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INTEGER-BASED TRAFFIC ASSIGNMENT FOR HIGH-PERFORMANCE CITY-SCALE VEHICLE SIMULATIONS

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ABSTRACT

Developing realistic traffic simulations requires accurately modelling the routing and movement of personal and freight vehicles under network congestion. Since routing decisions impact traffic dynamics, capturing congestion effects is essential for credible simulation outcomes. Traffic assignment methods address this by modelling how vehicles choose routes in congested networks. While All-or-Nothing (AoN) assignment is simple and widely used, it ignores congestion and produces unrealistic traffic patterns. The Frank-Wolfe (FW) algorithm improves realism by solving the Traffic Assignment Problem under user equilibrium, but it outputs continuous flows, which are unsuitable for agent-based simulations requiring explicit vehicle routes. We evaluate Incremental Loading (IL), a heuristic that generates discrete, congestion-aware routes in a single pass. AoN, FW, and IL are compared using over 130,000 vehicle trips on a city-scale road network with 354,067 nodes and 502,431 edges. IL reduces the Beckmann objective by 36% over AoN and requires only 33% of FW's runtime.

1 BACKGROUND AND INTRODUCTION

Creating an agent-based vehicle simulation requires a routing system capable of generating vehicle trajectories across city-scale road networks. To design such a system, it is crucial to accurately model the routing and movement of individual personal and freight vehicles through the network. However, large-scale traffic simulations often rely on shortest travel-time routing that ignores congestion, leading to unrealistic traffic patterns and uneven road utilization.

These inaccuracies can be addressed by solving the Traffic Assignment Problem (TAP) under the User Equilibrium (UE) assumption, where each vehicle selects the route with the shortest travel time based on prevailing road congestion. When using the Bureau of Public Roads (BPR) travel time function, the TAP becomes a convex optimization problem solvable by the Frank-Wolfe (FW) algorithm (Frank, Wolfe, et al. 1956). However, FW produces continuous flow solutions rather than discrete vehicle trajectories, limiting its use in agent-based simulations.

To generate explicit vehicle routes, we consider Incremental Loading (IL) (Chen and Alfa 1991), a heuristic method that assigns trips in batches while accounting for congestion effects. IL not only produces agent-level trajectories but also operates in a single pass, offering better scalability on large networks such as Singapore's. In contrast, FW's iterative nature results in significantly higher computational costs.

This work evaluates the performance and suitability of FW and IL in generating realistic, city-scale traffic assignments for agent-based simulations.

2 TRAFFIC ASSIGNMENT METHODS

Using a processed version of the Singapore road network retrieved from OpenStreetMap, each traffic assignment method was evaluated with 132,726 vehicle origin-destination itineraries, magnitudes larger than most TAP test problems. The road network contained 354,067 nodes and 502,431 edges. The methods were compared in terms of the Beckmann function value (Beckmann, McGuire, and Winsten 1956) and the runtime of the program. Concerning these criteria, we see the result as shown in Table 1. We also briefly describe the traffic assignment methods tested.

Table 1: Comparison of traffic assignment methods.

Assignment Method	**Beckmann Objective Value (min)**	**Program Runtime (min)**
All or Nothing Assignment	1.3466×10^8	1.19
Frank-Wolfe Optimal Assignment (Not Discrete Trajectories)	8.5391×10^7	-
Frank-Wolfe Actual Assignment	8.7414×10^7	19.92
Incremental Loading Assignment	8.6684×10^7	6.61

All or Nothing (AoN) assignment refers to assigning each trip to the fastest path between the origin and destination, assuming free-flow travel times.

Frank-Wolfe (FW) assignment is done by first finding an optimal assignment pattern using the FW method, where the Beckmann value is minimized, but the integrality constraints of the flow are not preserved. A final re-assignment is done by performing shortest path calculations assuming the optimal assignment pattern's travel times.

Incremental Loading (IL) assignment gradually loads pre-determined groups of the total demand onto the network in sequential steps, updating travel times after each increment to account for increasing congestion effects. Parameters of IL can be modified as well, such as the order and the grouping size of the itineraries.

3 RESULTS

AoN assignment resulted in roads with higher speed limits, expressways, having higher usage rates. On the other hand, for FW, the optimal assignment pattern shows a reduction in load on the expressways compared to AoN and produces a pattern with higher secondary and tertiary road usage. However, the re-assignment step produces a pattern that increases congestion compared to the optimal assignment. Thus, FW is only useful for using the optimal assignment as a benchmark. IL managed to produce a pattern similar to FW optimal assignment but still had slightly lower utilization on secondary and tertiary roads. This is seen in its Beckmann value being only 1.5% higher than FW optimal. The additional benefit of IL is due to the one-pass nature of the assignment, it's program runtime is 67% faster compared to FW, but still produces a Beckmann value that is 36% lower compared to AoN.

4 CONCLUSION AND FUTURE WORKS

As IL represented the most ideal approach, balancing performance and computational speed, the team has implemented IL assignment as our pre-simulation step in our large city-scale agent-based modelling simulation platform and has successfully run several scenario runs. The designed traffic assignment module using IL produces vehicle trajectories that better represent real-world route choices compared to AoN and allow for quicker turnaround of the simulation due to its faster computation time than FW. The team plans to expand this module to include differentiated routing behaviour of personal and freight vehicles.

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