Greening A Top-20 Economy:
Energy Efficient Timely Transportation of Long-Haul Heavy-Duty Trucks

Lei Deng

2017.09.26

US Trucking Industry: A Top-20 Economy

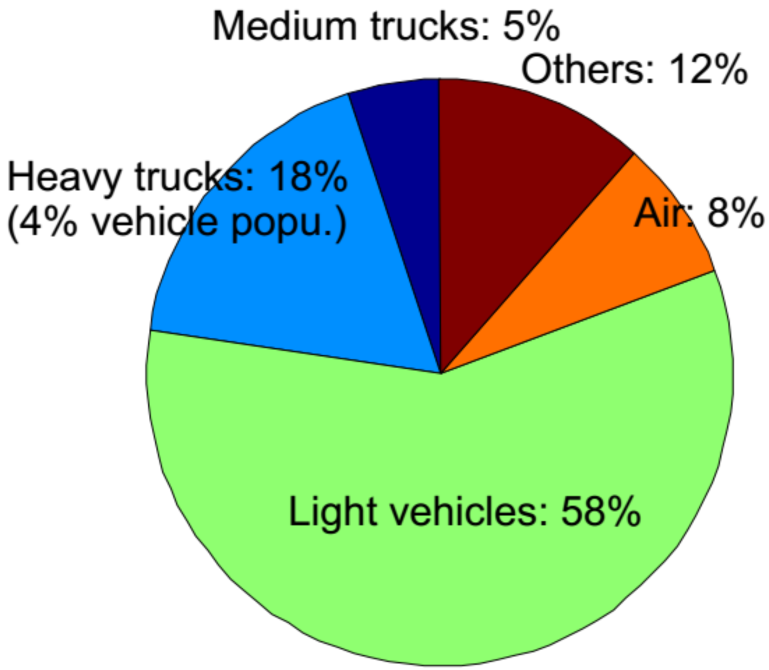
- Freight revenue[1]: $726B in 2015 (2.3x HK GDP)
- Freight tonnage[1]: 10B (70% of all freight), 2015
- Number of heavy-duty truck drivers[2]: 1.8M, 2014

Rank	Country	GDP (millions of US$)
	World	**73,433,644**
—	*European Union*[n 1][9]	18,460,646
1	United States	17,946,996
2	China[n 6]	10,866,444
3	Japan	4,123,258
4	Germany	3,355,772
5	United Kingdom	2,848,755
6	France	2,421,682
7	India	2,073,543
8	Italy	1,814,763
9	Brazil	1,774,725
10	Canada	1,550,537
11	South Korea	1,377,873
12	Australia	1,339,539
13	Russia[n 2]	1,326,015
14	Spain	1,199,057
15	Mexico	1,144,331
16	Indonesia	861,934
17	Netherlands	752,547
18	Turkey	718,221
19	Switzerland	664,738
20	Saudi Arabia	646,002
21	Argentina	548,055

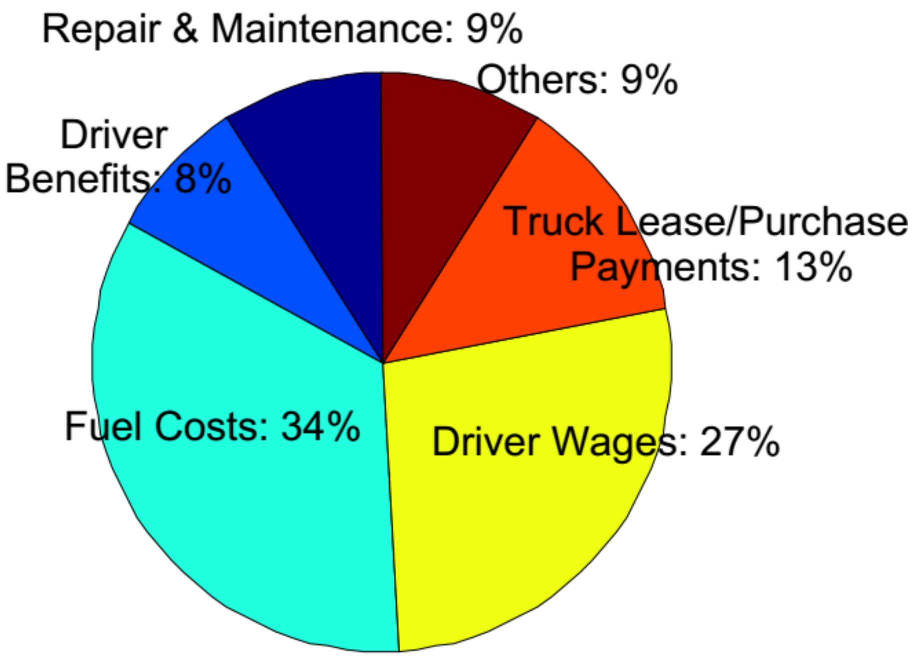
GDP Rank 2015, Source: Wikipedia

Source 1: ATA American Trucking Trends 2016
Source 2: Bureau of Labor Statistics,
U.S. Department of Labor

Greening Heavy-Duty Trucks is Relevant



Transportation energy use
(US 2013, source: US DOE)



Operational costs of trucking
(US 2014, source: American Transportation Research Institute)

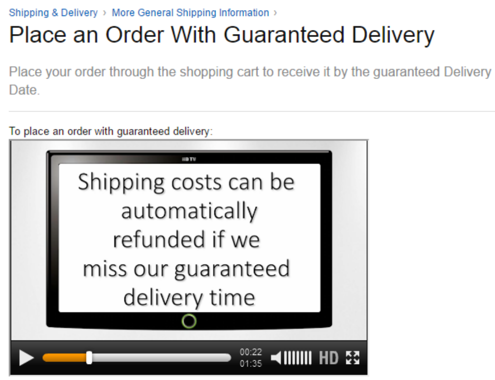
How to Reduce Fuel Consumption?

- □ Fuel-economic truck design
  - – Designs better engines, drivetrains, aerodynamics and tires, etc. Example: SuperTruck

- □ Energy-efficient truck operation
  - – Route planning
  - – Speed planning

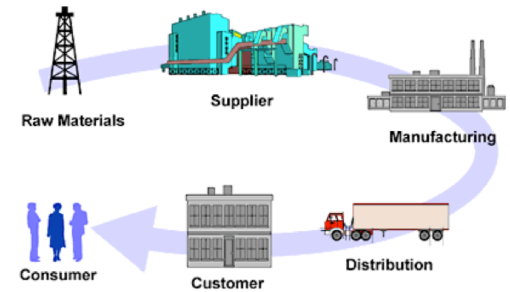
Truck Operation Centers around Timely Transportation

Perishable Food



Amazon SLA

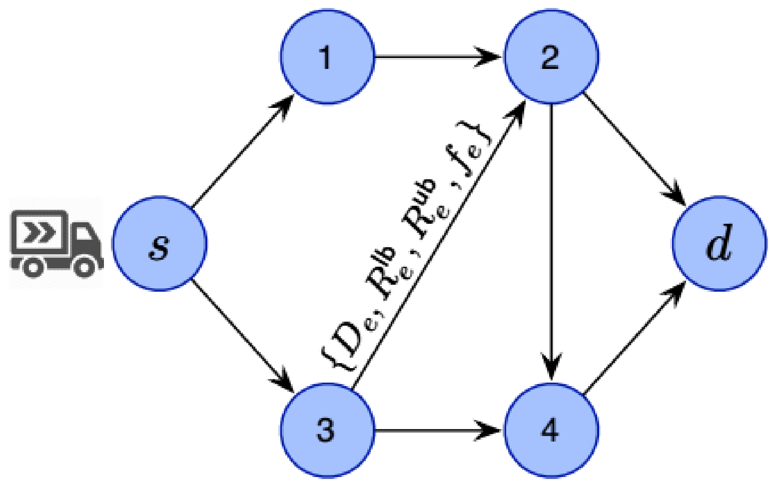
(Source: Internet)



Logistic role in a supply chain

- As estimated by [US FHWA](), unexpected delay can increase freight cost by 50% to 250%

Energy-Efficient Timely Transportation



- Objective: minimize the fuel consumption of travelling from city s to city d
- Constraint: a hard deadline constraint
- Design Space: route planning and speed planning

Existing Work on Energy-Efficient Trucking

Paper	Hard Deadline	Route Planning	Speed Planning
[1][2][3]	✘	✓	✘
[4]	✘	✘	✓
[5]	✓	✘	✓
Current Practice	human intelligence		
This Work	✓	✓	✓

[1] Eva Ericsson, et al, Optimizing route choice for lowest fuel consumption – Potential effects of a new driver support tool, *Transportation Research Part C*, 2006.

[2] K. Boriboonsomsin, et al, Eco-routing navigation system based on multisource historical and real-time traffic information, *IEEE Transactions on Intelligent Transportation Systems*, 2012.

[3] G. Scora, et al, Value of eco-friendly route choice for heavy-duty trucks, *Research in Transportation Economics*, 2015.

[4] E. Hellstrom, et al, Look-ahead control for heavy trucks to minimize trip time and fuel consumption, *Control Engineering Practice*, 2009.

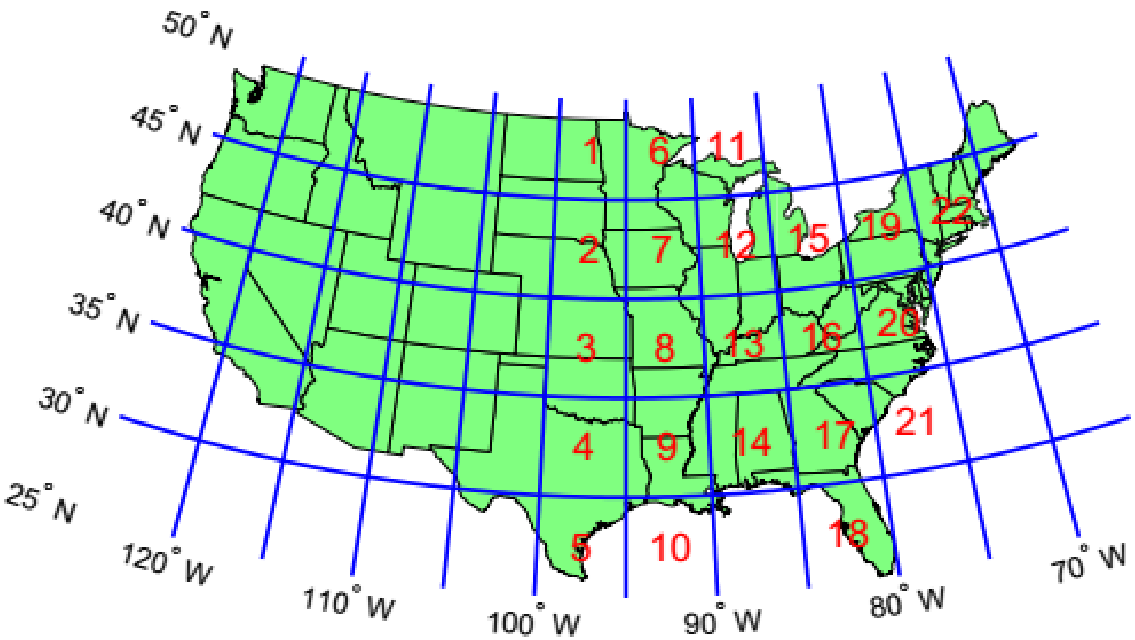
[5] E. Hellstrom, et al, Design of an efficient algorithm for fuel-optimal look-ahead control, *Control Engineering Practice*, 2010.

Our Contributions

- Formulate the problem and prove that it is NP-Complete
- Propose an **FPTAS** to achieve a $(1+\epsilon)$-approx. solution with complexity $O(mn^2/\epsilon^2)$
- Propose a near-optimal **heuristic** algorithm with complexity $O(m+n\log n)$
- Use simulations based on **real-world US highway networks** to show that our heuristic solution reduce fuel consumptions by up to 17%, as compared to fastest/shortest path algorithm

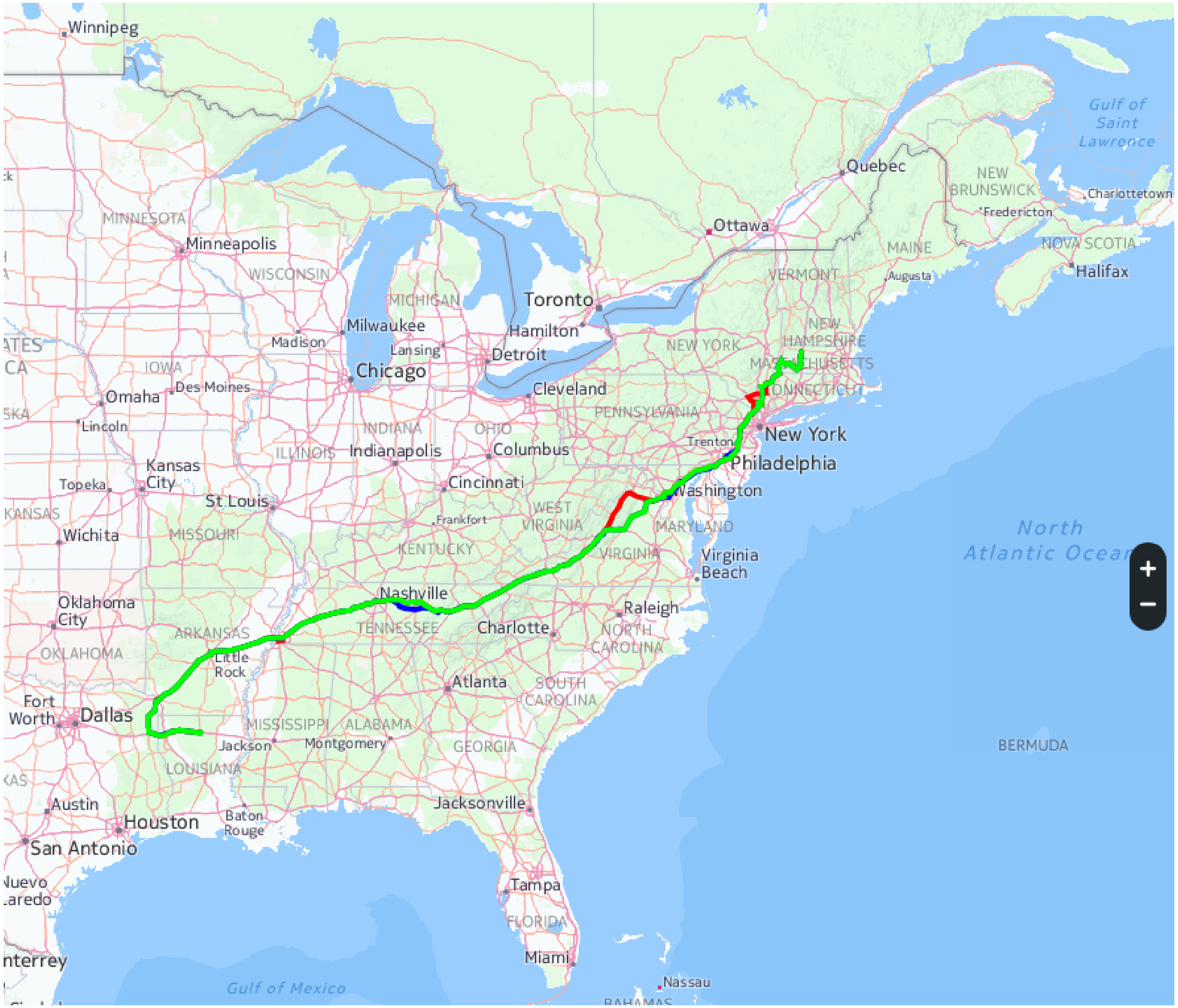
n, m are the number of nodes, edges of the network

Simulation: Network Statistics



n	m	avg D_e (mile)	avg R_e^{lb} (mph)	avg R_e^{ub} (mph)	avg $\lvert\theta\rvert$ (%)
38213	82781	3.26	36.43	54.19	0.82

A Solution Example



Fastest/F
Shortest/S
Optimal/O

Sol	Time (hour)	Dist. (mile)	Fuel (gallon)
F	36.11	1821	332.1
F-SO	40	1821	308.3
S	38.58	1773	318
S-SO	40	1773	307
OPT-LB	40	1778	300.1
OPT-UB	40	1778	300.1

F Path Add Remove
S Path Add Remove
O Path Add Remove

Note : The solutions OPT-LB and OPT-UB are the same, and thus they are the optimal solution. O Path (optimal path) is the corresponding path of the optimal solution.

Performance of Our Heuristic Algorithm

Average performance of **2704** instances (s, d, T)

Sol.	Avg Time Incre.(%)	Avg Dist. Decre.(%)	Avg Fuel Decre.(%)	Avg Fuel Econ.(mpg)
Fastest path	-	-	-	5.05
Shortest path	2.82	1.63	3.08	5.13
Heuristic	32.89	1.46	16.37	5.96
OPT-LB	32.95	1.47	16.39	5.96

Save ~17% fuel as compared to shortest/fastest path algorithms
Enough to power 90% of the transportation sector in New York State

See: Energy consumption estimates by end-use sector, ranked by state, 2013.
http://www.eia.gov/state/seds/data.cfm?incfile= /state/seds/sep sum/html/rank use.html&sid=US

Thank You!

Lei Deng

http://personal.ie.cuhk.edu.hk/~dl013/

Lei Deng, Mohammad H. Hajiesmaili, Minghua Chen, and Haibo Zeng, "Energy Efficient Timely Transportation of Long-Haul Heavy-Duty Trucks,"
in *Proc. ACM e-Energy*, June 2016. (Best Paper Award Candidate)
To appear in *IEEE Transactions on Intelligent Transportation Systems.*