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COLLABORATIVE FREIGHT TRANSPORTATION TO IMPROVE EFFICIENCY AND SUSTAINABILITY

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Abstract

Collaborative distribution offers the potential for substantial improvements in freight transportation. As collaboration increases, more loads are available for sharing among transportation service providers, leading to more fully loaded trailers that travel fewer miles and reduce the cost per load on average. In this study, we develop approaches to analyze improvements in key performance measures as collaboration increases in freight transportation. For the data sets analyzed, improvements include a 34% increase in trailer fullness, a 29% reduction in average costs per load, and a 25% decrease in average miles per load. Based on this analysis, collaboration provides substantial improvements for transportation service providers and opportunities for increased driver retention. Drivers would benefit from a better quality of life, more local routes, and more time home with their families. In addition to the economic and social benefits, the environmental benefits include reducing the miles driven and the resulting CO_2 emissions.

1 Introduction

Within the transportation sector, trucks transport approximately 72% of the total value of freight in the U.S. [1]. The three primary logistics modes employed today for truck-based freight transportation include: (1) private fleets that deliver loads and then generally return empty; (2) full truckload carriers that try to construct routes that link loads, but generally dispatch drivers for weeks at a time; or (3) less-than-truckload (LTL) carriers who ship through their private hub-and-spoke network.

For these modes combined there was a total of 8.96B tons of freight transported by truck [2] over a total of 145B miles in the U.S. [1].

Although the majority of freight distribution is by truck, transporting freight by truck is particularly inefficient. As illustrated in Figure 1, approximately 25% of the miles traveled were with completely or nearly empty trailers and the remaining 75% were only 56.8% full on average, resulting in a blended fullness of 42.6% [2]. This highlights two main inefficiencies of freight transportation: trailers travel without a load 25% of the time and even when loaded, they are not full. Another major issue facing the industry is that long-haul truck drivers have a turnover rate of nearly 100% [3].

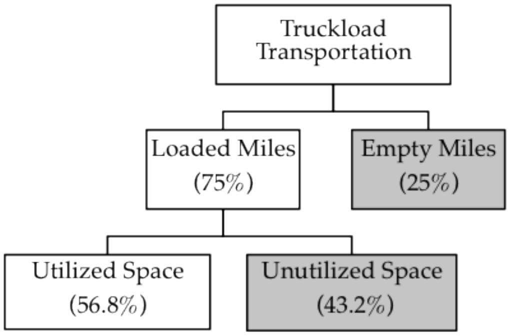

Figure 1: Breakdown of Blended Trailer Fullness.

In recent research, Montreuil [4, 5] described the Global Logistics Sustainability Grand Challenge as enabling the global sustainability of physical object mobility, storage, realization, supply and usage. Concluding that this goal is not achievable with the current logistics system, he described the Physical Internet (PI) as a new paradigm to achieve the grand challenge. The PI is conceptualized as a transformative, open, and global logistics system founded on physical, digital, and operational interconnectivity through encapsulation, interfaces and protocols. The aim of the PI is to enable an efficient and sustainable logistics web [5].

With the backdrop of the PI, the objective of this research is to evaluate potential logistics gains of a collaborative freight transportation system [6]. We investigate the potential improvements in for key performance measures such as total miles, shipment costs, trailer fullness, and driver turnover as collaboration and adoption of the PI increases. To demonstrate the potential logistic system gains achievable through collaboration in the PI, the following questions are addressed: (1) what are the effects on total transportation costs, distances, and the fullness of trailers as collaboration increases? (2) as loads progress through the system, what is the effect on the number of load transfers? (3) as we increase the requirement to return drivers to their domiciles more frequently, what is the effect on costs and driver retention?

2 Load Planning Problem Description

The adoption of the PI increases collaborative freight opportunities for transportation service providers (TSPs) and increases the opportunity to return drivers to their domicile more frequently, while reducing empty back hauls. As shown in Figure 2, the PI aims to transform the current fragmented logistics system, composed of independent providers with limited visibility of loads, into an interconnected and open network, with visibility of available freight shipments.

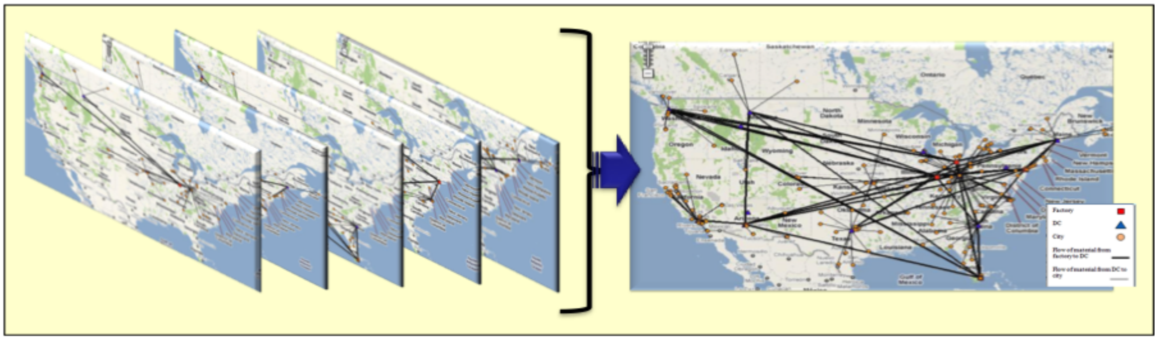

Figure 2: Illustration of an Interconnected Network with the PI.

With collaboration among TSPs, opportunities emerge for co-loading of shipments, continuous move routes, and relay networks. With co-loading, shipments that require less than full capacity and have origins and destinations that are in close proximity are combined. With continuous move routing, multiple pick-ups and deliveries are coordinated to create a continuous route for a trailer. In a relay network, a load may be transferred between drivers at transfer nodes until the load reaches its destination. The concept of relay networks is further illustrated in [7]. The use of these collaborative distribution opportunities can increase overall supply chain efficiency. Nestle and Mars utilized co-loading to reduce miles. In just three of their peak months, the two companies were able to combine over 60 shipments and eliminate over 7,500 miles [8]. Colgate also utilized collaborative distribution opportunities within its own supply chain network to eliminate over 1.8 million line haul miles [9].

To evaluate the potential benefits of collaboration, a mixed-integer model was formulated to capture the network flow and resource sharing characteristics of the load planning problem. Given the complexity of the problem, a two-phase solution approach was developed to evaluate industry representative data sets.

3 Load Planning Solution Apporach

To capture the characteristics of the load planning problem, a mixed-integer programming model was formulated. Given a set of loads, a set of nodes, a set of arcs

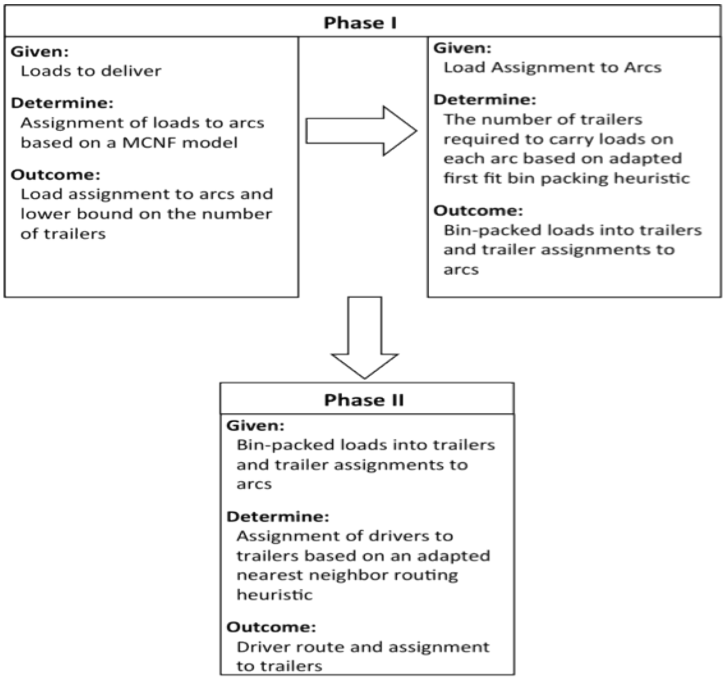

Figure 3: Solution Apporach Overview.

linking nodes, and a set of potential resources (trailers as well as drivers), the model determines the flow of loads on the arcs, the assignment of loads to trailers, the flow of trailers on arcs, and the assignment of drivers to trailers. The objective is to minimize the costs of transporting the loads, transferring the loads at nodes, and utilizing trailers and drivers. The constraints for the model ensure that all loads are transported and driver time away from domicile is not exceeded. For this analysis, we assume that a fair and competitive pricing structure is in place for participants, transfer costs at a hub or distribution center are independent of the load, and fuel consumption and carbon emissions are proportional to miles driven. In addition, liability and negligence are not considered. The goal is to determine the preferred routes and transfer points for loads, the resource levels required for trailers and drivers, and the assignment of loads to trailer and drivers. Given space limitations, the model is not presented, but can be found in Roesch et al. [10].

Due to the general size and difficulty of solving industry-representative problems, a two-phase heuristic approach is developed and employed to solve the model. As shown in Figure 3, Phase I addresses the assignment of loads to trailers on arcs, and Phase II assigns drivers to transport trailers.

Using an adapted network flow approach [11], Phase I assigns loads to arcs and provides a lower bound on the number of trailers required. The approach assumes a cost to travel the arc, a cost for a container to travel an arc, a cost to transfer a load at a node, but does not require the assignment of loads to specific trailers as they may be split across trailers. Next, the number of trailers actually needed to transport the loads across the arcs is determined. An adapted fit-first, bin-packing heuristic is employed to assign loads to trailers based on the space available.

Given the load and trailer assignments from Phase I, Phase II assigns drivers to trailers, which considers the cost of using a driver on an arc and ensuring that drivers return to a base node after service. The problem has an underlying structure similar to vehicle routing problems with simultaneous pick-up and delivery (VRPPD) [12, 13] because goods can be picked up and dropped off at the same time. With our problem, however, vehicles start and end at a base node , rather than a central depot. The problem also has similarities to the general pick-up and delivery problem in [14]. The approaches for these similar problems provide a strong framework for our solution approach, which is based on an adapted nearest neighbor heuristic. Drivers are assigned to transport a trailer to the closest destination from their current node that has a trailer assigned to go there assuming they have sufficient driving time to travel there and still return to their base node.

4 Case Study Overview

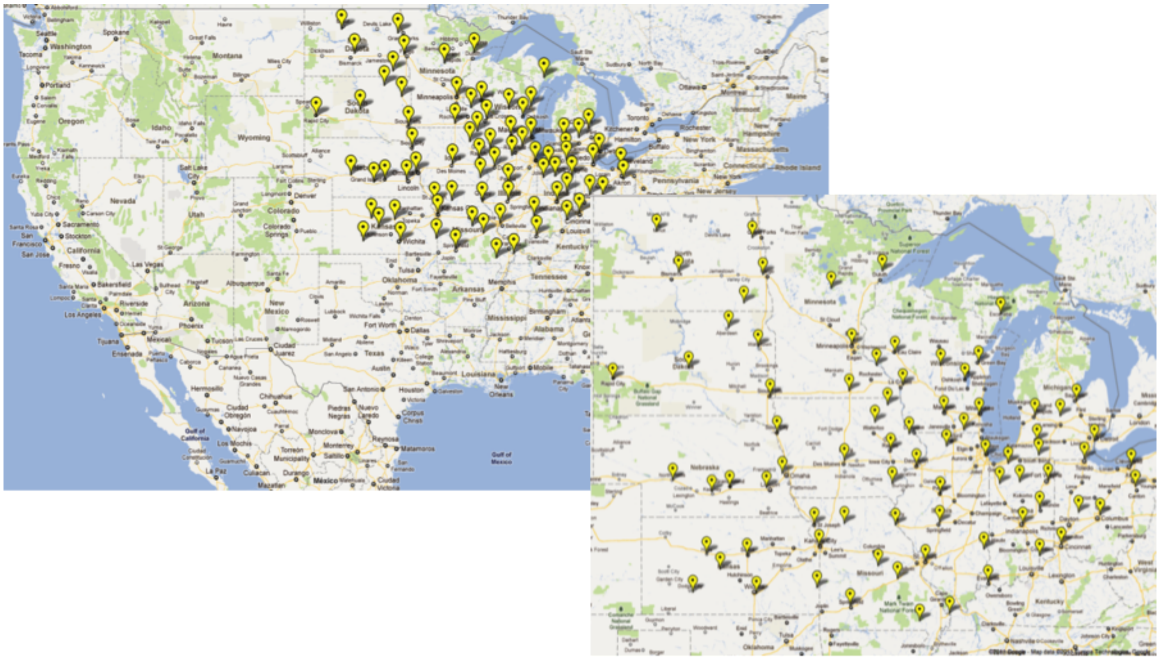

Figure 4: Cities Considered in the Midwestern Data Set.

The potential gains from the implementation the PI were evaluated using a representative sample of yearly load bids provided by a leading transportation service provider for the Midwestern United States. As illustrated in Figure 4, the data set included 78 cities, 23,000 shipments, and 510 unique origin-destination pairs. For this analysis, a shipment is considered to be a load traveling between an origin and destination that occupies 25%, 50%, 75%, or 100% of a trailers capacity. The cost of shipping a load is \$1.50 per mile [15], and the cost to load a shipment on a trailer at a hub or distribution center is \$25 per shipment per transfer. The transfer cost is incurred when a shipment passes through a node that is not its origin or destination. All nodes can serve as an origin, destination, or a transshipment point, and each facility at a node is assumed to have sufficient capacity to process shipments. Trailers are all assumed to be interchangeable and have the same capacity. Drivers have base nodes from which they must depart from as well as return. The estimated costs for driver turnover range from \$2,000 to \$21,000, with around \$8,000 often used as an average [9].

The data set provided a yearly volume estimate, and daily demands were extracted based on this aggregate estimate to form data sets comprised of one, two, three, four, or 10 days of loads. Each data set was then further decomposed into random 5%, 25%, 50%, 75%, and 100% samples of the loads to represent the adoption level of the PI (the percent of loads that are available for collaboration). Multiple instances of each percentage for a given day (or days) were evaluated, and then the outputs from the runs were averaged for this analysis.

5 Results

As the adoption of the PI increases, more loads are available for sharing. This leads to the opportunity for more fully loaded trailers that travel fewer miles, thus reducing the average cost per load.

In fact, the model results suggest substantial improvements in blended fullness and substantial reductions in total miles required to transport a set of freight, where loaded, partially loaded, and empty miles are all considered in estimating total miles. As shown in Figure 5, with 25% adoption of the PI, blended fullness increases from 42% to 64%, a 34% increase. One benefit of trailers that are more full is the reduction of total miles needed to transport loads. Whereas some shipments may end up traveling farther than they currently travel, on an aggregate level, fewer trips and resources required reduce the total number of miles. At 25% adoption, miles are reduced by 25% from 475 miles to 355 miles per load on average, eliminating more than 230,000 total miles out of 910,000 miles from the road.

With the combination of more full trailers and fewer total miles, the cost per load decreases as adoption in the PI increases. As shown in Figure 6, at 25% adoption, the cost per load is \$540, which is 29% less than our estimate of \$760 for current state. In addition, the results suggest that substantial gains are available with relatively low adoption. All of these improvements to the freight transportation system are a direct result of collaboration achieved though the adoption of the PI.

As collaboration increases, transportation service providers have access to addi-

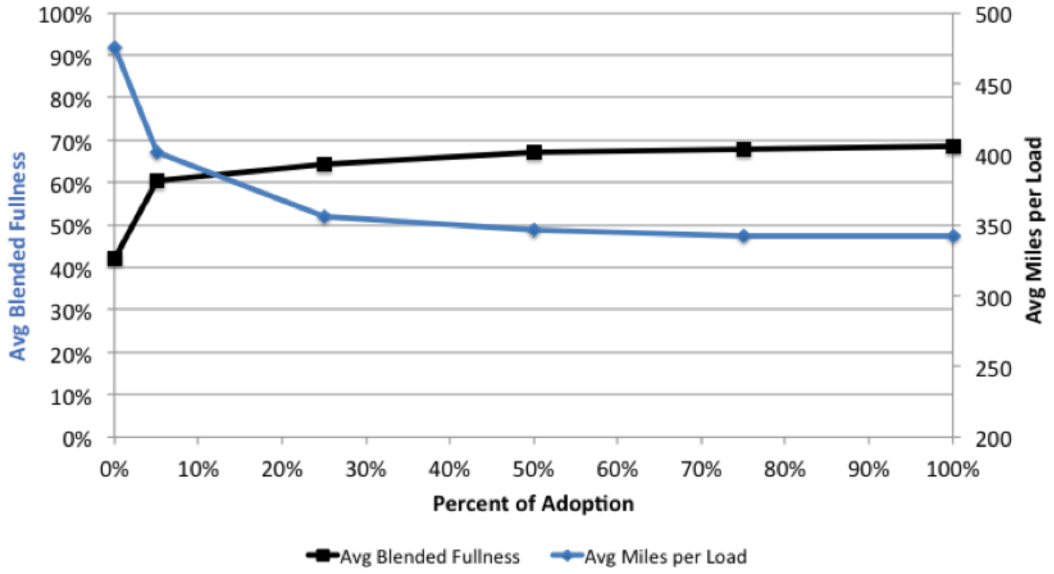

Figure 5: Average Blended Fullness and Miles per Load as PI Adoption Increases.

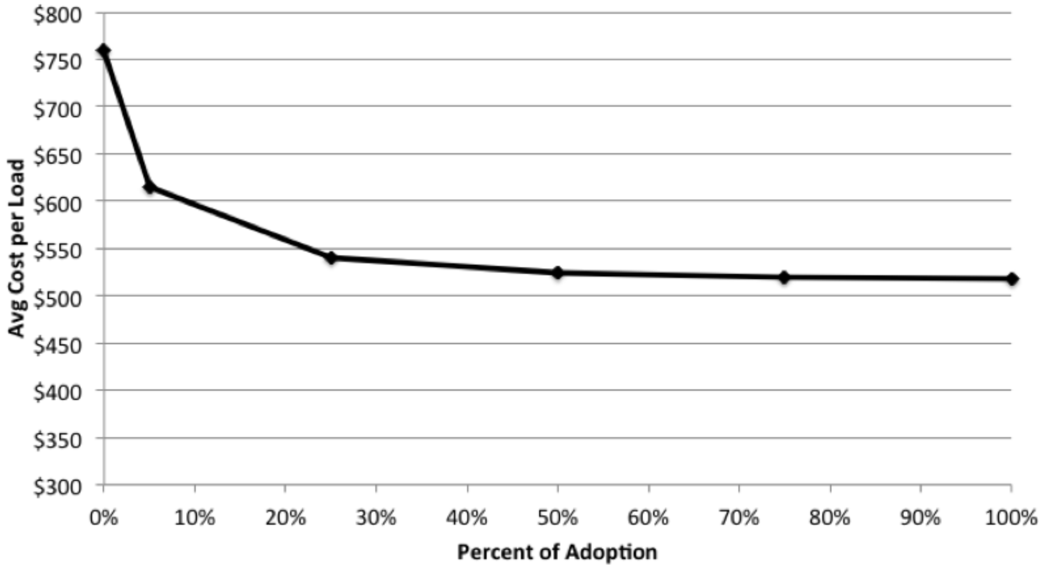

Figure 6: Cost per Load as PI Adoption Increases.

tional loads that may be closer in proximity. With current driver rules and restrictions, long-haul truck drivers often remain out for long periods of time, as much as one to two weeks at a time. This leads to a turnover rate that is currently around 90% [3] and during good economic periods has been as high as 200%. On the other hand, LTL drivers, who tend to return to their domicile every day, have turnover rates around 8% [3]. Driver turnover can be thought of as a function of time away from domicile as illustrated in Figure 7. The theory then is that as drivers are away or more than one day there is a significant increase in effort; therefore, a sharp increase in the turnover rate from one to two days away. Then, as drivers are away between 3 to 4 days this increase in turnover is less sharp as the initial impact of being away for a day has been incurred and each additional day to a point does not fundamentally increase this impact. However, as the average time away increases to 5 days there again would be a large impact and turnover would rise again steeply. This rate would continue through two weeks away, at which point we estimate the turnover rate as 100%, which approximates the current turnover rate of truckload drivers.

Our solution approach was modified to enforce that drivers return to their domicile within a given number of days (ranging from 1 to 10 days) to evaluate the total cost of transporting freight under various constraints. We found that returning drivers to their domicile every two days in a PI would have a similar cost to todays system.

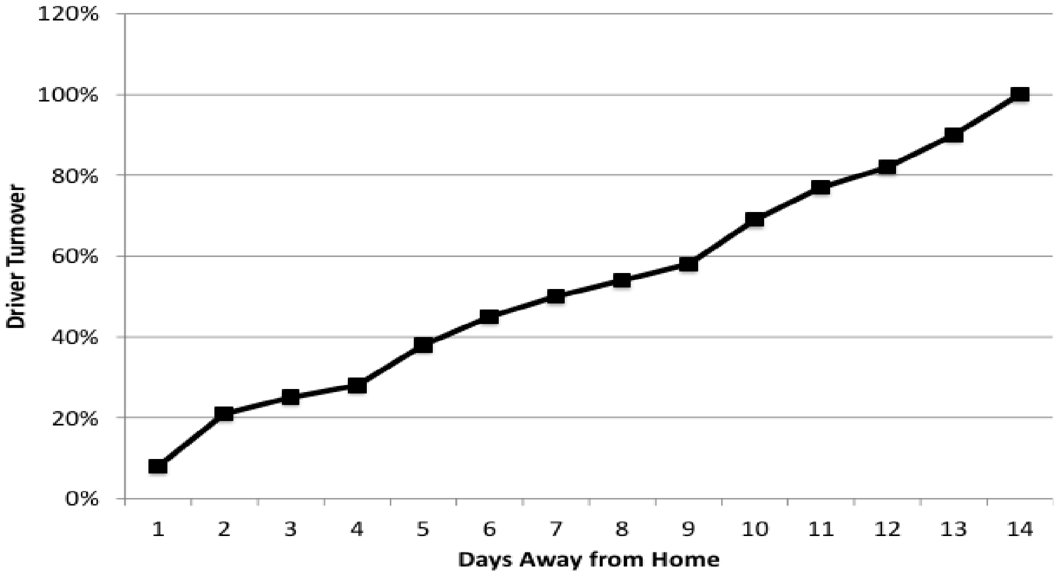

Figure 7: Assumed Turnover Percentage for Days Away from Home.

As adoption in the PI increases, drivers have access to loads in closer proximity to their domicile. Thus, it becomes less costly to return drivers to their domicile more frequently. The average cost per load as a function of PI adoption rates and days away from domicile for drivers is illustrated in Figure 8. With an average driver turnover cost of $8,234 and 25% adoption, the results suggest that drivers could return home as often as every two to four days at less costs than the current state. At the same time, estimated driver turnover is reduced from 100% to approximately 25%. As the adoption rate increases, the cost of returning drivers to their domicile more frequently decreases and the incremental cost to return drivers to their domicile more frequently decreases as well. As shown in Figure 8, however, there is still motivation for transportation service providers to design 10 day tours for their drivers (where this represents the lowest cost on the graph for 25% adoption).

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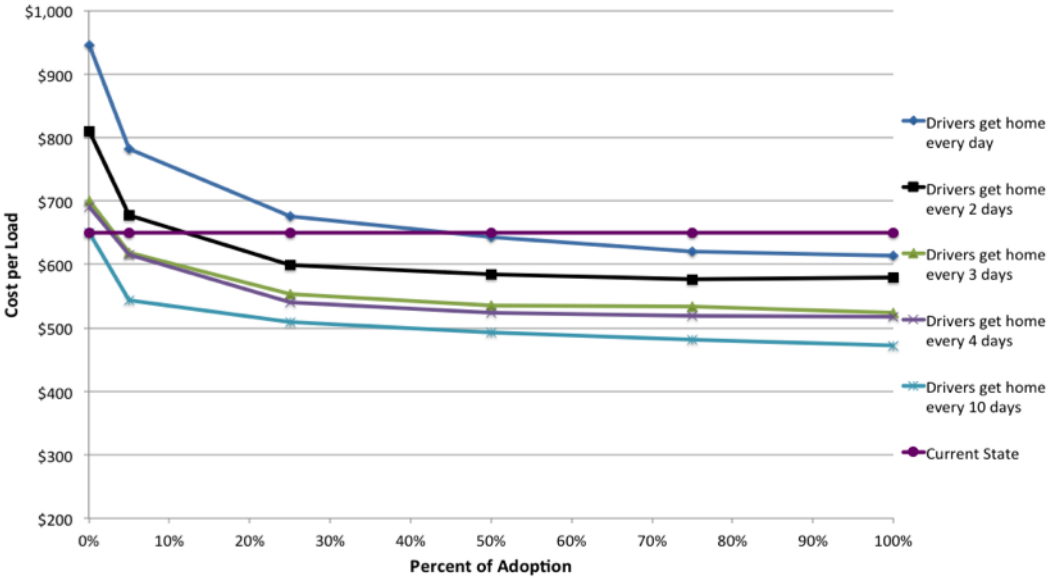

Figure 8: Cost per Load vs. Days Away from Home as Adoption in the PI Increases.

We also evaluated the sensitivity of these costs to the driver turnover costs. For 25% adoption, we evaluated the cost per load for turnover costs of $2,000, $8,234, and $21,000, as shown in Figure 9. As drivers return to their domiciles more frequently and turnover rate decreases, the cost per load is less sensitive to fluctuations in the turnover costs. For example, as turnover costs increase from $2,000 to $21,000 per turnover event, the average cost per load increases only $15 (from $582 to $597 per load) when a driver is away for two days whereas the average cost per load increases $36 when a driver is away for 10 days.

6 Conclusions

The Physical Internet offers the potential for substantial freight transportation improvements not only at full adoption, but also while collaboration is beginning and growing. For the data sets analyzed, improvements include a 34% increase in trailer fullness and a 29% reduction in average costs per load at 25% adoption. In addition, the total miles per load decreased by 25% on average.

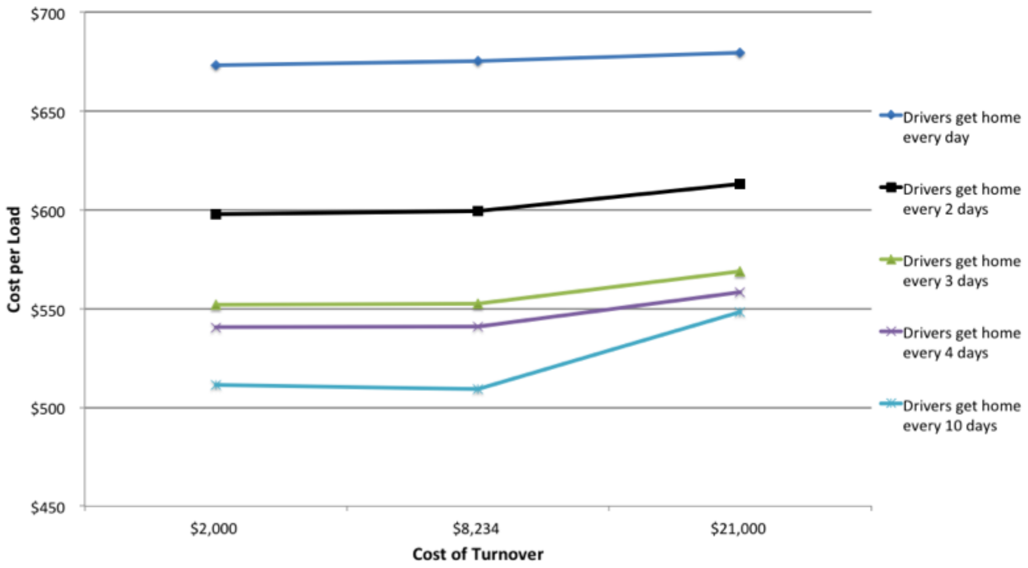

Figure 9: Cost per Load as Turnover Cost Changes at 25% Adoption.

The PI provides potential solutions for some of the major problems in the current freight distribution system. Based on this and related analyses [16], the PI provides transportation savings for transportation service providers and opportunities for increased driver retention. Drivers would benefit from a better quality of life, more local routes, and more time home with their families. In addition to the economic and social benefits, the environmental benefits include reducing the miles driven and the resulting CO_2 emissions. Based on discussions with our industry partners, a reasonable next step is to conduct pilot studies to evaluate the PI in action.

Acknowledgements

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