Bachelor Thesis

Assessment of approximation method for TSP path length on road networks: a simulation study

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1 Introduction

The Traveling Salesman Problem is an important problem in operations research. It is particularly relevant for last-mile carriers and other logistics companies where efficient routing directly impacts cost, time and service quality. Since the number of parcels worldwide has increased between 2013 and 2022 and is expected to keep increasing [Statista (2025)], the need for fast, scalable route planning methods becomes ever more pressing.

The TSP is an NP-hard problem, it is computationally intensive to find the exact solution for large instances. In many real-world scenarios, companies may not need the exact routes for deliveries, but instead require rough, reliable estimates. For instance a last-mile carrier or a food delivery chain expanding to a new area. Then this firm may only know what area they will serve and have some estimates of how many customers they will get. In such cases, they may need quick answers to questions like how many vehicles and personnel they will need.

Efficient approximation methods provide a solution for such practical applications where exact solutions are too computationally intensive to conduct or not feasible due to insufficient data. These methods aim at approximating the expected optimal total travel time or distance, while using minimal data and computational effort.

There is extensive research on such approximation methods and how they perform in the euclidean plane. Consider n uniformly drawn locations inside some area in $\mathbb{R}^2$ with area A. Beardwood, Halton, and Hammersley (1959) prove the relation:

$$L \to \beta\sqrt{nA}, \quad \text{as } n \to \infty \tag{1}$$

as an estimation for the length of the shortest TSP path measured by Euclidean distance through these random locations, where β is some proportionality constant. This formula is a very elegant result, approximation and it requires very little data. However, its assumptions, uniform random locations and euclidean space differ from real-world applications, which are defined by complex geographic features, such as road networks.

This research investigates how well this approximation method performs when we consider real road networks. Using OpenStreetMap data, we simulate TSP instances in a selection of different areas in the Netherlands, then solve these for the actual shortest paths using the Lin–Kernighan heuristic. Then we estimate β from from equation 1 and analyze the performance of this formula. Additionally, we compare the results for β and the performance across the selected areas, with the goal of understanding the driving factors behind the varying results.

In section 2 we dive deeper in the context and previous research in this field. Then, in section 3 we show the methodology …

2 Literature Review

Merchán and Winkenbach (2019) use circuity factors to measure the relative detour incurred for traveling in a road network, compared to the euclidean distance. This circuity factor is defined as, where p and q are locations:

$$c = \frac{d_c(p, q)}{d_{L_2}(p, q)} \tag{2}$$

c is greater or equal to 1, a value closer to 1 indicates a more efficient network. This circuity factor has been estimated many times for different road networks, with results ranging between 1.12 and 5.60 [Merchán and Winkenbach (2019)]. This is an efficient method of implementing the impact of traveling over a road network into the models for solving the TSPs, since the euclidean distance can simply be multiplied by a constant. However, this might be an oversimplification of reality: this circuity factor might differ strongly from area to area or differ by route length. Additionally, the locations used were generated from uniform distribution across the area. This might also be unrealistic since population density differs strongly from area to area, especially in a city where there is highrise, then the distribution of the delivery locations is clearly not uniform.

3 Methodology

4 References

Beardwood, Jillian, John H Halton, and John Michael Hammersley. 1959. "The Shortest Path Through Many Points." In *Mathematical Proceedings of the Cambridge Philosophical Society*, 55:299–327. 4. Cambridge University Press.

Merchán, Daniel, and Matthias Winkenbach. 2019. "An Empirical Validation and Data-Driven Extension of Continuum Approximation Approaches for Urban Route Distances." *Networks* 73 (4): 418–33.

Statista. 2025. "Global Parcel Shipping Volume Between 2013 and 2027 (in Billion Parcels)*." https://www.statista.com/statistics/1139910/parcel-shipping-volume-worldwide/.

5 Appendix

Province	Neighborhood	Beta
groningen	Hortusbuurt	1.2778
groningen	Binnenstad	1.1743
groningen	Oosterpoort	1.1404
groningen	Rivierenbuurt	0.9122
groningen	De Wijert	0.9263
groningen	Oosterparkwijk	1.0178
groningen	De Hoogte	0.9830
groningen	Korrewegwijk	1.1658
groningen	Schildersbuurt	1.3002
groningen	Paddepoel	0.9678
groningen	Oranjewijk	1.2096
groningen	Tuinwijk	1.3566
groningen	Selwerd	0.8333
groningen	Vinkhuizen	0.7597
groningen	Hoogkerk-zuid	0.6373
groningen	Gravenburg	0.7020
groningen	De Held	0.8763
groningen	Reitdiep	0.9308
groningen	Hoornse Meer	0.7626
groningen	Corpus den Hoorn	0.8834
groningen	Eemspoort	0.9543
groningen	Euvelgunne	0.9777
groningen	Driebond	0.8931
groningen	Winschoterdiep	0.9278
groningen	Eemskanaal	0.9456
groningen	Helpman	1.2851
groningen	Lewenborg	1.1241
groningen	Beijum	1.0329
groningen	Maarsveld	0.9216
noord$_{holland}$	Schrijverswijk	1.0589
noord$_{holland}$	Stad van de Zon	0.8607
noord$_{holland}$	Stadshart	0.9493
noord$_{holland}$	Jordaan	1.1630
noord$_{holland}$	Slotervaart	1.0224
noord$_{holland}$	IJburg	0.6820
noord$_{holland}$	Oostelijke Eilanden	0.9444
noord$_{holland}$	Oostelijk Havengebied	0.9338
noord$_{holland}$	Frederik Hendrikbuurt	1.2661
noord$_{holland}$	Van Lennepbuurt	1.0085
noord$_{holland}$	Da Costabuurt	1.4033

Province	Neighborhood	Beta
$\text{noord}_{\text{holland}}$	Kinkerbuurt	1.1128
$\text{noord}_{\text{holland}}$	Kersenboogerd	1.0067
$\text{noord}_{\text{holland}}$	Pax	1.2590
$\text{noord}_{\text{holland}}$	Graan voor Visch	1.0791
$\text{noord}_{\text{holland}}$	Vrijschot-Noord	1.1685
$\text{noord}_{\text{holland}}$	Toolenburg	0.7537
$\text{noord}_{\text{holland}}$	Floriande	1.2353
$\text{noord}_{\text{holland}}$	Overbos	1.0177
$\text{noord}_{\text{holland}}$	Bornholm	1.0644
$\text{noord}_{\text{holland}}$	Beukenhorst-Oost	0.7379
$\text{noord}_{\text{holland}}$	De Hoek	1.1886
$\text{noord}_{\text{holland}}$	West	0.9840
$\text{noord}_{\text{holland}}$	Zuid	0.9468
$\text{noord}_{\text{holland}}$	Oost	1.0466
$\text{noord}_{\text{holland}}$	Noord	0.9115
$\text{noord}_{\text{holland}}$	De President	0.7120
$\text{noord}_{\text{holland}}$	Graan voor Visch-Zuid	0.9107
$\text{noord}_{\text{holland}}$	Zuidwijk	0.7743
$\text{noord}_{\text{holland}}$	Buitenveldert-West	0.8271
$\text{noord}_{\text{holland}}$	Buitenveldert	0.7653
$\text{noord}_{\text{holland}}$	Apollobuurt	1.0411
$\text{noord}_{\text{holland}}$	Stadionbuurt	0.9073
$\text{noord}_{\text{holland}}$	Prinses Irenebuurt e.o.	0.8727
$\text{noord}_{\text{holland}}$	Hoofddorppleinbuurt	1.0270
$\text{noord}_{\text{holland}}$	Willemspark	1.1882
$\text{noord}_{\text{holland}}$	Schinkelbuurt	0.8164
$\text{noord}_{\text{holland}}$	Vondelparkbuurt	0.7705
$\text{noord}_{\text{holland}}$	Helmersbuurt	1.0691
$\text{noord}_{\text{holland}}$	Overtoomse Sluis	1.1580
$\text{noord}_{\text{holland}}$	Museumkwartier	1.0361
$\text{noord}_{\text{holland}}$	Rivierenbuurt	1.1910
$\text{noord}_{\text{holland}}$	IJselbuurt	0.9530
$\text{noord}_{\text{holland}}$	Scheldebuurt	1.0240
$\text{noord}_{\text{holland}}$	Rijnbuurt	1.1289
$\text{noord}_{\text{holland}}$	De Baarsjes	1.1530
$\text{noord}_{\text{holland}}$	Landlust	1.1953
$\text{noord}_{\text{holland}}$	Staatsliedenbuurt	1.1514
$\text{noord}_{\text{holland}}$	Spaarndammerbuurt	1.3621
$\text{noord}_{\text{holland}}$	De Pijp	1.4139
$\text{noord}_{\text{holland}}$	Grachtengordel	1.3627
$\text{noord}_{\text{holland}}$	Oud-Zuid	0.9476