Comparisons of heuristics and metaheuristics for optimizing congestion prices

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1 Background

In the last couple of years the interest for congestion pricing has risen in Denmark. In 2012 a toll ring around the city was very close to becoming a reality as it was one of the key topics in the recent government election campaign. However, the new government abandoned the toll ring due to many negative opinions and calculations from experts.

Since both of the other two Nordic capitols Stockholm and Oslo have implemented toll rings it could be a possibility to do the same in Copenhagen. However Copenhagen's geography is not well suited for a toll ring since there are few physical boundaries that encapsulates the city like the bridges in Stockholm or the relative few roads that leads to and from Oslo. This means that the implementation of a toll ring would be much more expensive since there would be many more passages of the ring.

An alternative approach to a toll ring would be to introduce a GPS-based tolling system in which users pay a toll depending on the amount of driven kilometres in Copenhagen. This approach can be refined by varying the driving cost for different areas of the city.

Much work has been done within the field of second best congestion pricing and much of it is focused on the Toll design problem, where toll points and toll levels are found (Verhoef, 2001; Shepherd & Sumalei, 2004; Ekström & Sumalei & Lo, 2012). When using fixed locations the problem is instead referred to as The Toll Level Setting Problem which is the problem that is worked on in this project since the different pricing areas is chosen initially.

Much of the work done in the literature is however focused on smaller to medium sized networks like the Sioux Falls network, however to the best of our knowledge the work being done in large scale models is fairly limited. In this work it is therefore sought to apply different heuristics for solving the problem for different sizes of networks in order to determine which types of heuristics are suited for different types of network. The main goal is however to optimize congestion pricing for a large scale traffic model.

2 Problem

Metaheuristics are a subset of heuristics that traditionally are used in problems where every single evaluation is very fast and many iterations can be made (Hillier & Liberman, 2005). The many iterations are needed since there is a large part of randomness connected to the metaheuristics and using them with few iterations results in lack of consistency of the results. Due to the size of the problem the question is whether a metaheuristics is even applicable to a large scale traffic model, or a heuristic with less randomness is more appropriate. The problem is a bi-level optimization problem where the lower level is solved with a multi-class stochastic user equilibrium model based on mixed probit (Nielsen & Frederiksen & Daly, 2002) using the well known BPR-function and the upper level is the optimization of the pricing scheme performed with different heuristics.

3 Method

The work done on the lower level consists of different ways of speeding up the assignment which due to the mixed probit cannot be formulated as closed form and solved as one joint optimization problem (Wang & Lo, 2009 - Ekström & Sumalei & Lo, 2012) and therefore is simulated instead. In intermediate iterations zone aggregation in outer non relevant zones, matrix thinning and merging of trip purposes are used to reduce the calculation time. The assignment is performed with a static user equilibrium model. We are aware of the shortcomings of this type of model with regards to simulating spatial elements of congestion. The goal of this work is however more focused on the performance of the different heuristics than the actual results and the experience gained through this work should be applicable to other more realistic queuing models.

In this paper, two methods are being used; 1) a metaheuristic, and 2) a normal heuristic. The metaheuristics used is a sort of parallel adaptive Simulated Annealing (Burke and Kendall, 2005, chapter 7), where different ways throughout the network is explored at the same time and the different solution trails are adapted towards better solutions by using the intermediate results from other trails. This means that areas in the solution space that give poor results can be avoided by other trails. The adaptive element is inspired by Roulette Wheel Selection (Goldberg, 1989) where promising changes to the pricing schemes are noted and will afterwards be chosen with a higher likelihood.

The normal heuristic that is applied shares elements with the metaheuristic. It is however not implemented as random walks and will greedily seek to improve the solution in every iteration based on level of service data from the previous iteration.

4 Case

Different networks have been used throughout the calculations, in order to test for network size. Initial calculations were made with different small experimental networks in order to improve the methods. Afterwards calculations were done for increasing sizes of networks like the Sioux Falls model (24 zones, 38 links) and the Winnipeg model (147 zones, 2836 links) and ending with a large scale network of The Greater Copenhagen region (835 zones, 30,000 links.

5 Results

In small networks it is possible to make a complete enumeration of the solution space. It is therefore not clear which methodology that performs best. However when the computational time is very long there is a clear tendency that the metaheuristics perform worse than the normal heuristic.

For large scale models it requires a long calculation period in order to achieve good consistent solutions. Obviously there will be a trade-off between computational effort and consistent results. The results did show promising results for networks up to medium size. However the full scale model needed much simplifying in order for the metaheuristics to perform satisfyingly.

References

Edmund K. Burke & Graham Kendall - 2005 - Search Metholodogies

Joakim Ekström, Agachai Sumalei, Hong K. Lo – 2012 - Optimizing toll locations and levels using a mixed integer linear approximation approach

David E. Goldberg – 1989 – Genetic Algorithms in Search, Optimization, and Machine Learning

Nielsen O. A. & Frederiksen R. D. & Daly A. – 2002 - A Stochastic Route Choice Model for car travellers in the Copenhagen region

Simon Shepherd, Agachai Sumalee – 2004 - A Genetic Algorithm Based Approach to Optimal Toll Level and Location Problems

Erik T. Verhoef - 2001 - Second-best congestion pricing in general networks. Heuristic algorithms for finding second-best optimal toll levels and toll points

David Z. W. Wang & Hong K. Lo – 2009 – Global optimum of the linearized network design problem with equilibrium flows

Hillier F. S. And Liberman G. J. Introduction to Operations Research, McGraw-Hill, New York (8th edn), Chapter 13, 2005.