OPERATING ECONOMICS OF AUTONOMOUS LONG-HAUL TRUCKS

Dale Lewis
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What private dollars are in play? What are the public impacts? What is the cost impact on delivered retail goods?

How would it work? Is there a range of reasonable operating assumptions under which autonomous trucks are economically feasible?

- Assumption 1: Levels 1 & 2 (Driver Assist) happens soon
- Assumption 2: Level 4 (Autonomous Linehaul) several years later

Where would you start? Private fleet? For hire?

Is there enough lane-specific freight available to make the economic case for several thousand automated trucks?

Are the private economics so strong that we should work through the public safety, emissions, infrastructure and regulatory issues?
AUTONOMOUS TRUCKS COULD OPERATE IN A “TERMINAL TO TERMINAL” MODEL

Existing Trucks Provide Direct Door to Door Service
& Usually Set the Maximum Revenue Available

Autonomous Trucks Could Operate in a “Terminal to Terminal” Model

Existing Intermodal Rail Linehaul
Crew Change Points

Origin Terminal

Dest. Terminal

Drayage Truck

Existing Trucks Provide Direct Door to Door Service

Shipper

Receiver

Drayage Truck

City Driver

The “city driver” could provide his own drayage truck, or could drive the “autonomous” vehicle.

The following examples assume the city driver will operate the autonomous vehicle.

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There are both big positives and big challenges.

**Private Gains**
- Avoided Linehaul Driver Pay
- More Operating Hours per Day
- More Operating Days per Year
- Improved Fuel Efficiency
- Increased Ratio of Loaded Miles
- Lower Costs of Insurance / Risk

**Public Impacts**
- Reduced Transportation Compensation
- Reduced Highway Maintenance Funds
- Potential Mode-Shift Emissions Increases
- Additional Safety Infrastructure Needs
- Small Consumer Cost Reductions
- New Regulatory Framework Needed
AVOIDING OPERATING PAYROLLS WOULD HAVE A MAJOR IMPACT ON COSTS

Mid-Range Assumptions

**Truck & Route:**
- $150,000 Truck (Level 0)
- $3.00/Gal Diesel
- 7.2 MPG
- 70% Loaded Miles
- 119,000 Miles/Year
- 800,000 Mile Limit
- 6.8 Year Truck Life
- $0.06 / Mile Insurance

**Driver Pay:**
- $50,000 per year
- 270 Days in service
- 2,100 On Duty Hrs/Yr
- 14 Hour Days
- 11 Hours Driving
- 1 Hour Rest
- 10 Hours Sleep

These illustrations use a set of generic starting assumptions. Driver Pay Scale, Terminal Dwell Time, Insurance Costs, Freight Available and other factors vary widely across routes. Actual costs are route-specific for each carrier.

This shows ONLY the impact of eliminating driver pay, but not the new associated capital and operating costs.

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HOS AND ROUTING CHANGES CAN DRIVE UP PRODUCTION PER TRUCK

Estimated $ per Load

With no driver in the cab, trucks can operate more hours per day and more days per year. The loaded mile ratio can improve, since route planning does not have to return the vehicle to the driver’s home terminal. This example illustrates a near-maximum benefit case.

Mid-Range Assumptions

**Truck & Route:**
- $150,000 Truck
- $3.00/Gal Diesel
- 8.2 MPG
- 75% Loaded Miles
- 426,000 Miles/Year
- 800,000 Mile Limit
- 1.9 Year Truck Life
- $0.04 /Mile Insurance

**Driver Pay:**
- $50,000 per year
- 350 Days in service
- 20 Hour Days
- 20 Hours Driving
  - 0 Hour Rest
  - 0 Hours Sleep

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INITIALLY, THE TECHNOLOGY WOULD SUPPORT TODAY’S DRIVERS

Technology dollars are invested first. Benefits come later, as operations improve. In particular, future insurance cost changes will depend on driver and fleet-specific performance.

This illustration assumes that the L4 level of technology has a $40,000 capital cost. Cost per load would be higher than today until the operating benefits are realized.

### Mid-Range Assumptions

**Truck & Route:**
- $190,000 Truck (L4)
- $3.00/Gal Diesel
- 7.2 MPG
- 70% Loaded Miles
- 119,000 Miles/Year
- 800,000 Mile Limit
- 6.8 Year Truck Life
- $0.06 / Mile Insurance

**Driver Pay:**
- $50,000 per year
- 270 Days in service
- 2,100 On Duty Hrs/Yr
- 14 Hour Days
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- 10 Hours Sleep

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Platooning Approved @ 40Ft

DBL Note: Peloton’s system (Level 1) identifies potential platoon partners, who then talk by radio and agree to work together.

https://peloton-tech.com/multimedia/
PLATOONING IS ONE TECHNOLOGY STEP

DBL Note: Platoon operation reduces total wind resistance and improves fuel mileage for both trucks. Drivers still steer their trucks.

https://peloton-tech.com/multimedia/
PLATOONING IS ONE TECHNOLOGY STEP

DBL Note: The following truck’s braking system is wirelessly coupled to the lead truck, so both trucks apply brakes at the same time.

https://peloton-tech.com/multimedia/
FUEL & INSURANCE COST REDUCTIONS COULD OFFSET LARGE TECHNOLOGY COSTS

Mid-Range Assumptions

**Truck & Route:**
- $190,000 Truck (L4)
- $3.00/Gal Diesel
- **8.2 MPG** (1 MPG Better)
- 70% Loaded Miles
- 119,000 Miles/Year
- 800,000 Mile Limit
- 6.8 Year Truck Life
- **$0.02/Mile Ins Savings**

**Driver Pay:**
- $50,000 per year
- 270 Days in service
- 2,100 On Duty Hrs/Yr
- 14 Hour Days
- 11 Hours Driving
- 1 Hour Rest
- 10 Hours Sleep

In this scenario, the driver is still in the cab, but the full L4 package has been installed. Saving 1 MPG and $0.02/Mile Insurance cost generates enough benefit to break even. This could help fund extensive L4 test miles with driver in cab.
AUTONOMOUS OPERATIONS COULD BE SUPPORTED BY CITY DRIVERS

This view includes:
All benefits from HOS changes, fuel use, improved empty ratio and lower insurance costs.

This view adds:
- $200 “City Drivers” for each load
- $50,000 per year Linehaul Monitors, who provide remote oversight of the move on the line of road (each monitor observes 3 loads)

In this scenario, there is no line-haul driver in the cab. Transition terminals would be located near towns, where city drivers would take over driving duties. At 2 trips per day, this would be a very good job.
CAPITAL CHARGES AND VEHICLE TAXES COULD HELP OFFSET PUBLIC IMPACTS

This view adds:
- A $0.24 per gallon fuel tax
- A one-time $25,000 capital charge per truck

Note: A “$ per Ton Mile” tax could be used instead of a fuel tax.

These funds could be used to:
- Create spatial or temporal separation between cars and trucks
- Create incentives intended to lower carbon footprint
- Reduce the funding gap on failing infrastructure

These examples are not proposals. They serve to illustrate that some part of the private benefits could be allocated to fund resolution of public issues.
Transportation Payroll Impact:
Total operating dollars decline.
TOTAL “OPERATING PAY” PER LOAD WOULD GO DOWN WITH L4 AUTOMATION

$25 per Hour
Linehaul Remote Monitor

$200/Load
City Driver

City Driver
$ + Linehaul Monitor $ per Trip
(3 Linehaul Trucks per Monitor)

Loaded Miles per Trip (70% LD Ratio)

“Operating Pay” per load using city drivers at $200 per load, along with a linehaul monitor being paid $25 per hour, watching 3 trucks.
POTENTIAL LOADS: INTERMODAL CONVERSION?
EXISTING INTERMODAL FREIGHT IS ONE POTENTIAL SOURCE OF VOLUME

U.S. Intermodal Moves Handled (M)

<table>
<thead>
<tr>
<th>Railroad</th>
<th>2016</th>
<th>2017</th>
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</thead>
<tbody>
<tr>
<td>CSX</td>
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<td>2.84</td>
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<tr>
<td>NSC</td>
<td>3.87</td>
<td>4.07</td>
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<tr>
<td>UPRR</td>
<td>3.26</td>
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<tr>
<td>BNSF</td>
<td>4.95</td>
<td>5.25</td>
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<tr>
<td>KCS</td>
<td>0.24</td>
<td>0.26</td>
</tr>
<tr>
<td>Total</td>
<td>15.09</td>
<td>15.71</td>
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Intermodal Rail
- U.S. handles over 15 M of the 18 M North American intermodal loads
- Truck competition sets the revenue, velocity and reliability limits
- Door to door rail service is not feasible, so final-mile moves are handled by Class 8 trucks, which serve multiple customers each day
POPULATION IS SPARSE IN THE WESTERN U.S.
RAILROADS OFFER LONG-HAUL INTERMODAL SERVICE IN THESE AREAS

BNSF Route Map

LOS ANGELES to MEMPHIS
RAIL   2,100 Miles, 90 to 106 Hours
TRUCK  1,850 Miles, 55 to 65 Hours

LOS ANGELES to CHICAGO
RAIL   2,210 Miles, 100 to 105 Hours
TRUCK  2,030 Miles, 60 to 70 Hours

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AUTOMATION COULD LOWER DIRECT COSTS TO NEAR-INTERMODAL LEVELS

- Over 5 Million TEUs of import intermodal freight flow Eastward from LA/LB (on BNSF + UPRR)
- A 30% reduction in long-haul truck costs makes trucking more competitive.
- Automated truck transit times and variability would be much lower than intermodal.

- High freight density would create hub to hub truck platoon opportunities
- Millions of ton-miles could be shifted from rail onto the highway system
- Fuel use and carbon output per load would more than double in a shift to trucks
Both modes are well understood, and choices can change week to week

Shipper relationships are THE key
CONSUMER IMPACT: ENOUGH TO SPUR RETAIL SALES?
A LESS THAN 1% IMPACT ON RETAIL PRICES IS LIKELY FOR MANY GOODS

- A 53 ft container can carry a wide range of consumer goods

<table>
<thead>
<tr>
<th>Item</th>
<th>Price Each</th>
<th>Cu Ft Each</th>
<th>Container Value *</th>
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<tbody>
<tr>
<td>Dewalt Deluxe Comp Miter Saw</td>
<td>$474</td>
<td>8.4</td>
<td>$193,000</td>
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<tr>
<td>Hunter Economy Fan</td>
<td>$99</td>
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<tr>
<td>GE 2.0 Cu Ft Microwave</td>
<td>$169</td>
<td>5.1</td>
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<tr>
<td>GE Washing Machine</td>
<td>$561</td>
<td>19.4</td>
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<tr>
<td>1 Patio Table Metal Frame</td>
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<td>GE 27” Electric Dryer</td>
<td>$389</td>
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<td>225 FT Capacity Hose Reel</td>
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<tr>
<td>2 Patio Chairs Metal Frame</td>
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In Addition to Transport Costs:
- A consistent 1 day reduction of transit time is worth about $50 in reduced inventory costs for a container with $115,000 of cargo.
- This would be less than $0.10 saved on an individual microwave at a 15% interest rate.

- A $400 to $800 reduction in truck costs on a $115,000 load yields 0.3% to 0.7% in potential savings on consumer goods ($800 / $115,000 = 0.7%)

* Example only. Containers normally move a mix of items.
Early adoption, using Levels 1 and 2, starts with fuel economy and safety improvements, with human drivers in control.

At Level 4, decline in linehaul driver income would be larger than the “safety monitor” and “city driver” payroll dollars gained.

Retail value impact is potentially less than 1% per load.

Carbon emissions would increase by more than 100% on loads converted from intermodal to automated trucks. Loads converted from intermodal would add stress to the highway system.

At the individual carrier level, autonomous Level 4 long-haul appears to be economically feasible, even after:

- Paying linehaul monitors to track vehicles on the line of road
- Using city drivers for the first and last miles
- Replacing trucks after 3 years or less in service
- Funding some level of infrastructure and emissions costs
Level 0 - The human driver does all the driving.

Level 1 - An advanced driver assistance system (ADAS) on the vehicle can sometimes assist the human driver with either steering or braking/accelerating, but not both simultaneously.

Level 2 - An advanced driver assistance system (ADAS) on the vehicle can itself actually control both steering and braking/accelerating simultaneously under some circumstances. The human driver must continue to pay full attention (“monitor the driving environment”) at all times and perform the rest of the driving task.

Level 3 - An Automated Driving System (ADS) on the vehicle can itself perform all aspects of the driving task under some circumstances. In those circumstances, the human driver must be ready to take back control at any time when the ADS requests the human driver to do so. In all other circumstances, the human driver performs the driving task.

Level 4 - An Automated Driving System (ADS) on the vehicle can itself perform all driving tasks and monitor the driving environment – essentially, do all the driving – in certain circumstances. The human need not pay attention in those circumstances.

Level 5 - An Automated Driving System (ADS) on the vehicle can do all the driving in all circumstances. The human occupants are just passengers and need never be involved in driving.
OVER 8 MILLION TEUS MOVE EAST BY RAIL FROM WEST COAST PORTS

Millions of TEUs Eastbound by Intermodal Rail
(3.51 Million TEUS Transloaded in 2017 = 1.3M 53 Ft Cont)

TTX Data: Transload to Rail Reports

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