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# **Designing Urban Transit Network using Memetic Algorithm**

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# Abstract

In the dynamic landscape of urban transportation, the design of transit networks stands at the intersection of innovation and efficiency. As cities evolve and expand, the need for sophisticated, well-orchestrated transit systems becomes increasingly paramount. Transit networks not only serve as the lifeblood of urban mobility but also play a pivotal role in shaping the character and accessibility of a city. This intricate dance of routes, nodes, and schedules reflects the intricate challenge of harmonizing diverse factors, from population density and geographical constraints to technological advancements and environmental considerations. The art and science of transit network design unfold as a multifaceted endeavor, requiring a delicate balance between meeting the evolving demands of commuters and fostering sustainability.

In this thesis we introduce the Memetic Algorithm (MA) as a solution to the Transit Network Design (UTND) problem. The MA builds upon the foundation of the traditional Genetic Algorithm (GA). The proposed algorithm incorporates a Hill Climbing Local Search (HCLS) algorithm to augment and refine the results obtained through the traditional GA.

The primary challenge in this problem revolves around determining an effective set of routes that optimizes passenger trips by minimizing travel time and the number of transits between routes. Our experiments are conducted on well-known benchmarks, including the Krakow city dataset, Mandl's Swiss network, and three extensive datasets known as Mumford networks. The results demonstrate that the HCLS significantly enhances solution quality when compared to traditional GA. In the case of the Krakow city network, a comparison of the MA fitness function applied to the current Krakow solution and the MA solution reveals an 8.48% improvement in direct transfers. This enhancement extends to other aspects, with improvements of 3.06%, 1.69%, and 3.72% for direct trips, trips with one transit, and trips with two or more transit, respectively.

In Mandl's network, our proposed algorithm excels in terms of direct trip percentages, achieving 100% satisfaction of total transfer demands directly in scenarios with eight and seven routes. On the other hand, the Average Transfer Time (ATT) values of our results are promising and comparable with other approaches. For Mumford networks, the suggested algorithm outperforms previous works in terms of direct trips with percentage differences of 3.37%, 3.78%, and 7.03% compared to Islam et al, (2019) in Mumford1, Mumford2, and Mumford3, respectively. Despite

the favorable results of MA, ATT values are nearly comparable to the best ATT of previous works, highlighting a trade-off in favor of seeking direct trips.

Another experiment was conducted to evaluate the efficiency of our proposed algorithm (MA) by computing the fitness values of both pure GA and MA without the mutation operator (relying solely on HCLS) in Mandl\_4 routes and Mumford3. Results from the experiments on Mandl and Mumford networks highlight significant enhancements in fitness function values achieved by the suggested MA compared to the slower pure GA and MA lacking the mutation operator, which tend to get trapped in local minima.

Additionally, in the conducted experiments using Mandl datasets, the average execution time of MA underwent a comparison with Particle Swarm Optimization (PSO) within the Mandl network context. The proposed MA showcased its efficiency when juxtaposed with the approach by (Kechagiopoulos and Beligiannis, 2014), which solely relied on the PSO algorithm to address the Mandl transit routing problem. The time disparities amounted to 94.17, 99.24, 101.38, and 95.34 seconds for the number of routes 4, 6, 7, and 8, respectively. However, due to inadequate data availability, a comparative analysis based on execution time for other datasets was not feasible. In general, the application of hill climbing search on solutions generated by GA yields significant improvements compared to previous works across Krakow, Mandl, and Mumford datasets.

The secondary challenge is employing a compression technique to condense large graphs, thereby reducing the time and effort required by the MA to discover the best transit network solution. The compression process unfolds in two phases. Initially, a random graph creator tool was devised to generate multiple graphs, designed with the same probability distribution of some characteristics as the Krakow city dataset. Upon completing this phase, we obtain several graphs, along with their corresponding travel time matrices and demand matrices, ready for compression. Subsequently, the compression technique is applied to these created graphs, resulting in compressed graphs as well as compressed travel time and demand matrices. Notably, this compression process maintains the integrity of the original data. Following this, the MA is employed to identify the best solution over both the compressed and uncompressed graphs, allowing us to evaluate the impact of utilizing the route-based compression technique. In our experiments, a series of randomly generated graphs, along with the Krakow network graph, underwent compression at rates of 45.6%, 51.0%, 52.3%, 54.3%, 57.7% and 62.4%, respectively.

Subsequently, the proposed MA was executed on both the original and compressed graphs. We then present a comparative analysis of the execution time required to obtain the best solution for our UTND problem, along with their corresponding fitness values. The graph compression technique yielded significant improvements, reducing the execution time by 50.8%, 53.9%, 55.6%, 56.4%, 56.8% and 57.2% respectively, in comparison to the original graphs. Remarkably, despite the compression, the quality of the best solution fitness values remained consistent when utilizing the maximum travel time for compressed edges while accumulating the passenger demand.

The third challenge is the progressive transition from the existing transportation network to the recommended network proposed by the MA. The transformation unfolds within the Krakow transport network, serving as a case study. Emphasis is placed on a meticulously defined execution of the transformation across several stages, aiming to minimize disruptions and ensure a smooth transition. The integration of the Hungarian Algorithm (HA) and HCLS is employed to ensure an effective transition from the current network to the new network. The HA addresses the assignment problem between existing and proposed network routes, while the HCLS determines the best combination among them, facilitating a gradual shift to the proposed network. The experimental results reveal fluctuations in both altered edge costs and fitness values throughout the entire process. However, these fluctuations are justified as a trade-off to achieve a flawless network, ensuring the fulfillment of passengers' demands in all the transformation steps.

In the following Chapter 1 we define the research problem and the related research questions that this thesis seeks to answer. Section 1.7 describes the structure of the main part of the thesis.