efficiency of a wide range of systems and processes.

The research on the Travelling Salesman Problem (TSP) has evolved over several periods, which can be broadly categorized as follows:

1. Pre-research academic space (1832 to late 1930s): This period saw the first conceptualization of travelling salesman problem and formulation of the problems. William Hamilton, Thomas Kirkman et al. made the necessary preparations for future researchers.

2. Early research (late 1930s to mid-1950s): This period saw the initial formulation of the TSP, along with the development of basic heuristics and algorithms to solve small instances of the problem. George Dantzig, who also developed the simplex algorithm, was one of the early pioneers of TSP research.

3. Integer programming approaches (late 1950s to mid-1970s): This period saw the development of mathematical programming formulations of the TSP, which enabled the use of powerful optimization algorithms such as branch-and-bound and branch-and-cut. Researchers like George Dantzig, Michael Held, and Richard Karp made significant contributions during this period.

4. Heuristics and approximation algorithms (mid-1970s to late 1980s): This period saw the development of various heuristics and approximation algorithms that could solve larger instances of the TSP more efficiently than exact methods. The most notable of these was the Christofides algorithm, which

guarantees a solution that is no worse than 1.5 times the optimal.

5. Exact algorithms and computational complexity (late 1980s to mid-2000s): This period saw significant progress in the development of exact algorithms for the TSP, which could solve instances with thousands of cities. Researchers also focused on studying the computational complexity of the problem, and showed that it is NP-hard.

6. Metaheuristics and hybrid approaches (mid-2000s to present): This period has seen the development of various metaheuristics and hybrid approaches that combine elements of different algorithms to solve the TSP more efficiently. Examples of such methods include genetic algorithms, ant colony optimization, and tabu search. Researchers are also exploring new formulations of the TSP, such as the capacitated TSP and the dynamic TSP, which have applications in various real-world settings.

In this article we conducted research observing articles from 1900 – 2020 years. After collecting data for 120 years of research on the traveling salesman problem, the following findings were concluded: history had 4 bursts in the number of research papers; more than 203999 works were documented; The main source of information was the academic search engine from Google, scholar.google.com.

Statistical information gathered and compiled in diagram (figure - 1), describes following points :

- The graph is a line graph that shows the number of TSP papers published each year over the course of 120 years.
- The x-axis represents the years, while the y-axis represents the number of papers published.
- The graph shows a significant increase in the number of TSP papers published from the 1950s onwards, with a peak in the 1990s.
- There are also noticeable dips in the number of papers published during certain time periods, such as during World War II.
- Overall, the graph demonstrates a clear trend of increased interest and research in the TSP over the past several decades.

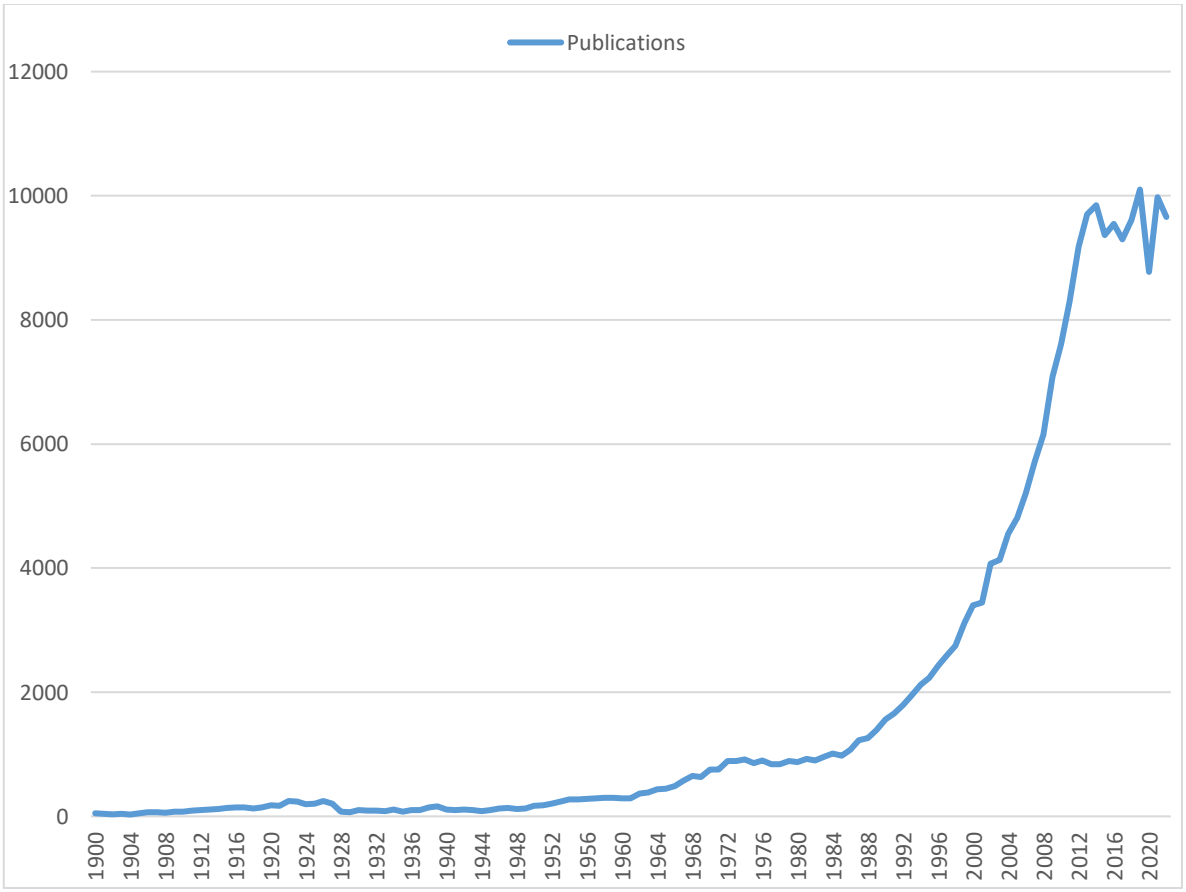

Figure 1 – Amount of academical research about TSP over the years

In order to get the more detailed information on evolution of TSP research, we selected 1009 articles sorted by relevancy from across 100 years period. This method can provide a broad overview of the major themes and trends in TSP research over the past century, and can also help to identify important papers, researchers, and milestones in the field.

By carefully selecting a representative sample of articles from a variety of sources, including academic journals, conference proceedings, and technical reports, this approach can help to ensure a balanced and diverse collection of papers. Additionally, by focusing on papers that have been published in reputable and peer-reviewed outlets, this method can help to ensure that the information gathered is reliable and of high quality.

In the process of gathering information, it has been noticed that out of 1009 articles, the oldest publication comes from 1954 and there are no publications in 1957. Although it has been predicted that the cluster of publications will be trend of publications, it was unexpected that there will be years without any publications documented. Also one of speculations was that Open Access (OA) articles will greatly overcome the percentage from overall publications up until latter quarter of the century, but in reality – averaging in 42,81% from publications. Thus, leading to 432 OA and 577 accessible only after payment (figure - 2).

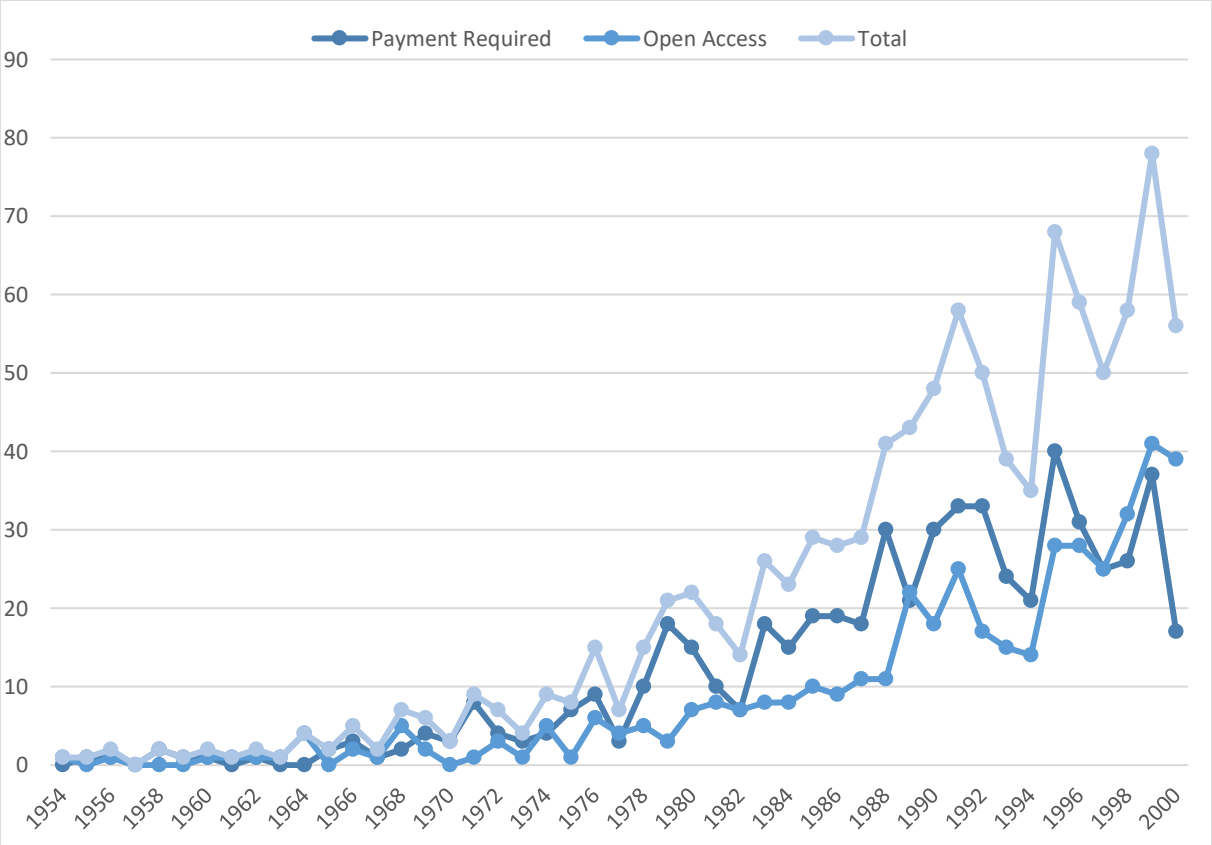

Figure 2 – Publications sorted by accessibility from 1009 articles

2. TSPLIB publications

TSPLIB is a comprehensive library of benchmark instances for the Traveling Salesman Problem (TSP) and its variants [4]. The impact of TSPLIB on the study of the TSP and optimization, in general, has been significant. First and foremost, it has provided researchers with a common set of benchmark instances that can be used to evaluate and compare new algorithms and techniques for solving the TSP. This has helped to standardize the evaluation of TSP solutions and has made it easier to measure progress in the field.

In addition to providing a standard benchmark set, TSPLIB has also played a role in the development of new TSP algorithms and heuristics. Researchers have used the benchmark instances to test and refine their algorithms and to identify areas where new approaches are needed. This has led to the development of many new and innovative techniques for solving the TSP, some of which have been applied to other optimization problems as well.

TSPLIB has also facilitated the dissemination of TSP research by providing a common language and set of tools for researchers to use. By standardizing the benchmark set and evaluation criteria, TSPLIB has made it easier for researchers to compare and build on each other's work. This has accelerated the pace of TSP research and has led to a better understanding of the problem and its solutions.

Moreover, TSPLIB has been used as a reference for teaching and research purposes. Researchers and students can use the benchmark set to test and evaluate their own TSP algorithms and to compare their results with those obtained using existing techniques. This

has led to a better understanding of the strengths and weaknesses of different TSP algorithms and has helped to guide the development of new techniques.

Finally, TSPLIB has helped to raise awareness of the TSP and optimization in general among the wider scientific community. By providing a comprehensive set of benchmark instances and evaluation criteria, TSPLIB has made it easier for researchers in other fields to appreciate the importance and relevance of the TSP to their own work. This has helped to foster interdisciplinary collaborations and has led to new insights and applications of the TSP in fields such as operations research, economics, and engineering.

Therefore, in this section, we will provide a critical evaluation of the impact of TSPLIB on TSP research, highlighting its strengths and weaknesses as a tool for evaluating TSP algorithms. We will also discuss some of the alternative approaches that have been proposed for evaluating TSP algorithms and the potential benefits and drawbacks of these approaches.

TSPLIB being great benchmark, for researching purposes have been collected 260 publications in period from publication of original paper to 2000th year. From selected publications 166 are Open Access and 94 accessible only after payment (figure 3). After reading through those Open Access publications following types of publications has been found:

- Broken pages, those are the publications that cannot be accessed, removed from publishers' database/website, or even publication of problems [5;6;7];
- Have instances from TSPLIB, publications are using instances from library to experiment and test algorithms [8;9;10];
- Have other instances, meaning that it only cites TSPLIB and uses instances from other libraries and databases [11;12;13];
- Only cites TSPLIB, publication has theoretical work and doesn't contain any problems that can be rerun using suggested algorithm or method [14;15;16].

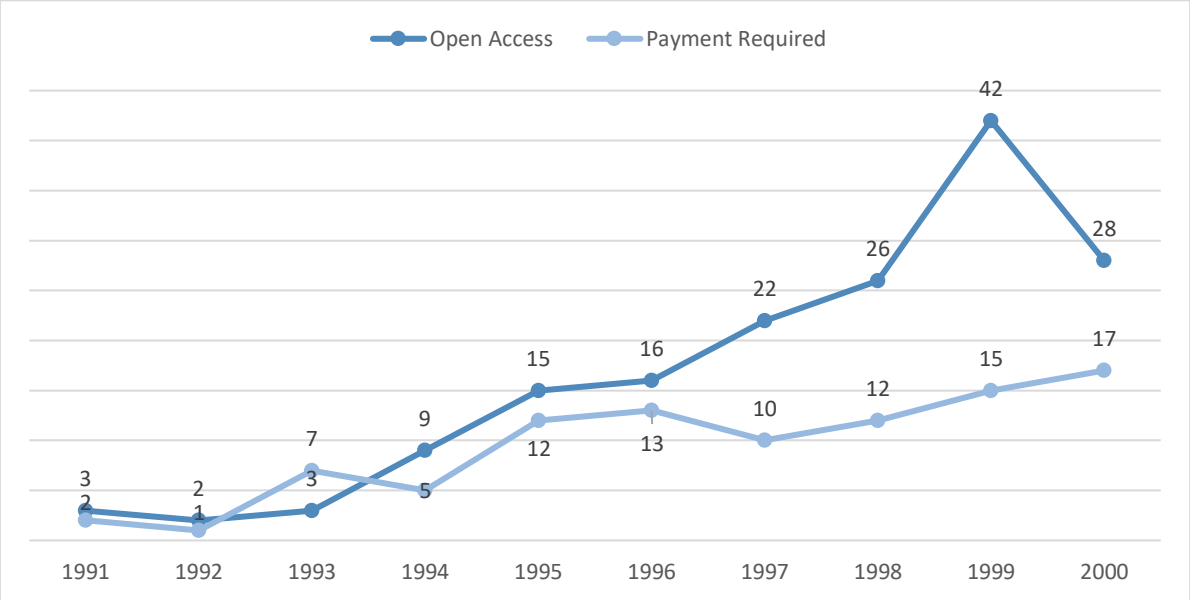

Figure 3 – TSPLIB's cited publications from first publication till 2000th year

Sorted chart of those publications can be seen in (figure 4). This chart presents that most publications that decide to cite TSPLIB are actually using it's vast library of instances to test and examine the results of experiments [17].

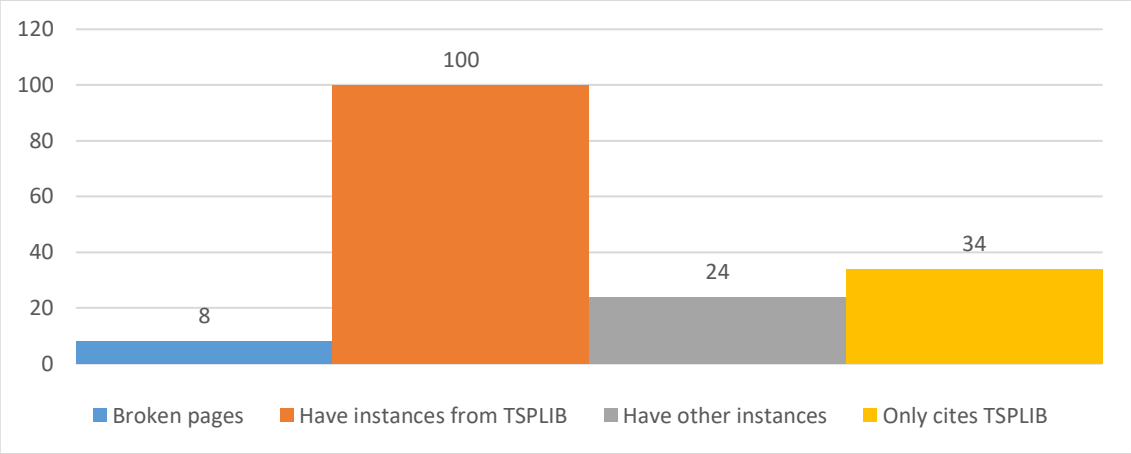

Figure 4 – Filtered Open Access publications of TSPLIB

Conclusion

Researching the Traveling Salesman Problem (TSP) is important for several reasons. Firstly, the TSP is a classic and fundamental problem in the field of combinatorial optimization, which has a wide range of practical applications in logistics, transportation, and scheduling, among other areas. By solving the TSP, we can gain insights into how to optimize complex routing and scheduling problems, which can lead to more efficient and cost-effective solutions.

Secondly, the TSP is an NP-hard problem, which means that it is computationally difficult to solve for large problem sizes. As a result, the development of efficient algorithms and techniques for solving the TSP is an active area of research in computer science and mathematics. This research has led to the development of a wide range of algorithms and techniques, such as heuristics, approximation algorithms, and exact algorithms, that can be applied to a variety of other optimization problems.

Finally, research on the TSP is important for advancing our understanding of fundamental concepts in mathematics and computer science, such as graph theory, complexity theory, and algorithmic design. As such, the TSP serves as a challenging and interesting test bed for new ideas and techniques in these areas, and the progress made in solving the TSP has broader implications for other fields as well.

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