The "sidekick" routing paradigm for VMT reduction and improved accessibility

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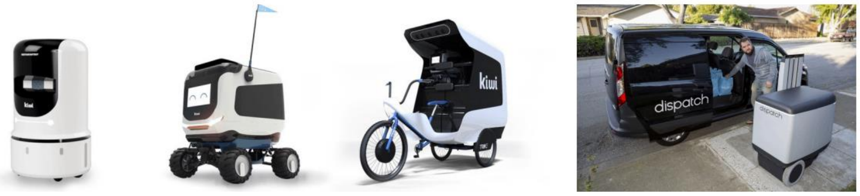
Project Objective

This project has combined tools from geospatial analysis, mathematical optimization theory, and computational geometry to study a routing paradigm that we call *sidekick routing*. A sidekick routing scheme is a logistical framework in which a large vehicle, such as a truck or van, serves as a mobile base for a fleet of small vehicles (the "sidekicks"), such as autonomous ground vehicles (AGVs) or unmanned aerial vehicles (UAVs). Systems of this kind have significant potential to simultaneously reduce vehicle miles travelled (VMT) – because the sidekicks are not restricted to streets – and to improve accessibility to goods, because the so-called "last mile" cost of transporting those goods is reduced.
The sidekick paradigm has very recently seen use in many public and private sector organizations, both in California and elsewhere. However, although the requisite *physical* technology is reasonably mature, the requisite *management* technology (i.e. systems for determining efficient routing strategies) are relatively nascent. Moreover, the extent to which such services can provide a societal benefit are not yet understood, although the results from this report indicate that the potential is very high.

Problem Statement

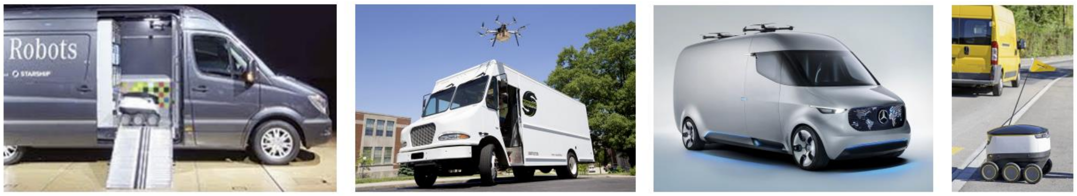
One of the more novel recent innovations in the logistics world, both in theory and in practice, is the use of small autonomous vehicles to facilitate last-mile delivery. One particular scheme that has received considerable recent attention is the a "sidekick" scheme, in which a large cargo truck acts as a mobile "base" that deploys smaller vehicles, such as drones or unmanned ground vehicles (UGVs), which is shown in Figure 1. The sidekicks alternate between visiting the truck to pick up items and visiting the customers, and the overall objective is to determine a coordinated set of routes for all vehicles in order to optimize system efficiency, such as minimizing the time to completion or the vehicle miles travelled (VMT).

Although the hardware for these systems is fairly mature, the problem of determining efficient routes has not been considered until very recently. From the perspective of routing these systems pose an exceptionally difficult challenge due to the need to synchronize multiple vehicles that can all be traveling at the same time and at different speeds. We cannot consider vehicles' routes separately as we must include the possibility of vehicles carrying other vehicles for periods of time and the need for intermittent meetings of vehicles at the same position at the same point in time. Thus we see that individual vehicles' routes are highly interdependent, and any reasonable objective will be impacted by this interdependence, making the optimization very hard. Furthermore, the high-level attributes of these systems are not at all clear: how much more efficient can they be? When are they useful? What are the trade-offs inherent in such a scheme? In this report, we develop a continuous approximation model that estimates the improvements to efficiency that such a system provides, in the asymptotic limit as many demand points are drawn from a continuous probability distribution. Our analysis indicates under what circumstances these sidekicks can offer the most benefit, as a function of their speeds and the number of sidekicks available.



(a) Kiwi “bots” and “trikes”

(b) Dispatch van and robot



(c) Starship van and robot

(d) The “horsefly” system from AMP Electric Vehicles

(e) Mercedes Vision Van

(f) Swiss Post van and robot

Figure 1: Various hardware implementations of sidekick routing schemes from Kiwi Campus, Dispatch, Starship, AMP Electric Vehicles, Mercedes-Benz and Matternet, and the Swiss Post.

Research Methodology

Our research approach consisted of three phases:

- The first phase of our project consisted of constructing a precise mathematical model for calculating efficient “sidekick” routes using integer and linear programming as well as tools from geospatial analysis such as the continuous approximation paradigm. There are many variants of such problems, and we developed an umbrella formulation that unified many of them. Several problem attributes include the following:
- The second phase of our project consisted of formulating a *continuous approximation* model. This means we make some simplifying assumptions about the problem structure, such as assuming that all customers are independent samples from a probability distribution or that vehicle travel occurs in some natural and predictable way, and then prove mathematical theorems about the properties of the solution.
- The third phase of our project consisted of conducting computational experiments to determine when sidekick routing schemes can provide the most societal benefit. We made these conclusions based on the results of the theorems we proved as well as how consistent they were with our computational experiments.

Results

The major conclusion from our study is a mathematical theorem that describes how much benefit one can realize from using a sidekick routing system. Broadly speaking, our analysis indicates that when a vehicle traveling at speed ϕ_0 makes use of *k* sidekicks that travel at speed ϕ_1, the makespan (i.e. the total time until completion) reduces by a factor of $\sqrt{\frac{\phi_0}{k\phi_1}}$. For example, if a truck travels at 20 miles per hour, and makes use of 3 sidekicks that travel at a speed of 30 miles per hour (typical performance for a drone), then the amount of time needed to complete all necessary work would decrease by $\sqrt{\frac{\phi_0}{k\phi_1}} = \sqrt{\frac{20}{3\times 30}} \approx 47\%.$