

Solving the First and Last Mile Problem with Connected and Autonomous Vehicles

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ABSTRACT

The *first and last* mile problem describes the difficulty of starting and completing a journey when using public transport, where there are limited options once away from centralised transport infrastructure such as train stations. It is particularly an issue for commuter journeys where time lost on regular repeated trips becomes a barrier to the use of public transport so that commuters use their own cars, which consequently contributes towards increasing pollution. With the potential advent of connected autonomous vehicles (CAVs) on our roads in future, it may be possible to reduce the travel time of commuters between the train station and their home or place of work and therefore potentially reduce the number of car trips that are made. In this paper, we model commuters using CAVs, and for the first time optimise the locations where CAV hubs should be placed to increase the number of commuters opting to travel by trains using an evolutionary optimiser. In a real world case study between Exmouth and Digby & Sowton stations in UK, we demonstrate that with only 11 hubs shared between the origin and the destination stations, we may halve the number of car trips.

CCS CONCEPTS

• **Mathematics of computing** → **Combinatoric problems**; *Evolutionary algorithms*; • **Applied computing** → *Transportation*;

KEYWORDS

last mile problem, connected and automated vehicles.

ACM Reference Format:

Alma Rahat, Ralph Ledbetter, Alex Dawn, Robert Byrne, and Richard Everson. 2019. Solving the First and Last Mile Problem with Connected and Autonomous Vehicles. In *Genetic and Evolutionary Computation Conference Companion (GECCO '19 Companion)*, July 13–17, 2019, Prague, Czech Republic. ACM, New York, NY, USA, 2 pages. <https://doi.org/10.1145/3319619.3321919>

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GECCO '19 Companion, July 13–17, 2019, Prague, Czech Republic

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ACM ISBN 978-1-4503-6748-6/19/07...\$15.00

<https://doi.org/10.1145/3319619.3321919>

1 INTRODUCTION

One of the primary deterrents for commuters taking a form of public transport (e.g. train) is the problem of going from home to a transport station (first mile) and from the destination station to the final destination (last mile) due to poor local public transport coverage or long walking distances. This problem is more commonly known as the *first and last mile* problem. As connected and autonomous vehicles — autonomous vehicles that are networked allowing coordination of a fleet — (CAVs) become more common, it will be possible to transport people between home (or workplace) and stations rapidly, which may potentially solve the first and last mile problem by making it faster for commuters to use public transports. In considering such a futuristic scenario, it would be necessary for urban planners to optimally distribute stations for CAVs — we denote such stations as hubs — near peoples' homes and workplaces to encourage the use of public transport and consequently reduce congestion. In this paper, we propose a model and use an evolutionary optimiser to estimate optimal locations of a fixed number of hubs.

2 LAST AND FIRST MILE MODEL

A commuter goes from his or her home in an output area (OA)¹ to work in a workplace zone (WZ) everyday using different modes of transport. S/he will prefer a car if it is faster than other modes of transport. A large number of cars on the roads increases pollution and congestion. We are therefore particularly interested in reducing the number of car trips between each pair of OA and WZ by making it faster for commuters to use public transport (e.g. trains) instead. As a preliminary study, we only consider a pair of origin and destination train stations in this paper, and develop a model accordingly.

Let T_o and T_d be the train stations at the origin and the destination respectively. A complete train journey for a commuter from the i th OA to the j th WZ consists of the following components: a trip to T_o , train travel and a trip from T_d to a WZ. With this, we may compute the total time spent in a complete trip:

$$t_{ij} = t_{io} + t_{od} + t_{dj}, \quad (1)$$

where t_{io} is the time it takes to go from the i th OA to T_o , t_{od} is the time on train plus the waiting times, and t_{dj} is the time to go from T_d to the j th WZ.

¹In the United Kingdom, the Office for National Statistics (ONS) codifies geographic areas where people live and work, and these areas are denoted as output areas (OAs) and workplace zones (WZs) respectively.

Note that a trip to (or from) a train station either involves walking, taking a CAV from the nearest hub or a combination of both. We approximate walking times with an average walking speed of 1.4 m/s, and CAV times from a hub to a station with a constant CAV speed of 25 km/h under normal traffic conditions. The same strategy is adopted to compute times for T_d and WZs. Similarly, we compute the shortest time for a car trip t_{ij}^c between the i th OA and the j th WZ under normal traffic conditions.

Furthermore, we consider the centroid of an OA or a WZ as a potential location for a hub. To determine the locations of k hubs, we search over a combination of k centroids with l hubs allocated to the origin station T_o and $k - l$ hubs allocated to destination station T_d . Thus we construct sets of tentative locations $L_o \subset O$ at T_o and $L_d \subset D$ at T_d , where O and D are the sets of centroids for OAs and WZs respectively.

We query a database for the number of car trips N_{ij} between the i th OA and the j th WZ. With this, the number of car trips that may be saved is defined as:

$$P_{ij} = \begin{cases} N_{ij}, & \text{if } t_{ij} \leq t_{ij}^c. \\ 0, & \text{otherwise.} \end{cases} \quad (2)$$

Hence, the total number of car trips saved for given sets of hub locations L_o at origin and L_d at destination is:

$$f(L) = \sum_{i \in L_o, j \in L_d} P_{ij}, \quad (3)$$

where $L = L_o \cup L_d$ is the set of centroids where hubs are to be located.

The goal of optimisation is to maximise the number of car trips that may be saved taking the train for a fixed number of hubs k :

$$\max_{L \in \mathcal{L}} f(L), \quad (4)$$

where $\mathcal{L}$ is the feasible solution space that is determined by $L_o \subset O$, $L_d \subset D$ and $|L| = |L_o| + |L_d| = k$.

This is essentially a combinatorial optimisation problem. We therefore use an evolutionary optimiser with tournament selection, uniform cross-over, mutation and a repair strategy to search over the combinations of a fixed number, k , of potential hub locations (see supplementary materials for details of the algorithm and further discussions).

It should be noted that some research has been conducted to solve the last mile problem with locations of hubs for bicycle sharing, but they often concentrate on the last mile problem with a single destination disregarding the first mile or the origin [1]. We instead present this as a global problem considering multiple origins and destinations. Also, our work is complementary to CAV scheduling approaches such as [2].

3 CASE STUDY: COMMUTE BETWEEN EXMOUTH AND DIGBY

As a case study, we consider the commute between Exmouth and Digby in Devon, UK. A car trip takes on average 1487 s with a standard deviation of 92 s. On the other hand, a train trip takes about 936 s with an average waiting time of 120 s. Considering, the travel time to and from a station, it is often more time consuming to take the train. As a consequence, many commuters still travel by car as a quicker mode of transport, and it is estimated that there are

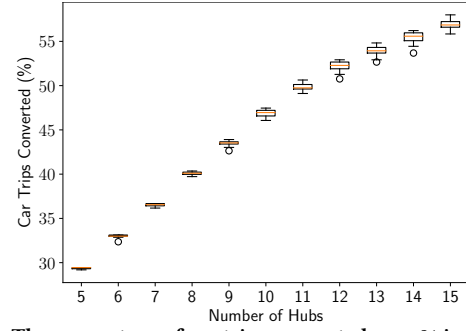


Figure 1: The percentage of car trips converted over 21 independent repetitions of the optimisation process for varying the number of hubs $k = 5 \rightarrow 15$. The narrow width of the interquartile ranges indicate desirable repetition and convergence properties of the optimiser.

an average of 788 car trips from Exmouth to Digby every day. We plan to introduce CAVs and their hubs so that the total travel time by train is reduced, and consequently encourage the commuters to take the train instead.

We investigated the optimiser performance for varying the number of hubs $k = 5 \rightarrow 15$ (Figure 1). The results show that the optimiser is capable of consistently producing similar (good) results over 21 repeated runs. Furthermore, with $k = 5$ hubs, it is possible to save nearly 30% of the car trips, while nearly 57% trips may be saved with $k = 15$ hubs. We note that 50% of trips are saved when $k = 11$ and when $k > 11$ the rate of savings increase is slower than for smaller numbers of hubs. As anticipated, there is a clear trade-off between the number of hubs and the number of car trips.

4 CONCLUSIONS

In this paper, we discussed a potential futuristic solution to the first and last mile problem with the use of CAVs. A commuter may take a CAV from a designated station called hub and rapidly travel to a station. So long as the total time to commute is less than a car trip to destination, the commuter will opt to travel by train. With this, the challenge becomes where to place these hubs in order to maximise the number of people travelling by train. We model this as a combinatorial optimisation problem and propose an evolutionary algorithm to solve it. We demonstrated the proposed approach on a real world case study: the commute between Exmouth and Digby. Future work will incorporate multi-objective optimisation considering the conflicting objectives of the number of hubs, the number of car trips and the cost of building hubs with realistic constraints on number of vehicles and demands.

ACKNOWLEDGEMENT

This work was supported by the European Regional Development Fund (grant number: 16R16P01302).

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