

Supplementary Information: Impact of automation on long haul trucking operator- hours in the United States

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1 Study limitations

We note several limitations of our analysis. First, operators may not be taking routes that are suggested by Google Maps. In fact our interviews with operators revealed that they use trucking specific routing applications or plan their journey using the well known trucking road atlas. However, the operators did confirm that in most cases those routes are the same as those suggested by Google Maps which indicates that the loss in accuracy from this approximation in estimating routes and operator-hours is likely to be low.

Second, we assume that operator rest hours needed as per hour of service (HOS) requirements may be part of either highway or urban operator-hours depending on the route. In reality, it's highly likely that operators plan their route and breaks in such a way that they avoid rest stops near urban areas because rest areas may be more easily found away from urban areas. Operators are also more likely to plan their journey in such a way that the final stretch of driving towards the very end of the route into an urban area does not require an additional rest period. Our algorithm may therefore be overestimating the urban operator-hours. We therefore run a sensitivity analysis with all rest hours assigned to highway operator-hours. The results do not differ significantly from the results presented in the paper - the at risk share of operator-hours in the widespread deployment scenario increases from 94% to 95% as a result of this change.

Third, while our described model of AT shown in Figure 1 in the main manuscript text involves urban driving at the start and end of the journey, our routing method simply assigns urban and highway driving time on the basis of recorded average speeds through the journey. Therefore,

highway to highway exit ramps for example may be counted as urban driving as it is below 50mph but in reality is a part of the highway leg. On the other hand it is also possible that some of the more involved highway to highway exits may not be automated in the near future and truck ports may be set up near such exits to facilitate transfers which require human operation. In such a scenario our routing methods would correctly assign these hours to human operators. It is therefore unclear in which direction this would impact our results but we note that the share of routes that have such involved maneuvers is likely to be low.

Fourth, our limited sample of trucking operators who we interviewed is biased towards more experienced, established truckers who have been in the industry for several years. Their views may not be representative of new operators joining the workforce who make up different demographics compared to older operators [1]. As we noted in the paper, new drivers may prefer short haul jobs for their urban locations and the fact that they do not require long stretches of time away from home. We believe that the propositions that we put forward in the paper merit further research.

Lastly, while we incorporate daily HOS requirements in our estimates of highway and urban operator-hours, we do not incorporate weekly HOS requirements. These are applicable to drivers not routes as there are no routes which require more than 60 hours of driving in the CFS dataset. As such it is not possible to model this using our methods. Qualitatively one can see that enforcing weekly rest requirements will further increase operator-hours required to complete shipments and therefore further increase the share of operator-hours at risk if those rest hours are part of highway driving.

2 Financial analysis of deployment of automation

Roland Berger [2] estimates that automated trucks will cost around USD 23,400 more compared to conventional trucks available today. Automated trucks will not be bound by hour of service requirements and therefore will only need to stop for fuel and maintenance. If we assume a 50% increased utilization [3], automated trucks would travel 165,000 miles per year compared to the current human average of 110,000 miles.

We assume a 10% interest rate given private investment. Long haul trucks complete most of their service within the first 5 years after purchase so we apply a 5 year lifetime. Using these parameters and applying the capital recovery factor to the capital cost of the automated system, the per mile cost of the automated system comes to 4 cents per mile.

Long haul truck drivers currently earn a wage of roughly 50 cents per mile [4]. Deployment of an automated truck for the highway leg will save the labor cost on the highway but incur a labor cost at the truck ports as well as for human operation to complete both urban legs.

Let c_O and c_A be the respective total per mile cost of human trucking as currently used and for an automated system deployed using a transfer hub model. Let the shipment distance be D . Further we assume that highway miles are 90% of the total shipment distance.

Then,

$$c_A = 0.04 * (D * 0.9) + 0.5 * (D * 0.1) + 15 * 2 \quad (1)$$

where the cost of automated trucking includes the per mile cost of the automated system multiplied by the highway distance, the cost of human operation of the urban leg, and finally the cost of an assumed 1 hour of labor at each of the two truck ports required for switching trailers at an assumed wage rate of \$15 per hour.

The cost of human driven operation instead is simply the long haul wage rate multiplied by the shipment distance:

$$c_O = 0.50 * D \quad (2)$$

For $c_A \leq c_O$ we have,

$$0.04 * (D * 0.9) + 0.5 * (D * 0.1) + 15 * 2 - 0.50 * D \leq 0 \quad (3)$$

or,

$$D \geq 75 \quad (4)$$

Automation can therefore make financial sense at even very short distances. Note that this analysis does not include the cost of land near highways that will be required for transfer hubs. On a per mile basis that cost would likely be low. Finally, the 2 hours lost at both ends for switching trailers and deploying the automated truck would likely not make sense if the human driver could simply complete the journey in one day without stopping. Given that human drivers can comfortably complete 500 miles in one day driving at average speeds of 50mph, this may represent a more

realistic threshold for automation in the near-medium term despite financial motivations at shorter distances.

3 Results for additional deployment scenarios

Table S1 summarizes results for additional deployment scenarios not shown in the main paper text.

Supplementary Table 1: Additional deployment scenarios and share of operator-hours impacted

Scenario	Share of Operator-hours at risk (%)
All non-Hazardous shipments	87%
All shipments over 250 miles	87%
All shipments over 1000 miles	48%

For instance, we consider the deployment of automation on highways for all shipments that do not involve hazardous materials. The CFS dataset provides a code for identifying hazardous material shipments which allows us to subset only non hazardous shipments. Second, we consider different distances which may make financial and logistical motivations for automation. Currently routes over 1000 miles usually involve two drivers driving in rotation and these trips may be automated due to the labor savings. We also consider automation for trips as short as 250 miles for further insight. Results for 500 miles and above were presented in the main paper.

4 Employment at truck stops

Automation of highway driving may mean truck stops are frequented much less than before. Over time this could lead to truck stops no longer being required on the highways. If we assume employees at truck stops work 40 hours a week for 50 paid weeks in a year, that translates to total operator-hours at truck stops (TS) of:

$$TS_{o-h} = N * 40 * 50 \quad (5)$$

where N is the number of employees at truck stops.

We compiled a list of major truck stop operators and their number of employees in Table S2 below to arrive at a first order estimate of the number of employees (N) who may be impacted by automation of highway driving.

Would employment at truck ports make up for the impact on truck stop employment? Through our analysis of shipment data presented in the main paper text, we collected on the number of trips for each origin-destination pair, assuming fully loaded semi trucks. We assume one hour of labor is required at each truck port for switching trailers from the human/automated prime mover to the other and for possible final safety checks on the automated truck prior to deployment on the highway. Combining this with the number of trips gives us an estimate of the number of operator hours required for operation of truck ports (TP).

Supplementary Table 2: List of truck stop owners and employees

Number	Owner	Employees	Reference
1	Travelcenters of America	13,150	[5]
2	Bowlin	185	[6]
3	Loves	27,000	[7]
4	Road Ranger	1,603	[8]
5	Roady's	45	[9]
6	Town Pump	1,800	[10]
7	Pilot Flying J	26,696	[11]
	Total (approx)	70,000	

$$TP_{o-h,i} = n_i * 2 \quad (6)$$

where n is the number of trips for origin-destination pair i and 2 is the total number of hours required which include one at year truck port. Then for the total truck port operator hours across all shipments we have:

$$TP_{o-h} = 2 * \sum_{i=1}^I n_i \quad (7)$$

where $i=1$ to I is across all origin-destination pairs in the the CFS dataset. Combining equation (5) with Table S2 and equation (7) with CFS data we get:

$$TP_{o-h} = 1.7 * TS_{o-h} \quad (8)$$

Therefore, our brief analysis shows that it is possible that the jobs created at truck ports more than make up for the operator-hours lost at truck stops on the highway. Note that it's also likely that some maintenance may shift to truck ports from truck stops and such workers will be retained.

We caution that the results presented here are only meant as a brief structure of how to analyze employment shifts in sectors related to long-haul trucking. Further research on these impacts is required.

5 References

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