TRUCK TRAVEL AND EMISSIONS REDUCTIONS FROM NEW COMMUNICATION TECHNOLOGY IN URBAN ARBORICULTURE

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ABSTRACT

Urban arboriculture (primarily management of trees) produces pollution emissions disproportionate to the size of the industry, partially due to the trucks and heavy machinery required. Research evaluating potential and implemented mitigation strategies in this industry is lacking. This paper evaluates the use of new information and communication technology (ICT) to improve operational efficiency and reduce pollution emissions of arborist truck travel activity. Chip Drop is an internet-based service that connects arborist with households seeking woodchips or logs. The service provides arborists with more potential locations to dispose of the wood byproducts of arboring activity than would otherwise be available, and thus potentially increases trucking operational efficiency. The travel and emissions impacts of the service are evaluated by estimating the travel distance savings compared to disposal of woodchips at the nearest city/commercial dumpsite. Emissions savings are also estimated using the MOVES model and information on typical arborist trucks. Results suggest potential for moderate reductions in arborist truck travel of 4-11%, or approximately 400-2,200 km/year/truck, with associated reductions in pollution emissions. There are also cost savings for arborists in trucking costs and dumping fees. Travel and emissions savings depend on the geographic distribution of participating households, proximity to city/commercial dump sites, and money offered by households as an incentive to arborists. This research suggests modest travel and emissions savings from implementing a cost-reducing ICT strategy with environmental co-benefits. Similar ICT strategies should be pursued in related industries with urban truck movements.

1 INTRODUCTION

Urban arboriculture (primarily management of trees) requires heavy machinery and heavy duty vehicles. The arboriculture industry produces seven times more carbon dioxide (CO_2) emissions per year than industries of similar size (by number of employees) (*1*–*3*). However, unlike larger industries that are required to at least monitor their greenhouse gas (GHG) emissions, smaller industries such as arboriculture are relatively unregulated, beyond broadly applicable vehicle emission standards (*4*, *5*). Urban arborists also typically operate diesel trucks, which creates disproportionally high health risks for nearby exposed populations (*6*–*8*). Previous research quantified the energy use and GHG emissions of the arboriculture industry and suggested potential mitigation strategies including improved routing and scheduling, operational efficiencies of the equipment, vehicle speed limiters, and lower-emitting equipment (*3*, *9*). However, existing literature lacks evaluations of implemented mitigation strategies in the arboriculture industry.

Information and communication technology (ICT) strategies can be applied to improve operational efficiency through provision of dynamic data relevant to arborist activity. Chip Drop (http://chipdrop.in/) is a relatively new ICT service launched in January 2014 to enable arborists to identify convenient locations to dispose of wood byproducts (woodchips and logs). Households seeking woodchips and/or logs sign up on Chip Drop, where arborists can view an interactive map of those households when they need to dispose wood byproducts (“drop” woodchips). Arborists pay $20 per drop to use Chip Drop, while households can offer $0-$80 to arborists to incentivize a drop at their location (in order to get woodchips sooner).

Alternatively, arborists typically dispose wood byproducts at city or commercial dumpsites, which are relatively sparse and charge fees of $20 - $700 depending on the load, or at a privately-owned site. In addition, some arborists maintain their own list of households that might want

woodchips, but the information is not dynamic and the process has significant administrative costs. Chip Drop potentially provides a cost benefit to households as woodchips for mulch or logs for burning typically cost around $80/yard. Similarly, arborists may potentially find cost and logistical benefits from using Chip Drop through lower dump fees and increased available disposal locations. Cost effects aside, increasing the number of locations for disposal of wood byproducts can potentially increase operational efficiency in urban arboricultural truck activity, with potential reductions in vehicle kilometers traveled (VKT) and associated pollution emissions. The objective of this study is to estimate the effects of utilizing Chip Drop on arborist truck VKT and emissions.

2 METHODOLOGY

2.1 Overview of method

Comprehensive data on all Chip Drop activity in Portland, Oregon were obtained from Chip Drop for the period May 20 – Aug 28, 2016. However, only the drop locations are known: full arborist trip data (access origin, egress destination, route) could not be obtained. Therefore, the effects of Chip Drop are estimated as a scenario analysis of all plausible origins and destinations (O/D) in the region. For each observed drop, VKT savings are calculated for each plausible O/D pair as the difference between disposal at the drop location (B in FIGURE 1) and a counterfactual scenario where Chip Drop does not exit and a drop is made at the nearest city/commercial dumpsite (A in FIGURE 1). Summary statistics are generated from the distributions of savings among plausible O/D for each drop. Emissions effects are estimated using rates from the MOVES2014a emissions model.

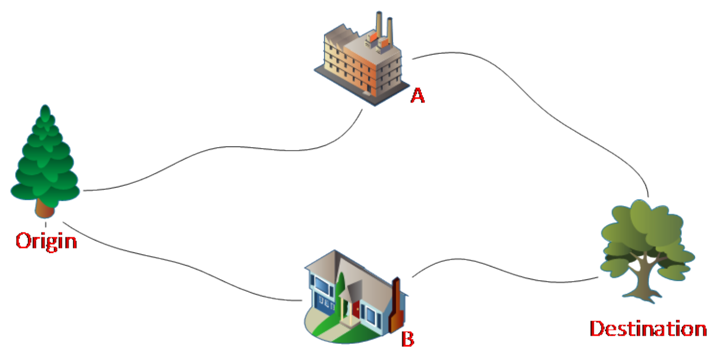

FIGURE 1 Comparison scenarios for VKT difference between woodchip disposal at the observed drop site (B) and at the nearest city/commercial dumpsite (A)

2.2 Data

Observed data for each of 732 drop events at 653 households include the timestamp, arborist, household, location, and money offered to the arborist. Records of all household availability changes in Chip Drop were also obtained, including preferences regarding receipt of woodchips or logs and money offered. A supplementary dataset included information about the hours, fees, and locations of 10 city/commercial dumpsites in the region.

To calculate travel distances, the regional street network, including road type and street direction, was obtained from civicapps.org (*10*). Network routing was performed in ArcGIS (*11*). The street network spanned four counties in the Portland metropolitan region: Clackamas, Multnomah, Yamhill and Washington Counties. The analysis area was defined as the intersection

of a 20 km buffer around the drop locations and a 1 km buffer around the regional street network, to allow for a wide range of possible origins and destinations that can still be mapped onto the street network. The set of all possible O/D was defined as the centers of each cell in a two-kilometer square grid overlaid on the analysis area. The 5,858 sq-km analysis area contains 1,463 grid centers as illustrated in FIGURE 2.

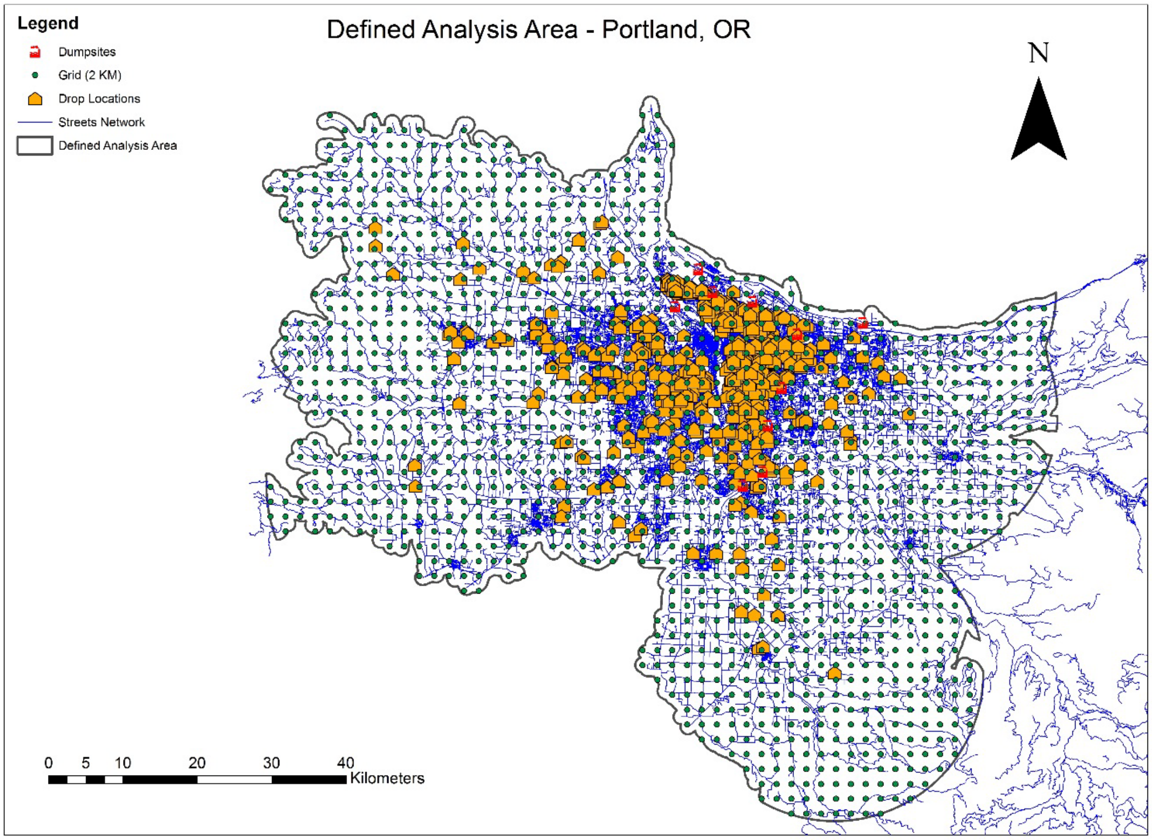

FIGURE 2 Overlay of analysis area, street network, and drop locations

2.3 Calculation of VKT savings

FIGURE 3 illustrates the algorithm to estimate VKT savings. For each observed drop event *(A)*, alternative drop locations are identified *(B)* as households that were available on the map at the same time, with the same preferences for woodchips or logs, offering at least the same amount of money, and at least some threshold distance away from the observed drop location. All O/D pairs in the analysis area are then stepped through *(C)*, and if an O/D pair is identified as plausible *(D)*, the VKT savings are calculated *(E)* as the difference between a drop at the observed location and a drop at the nearest city/commercial dumpsite for that O/D pair. Step C is repeated until all O/D pairs are exhausted, and then the next drop is selected *(A)*.

Arborists are assumed to choose a rational drop location based on consideration of travel distance and monetary cost. Therefore, if the observed drop is dominated by an alternative drop location (longer distance and equal or less money) for a given O/D pair, that O/D pair is considered not plausible *(D)*. This approach is conservative from the perspective of not eliminating O/D pairs, because it allows for any possible travel cost value for the arborist (distance/money trade-off). Alternative households within a threshold distance of the observed drop were excluded to prevent

an essentially equal choice from eliminating an O/D pair. Thresholds of 300-1,000 m were evaluated, with no discernable effect on the results; a threshold of 500 m (approximately five Portland blocks) is used. Due to high computation costs, straight-line distances are used for the plausibility assessment *(D)*, but network distances are used for the VKT savings calculation *(E)*.

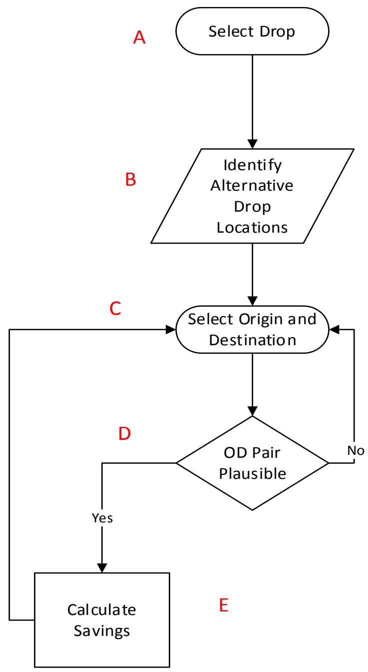

FIGURE 3 Overview of VKT savings calculation method

The algorithm generates a distribution of savings for each drop (one value for each plausible O/D pair). Summary statistics of mean, median, min and max were calculated per drop location. Total savings were calculated in two ways: summing the mean savings and summing the median savings of each drop. Savings were also calculated including city/commercial dumpsites as alternative drop locations, to examine the potential savings if arborist marginal travel costs are high, so that the disposal location choice is dominated by VKT minimization.

2.4 Emissions estimation

Emissions savings are calculated as the product of estimated VKT savings and modeled emissions rates. Applying static emissions rates neglects the effects of varying speed and congestion by route on emissions – a necessary limitation of the study due to the lack of route information.

Running emissions (crankcase, exhaust, brake/tire wear and evaporative) were modeled in MOVES2014a (*12*) to obtain emission rates per VKT for arborist trucks (diesel and gasoline medium heavy duty trucks). The modeled pollutants were carbon dioxide equivalent (CO_2e), oxides of nitrogen (NO_x), carbon monoxide (CO), hydrocarbons (HC), and fine particulates ($PM_{2.5}$). Emissions were modeled for 2016, from 5AM to 7 PM on weekdays, when most drops occurred as shown in FIGURE 4. MOVES default data for Clackamas, Multnomah, Yamhill and Washington Counties were used for meteorology, fuel composition, and inspection and maintenance programs.

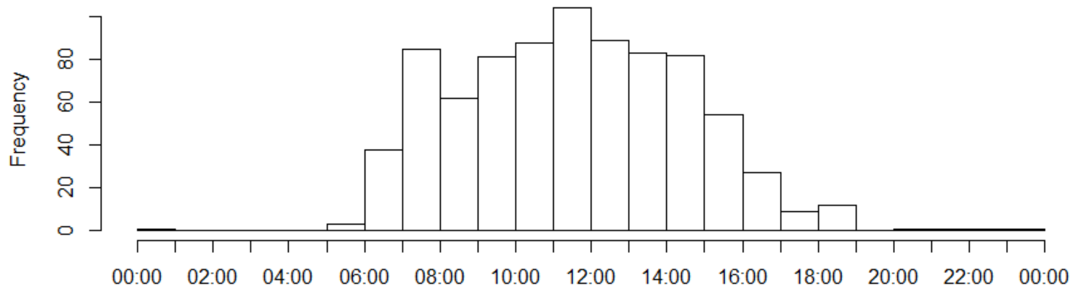

FIGURE 4 Distribution of observed drops per hour of day

To characterize typical arborist trucks, the “chipper trunks” category was searched in the vehicle for-sale listings on Kiji.com and CommercialTruckTrader.com. Gross vehicle weight ratings (GVWR) ranged between 14,000 and 19,500 lb., which falls under class 4 and class 5 trucks (*13*). Of the listed trucks, 78% were diesel and 22% were gasoline, which aligns closely to a 2016 Vehicle Technologies Market Report (*13*) that identifies an 80% diesel share for class 5 trucks. McPherson et al. (*9*) estimated GHG emissions from the arboriculture industry based on the assumption of a diesel-fueled GMC C6500 truck to transport woodchips, which is a class 6 truck (*13*). Arborist trucks can generally be characterized as Light Heavy Duty (LHD45) vehicles (class 4 or 5 trucks) or Medium Heavy Duty Vehicles (MHD67) (class 6 or 7 trucks) according to the regulatory classes in MOVES2014a (*14*), which have GVWR ranging from 14,000 lb. to 33,000 lb. The modeled arborist trucks were defined in MOVES as Single Unit Short-Haul trucks (SourceTypeID =52) which encompasses regulatory classes LHD45 and MHD67 (*14*). The default MOVES age, speed, and VKT distributions by facility type for SourceType 52 for the year 2016 were also used.

3 RESULTS AND DISCUSSION

Aggregating mean savings per drop, the total estimated VKT savings for 732 drops over the three-month period is 2,900 km, with average savings of 3.9 km per drop. Aggregating by medians results in total VKT savings of 2,450 km, or 3.3 km per drop. The results differ slightly because of positive skew in the savings distribution for most drops. Standard deviations average 5.5 km per drop and interquartile ranges average 7.6 km per drop. The VKT savings are on average 6.6% of the total trip distance aggregating by mean and 4.4% aggregating by median.

A previous study (*3*), private data from an arborist company using Chip Drop (*15*), and the mileage data found in the online vehicle listings, all suggest typical annual VKT of 10,000-20,000 km/year/vehicle for arborist trucks. Per-truck savings for full-time use of Chip Drop could then be 600 to 1,200 km/year assuming a 6% travel reduction. These savings could be considered substantial considering the low cost of the measure and likely net monetary benefit to the arborist.

FIGURE 5 shows boxplots of the mean VKT savings per drop, segmented by the money offered by the household. Estimated VKT savings decrease for drops where more money was offered because fewer alternative households were available at the same monetary level and hence a city/commercial dumpsite was more likely to be on a direct route between plausible O/D pairs. Negative savings are observed where city/commercial dumpsites are more direct than observed drop locations for a majority of the plausible O/D pairs. Negative savings are more likely with greater financial incentive to use Chip Drop, because arborists are increasingly likely to be willing to travel out of their way (increase VKT) to obtain the cost savings, depending on their marginal value of travel time.

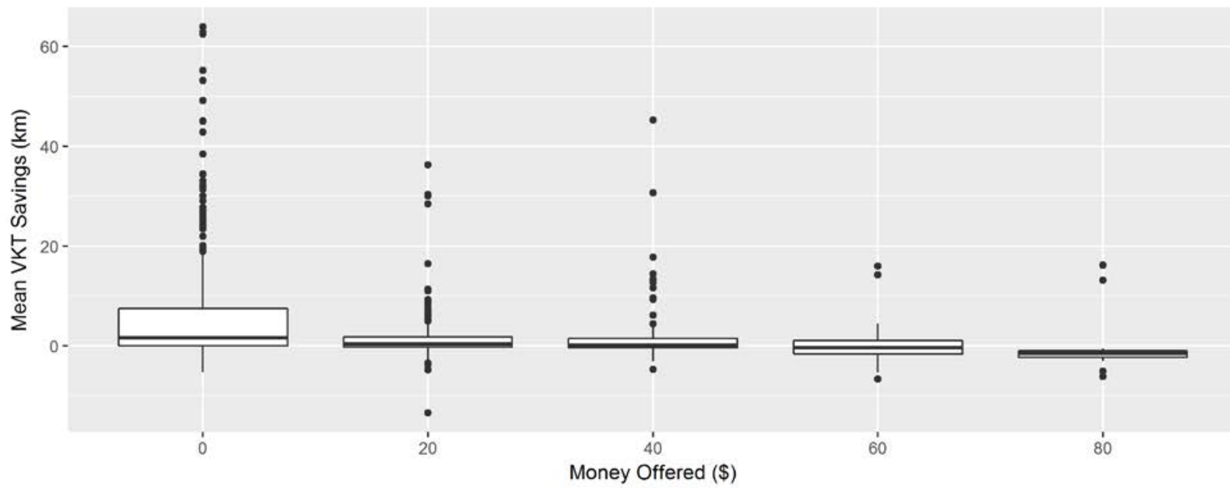

FIGURE 5 Mean VKT savings per drop, segmented by money offered by the household

The money offered for an observed drop affects the quantity and geographic distribution of alternative drop locations. Money offered is inversely correlated to the number of alternative locations (Pearson correlation factor of -0.8), but the geographic distribution of the alternative locations appears to be more important for VKT savings than the quantity. Examining drops with extreme values of VKT savings reveals that the greatest savings are estimated when alternative drop locations are near the city/commercial dumpsites, eliminating as implausible O/D pairs in those areas. VKT savings have a strong positive correlation with the distance between the observed drop location and the nearest city/commercial dumpsite (Pearson correlation factor of 0.9). FIGURE 6 shows the geographic distribution of mean VKT savings in the region. VKT savings increase with distance from the city center where the city/commercial dumpsites are clustered.

Arborist trucks typically carry 3-person crews, with a high value of time and priority for disposing of woodchips and returning to work. Hence, VKT minimization is potentially a dominant incentive in choosing a disposal location. If city/commercial dumpsites are included in the analysis as alternative drop locations for arborists seeking to minimize travel distance, they eliminate O/D pairs with negative savings as implausible. Aggregate mean VKT savings then increase to 4,820 km, or 6.6 km per drop, a travel reduction of 11%.

Modeled emission rates (in g/km) for the arborist trucks are 662 for CO_2e, 5 for CO, 2.2 for NO_x, 0.1 for $PM_{2.5}$, and 0.4 for HC. The modeled CO_2e rate is in line with previous studies of arboricultural GHG emissions using 604-667 g per VKT for chipper box trucks (*3, 9*). Combining the emissions rates with monthly VKT savings of 800-1,600 km, utilization of Chip Drop is estimated to have reduced arborist emissions in Portland by 530-1,060 kg CO_2e, 4-8 kg CO, 1.8-3.5 kg NO_x, 80-160 g $PM_{2.5}$, and 320-640 g HC per month. The mass reductions are modest, but potentially important given the predominance of diesel exhaust as a leading carcinogenic risk factor for residents of Portland (*8*). In addition, the relatively new service has the potential to grow and further increase arborist operational efficiency.

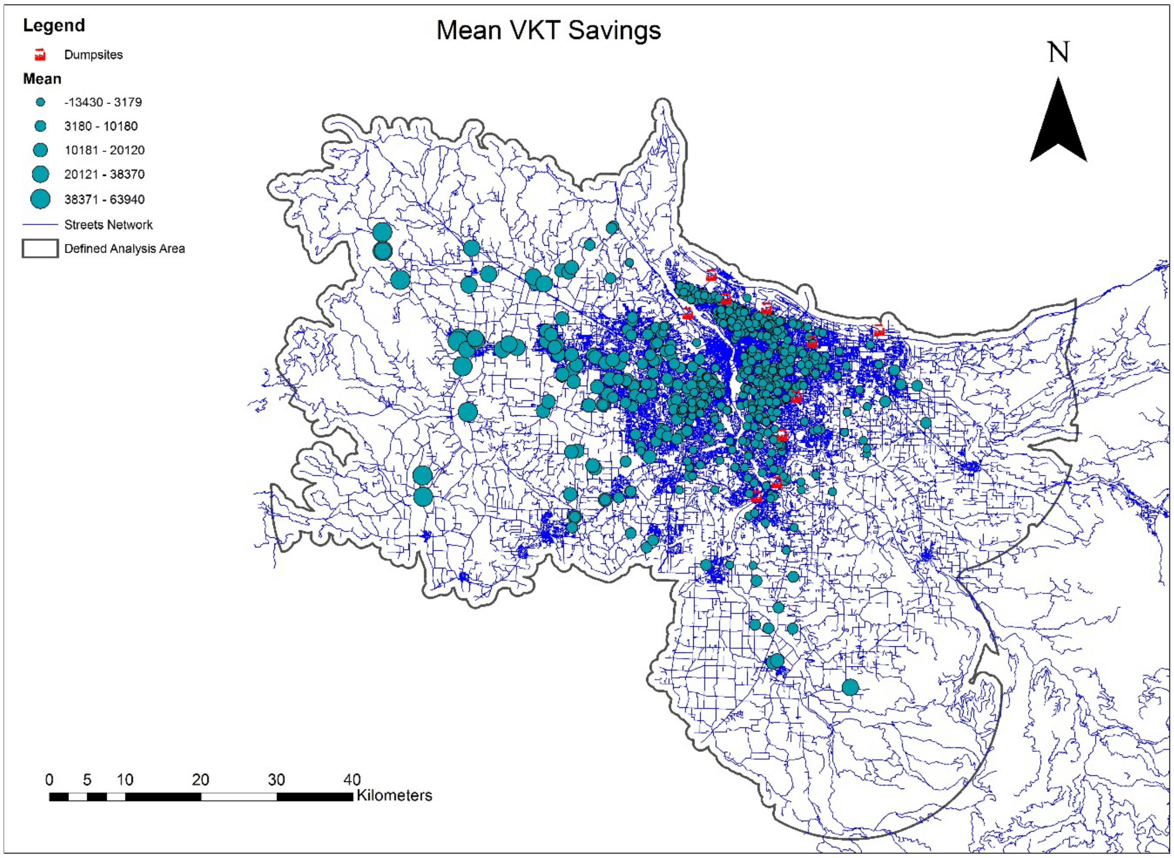

FIGURE 6 Geographic distribution of mean VKT savings per drop (m)

4 CONCLUSION

Through a relatively simple and low-cost ICT solution, Chip Drop is estimated to have modestly increased operational efficiency in urban arborist truck activity in Portland. Providing arborists with a wider geographic distribution of woodchip disposal sites is estimated to have reduced participating arborist truck travel by 4-11% or approximately 400-2,200 km/year/truck, with associated reductions in local and global air pollutants. VKT savings are correlated with the distance between the observed drop locations and the nearest city/commercial dumpsite. Hence, efficiency benefits from using Chip Drop are magnified in situations where arborists are working in peripheral locations far from city dumpsites.

In addition to the estimated travel and emissions reductions through operational improvements, Chip Drop likely provided cost savings to both arborists and homeowners. Thus, it appears to be a “win-win” strategy to be considered for further expansion. A service like this will be most effective at improving operational efficiency in cities with a limited spatial extent of existing city/commercial dumpsites. On the other hand, the emissions reductions are only modest, and this ICT strategy can be only one part in a suite of strategies to improve sustainability in the arboriculture industry.

The main limitation in this study was the lack of origin, destination, and route data for the observed drops. The scenario analysis provided an alternative method to estimate the range of potential effects of the service, but still falls short of a concrete assessment. Shortest-path routing was used for all trips, which does not account for potential effects of congestion on both routing and emissions. Emissions effects of varying truck loads are also excluded, due to unknown

directionality in the trips, even for hypothetical O/D pairs.

The results are time and location specific to summer 2016 in Portland, Oregon. Cities with more urban sprawl and less tree coverage are expected to have longer arborist trips, with potentially greater savings. Cities with more disperse city/commercial dumpsites will likely see smaller savings. The distribution of single-family homes is also important, because high-density urban areas my lack homeowners with potential drop locations.

Ideally, future assessments will include more explicit arborist travel data, although they will likely be difficult to obtain. Arborist surveys would be useful to enable modeling of the disposal location decision. Future work can also incorporate value of time estimates for explicit trade-offs between VKT and dump fees.

5 ACKNOWLEDGEMENTS

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