Electrifying aviation and ocean shipping

The near-term potential

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With support from

The Transportation Research Board's Airport Cooperative Research Program

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Taxiing with tugs

Image from The Economist

- Each diesel-electric tug costs $1.5 million
- At this point, only one manufacturer
- Calculations account for
  - Capex
  - APU and tug fuel
  - Labor
  - Maintenance
- For fully electric tugs
  - Assume battery costs $300/kWh
  - Assume battery sized for one day's use

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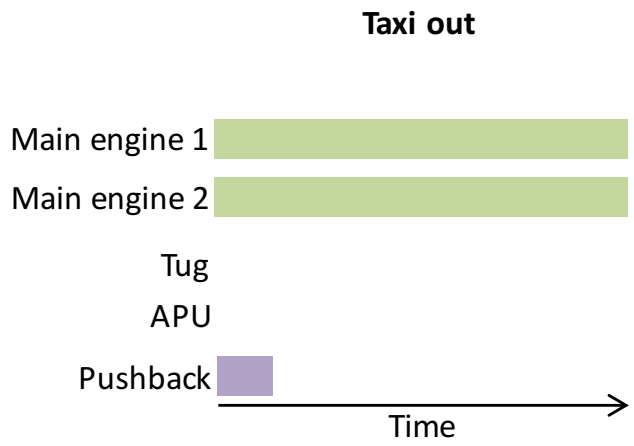
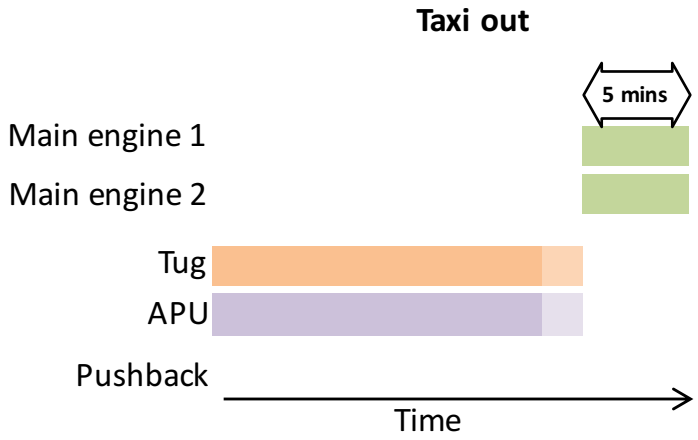
Base scenario…



…is compared to the Tug scenario



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There are limitations to where the solution can be deployed

- If tugs were used for every domestic flight, their use would cut emissions by 1.7 million tonnes of CO_2 annually, at a cost of -$20 per tonne.

But, their use is…

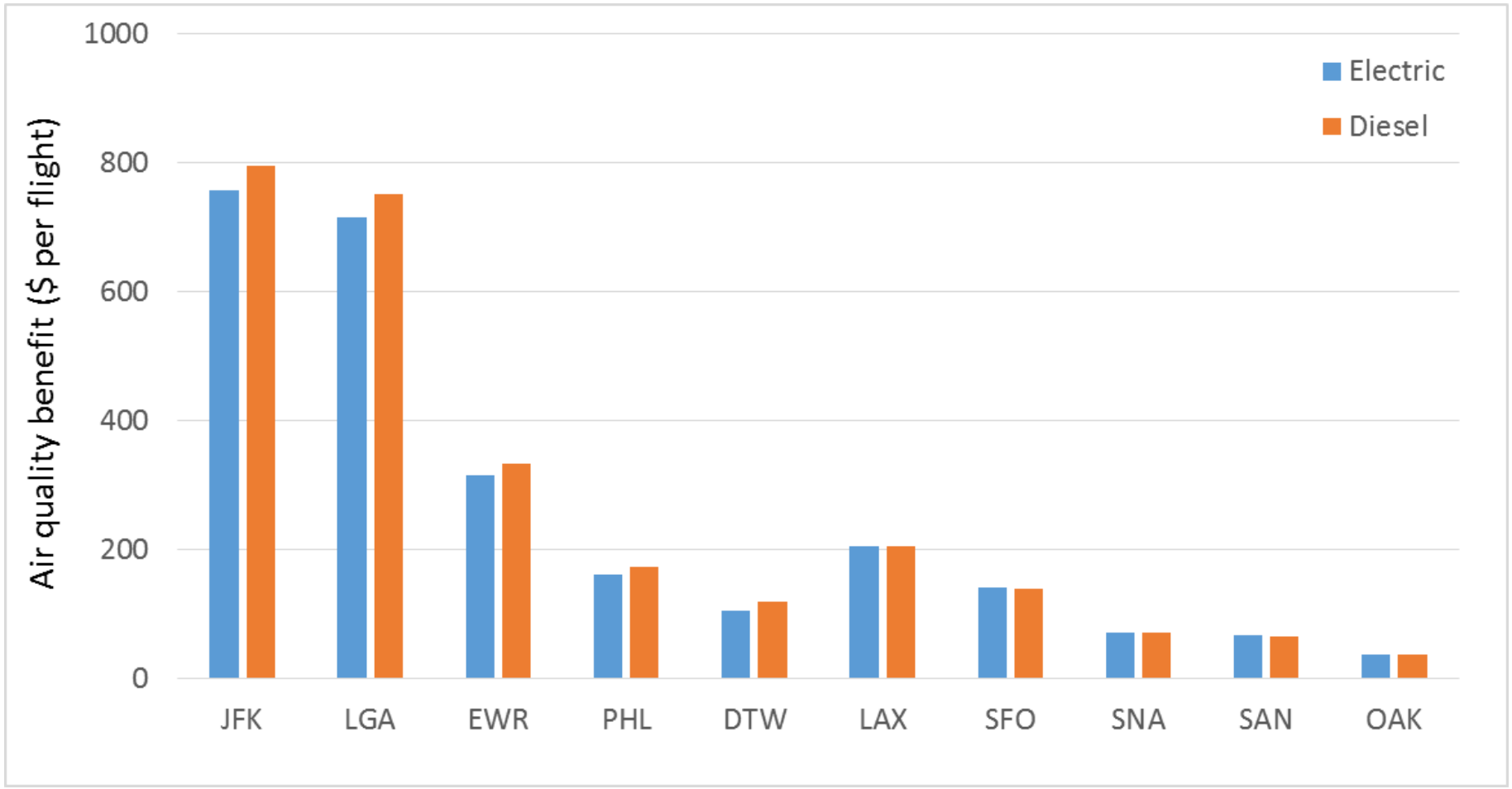
- Limited to aircraft ranging in size from A318 to B757
- Not economical at airports with short taxi times

Electric tugs would match diesel tugs only if they reduced capex

	Diesel tug	Electric tug	Electric tug (low capex)
Capex (millions)	$270	$310	$210
Annual net savings for airlines (millions)	$50	$40	$70
Annual CO_2 emissions reductions (millions of tonnes)	0.5	0.5	0.5
Cost per tonne of CO_2 emissions avoided	-$100	-$80	-$140
Annual value of air quality improvement (millions)	$140	$130	$140

- Low capex
  - Assume tugs require less complex controls and no pollution control equipment; so cost 50% of diesel tugs + battery
  - They are economical at more airports; so higher air quality benefits
- Air quality: Diesel used in Tier 4 engines is very clean (15ppm sulfur); and engines have a great deal of pollution-control equipment

Except in CA, the diesel tug is better for air quality than electric



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Conclusions and policy implications

- Electric tugs competitive only if they reduce costs very significantly
- Modest emissions reductions, but accompanied by a cost reduction (rare in aviation)
- Operational issues crucial; maybe even more so for electric tugs
- More generally: differences between airports and airlines
  - SouthWest flights seem spend considerably less time taxiing out (11 mins, on average) than other Boeing 737 aircraft (17 mins, on average)
- From a policy perspective
  - Different measures might be more or less attractive for different airline-aircraft-airport combinations
  - Would a broad CO_2 tax be more effective than prescriptive measures?

Shore power

Source: California Air Resources Board

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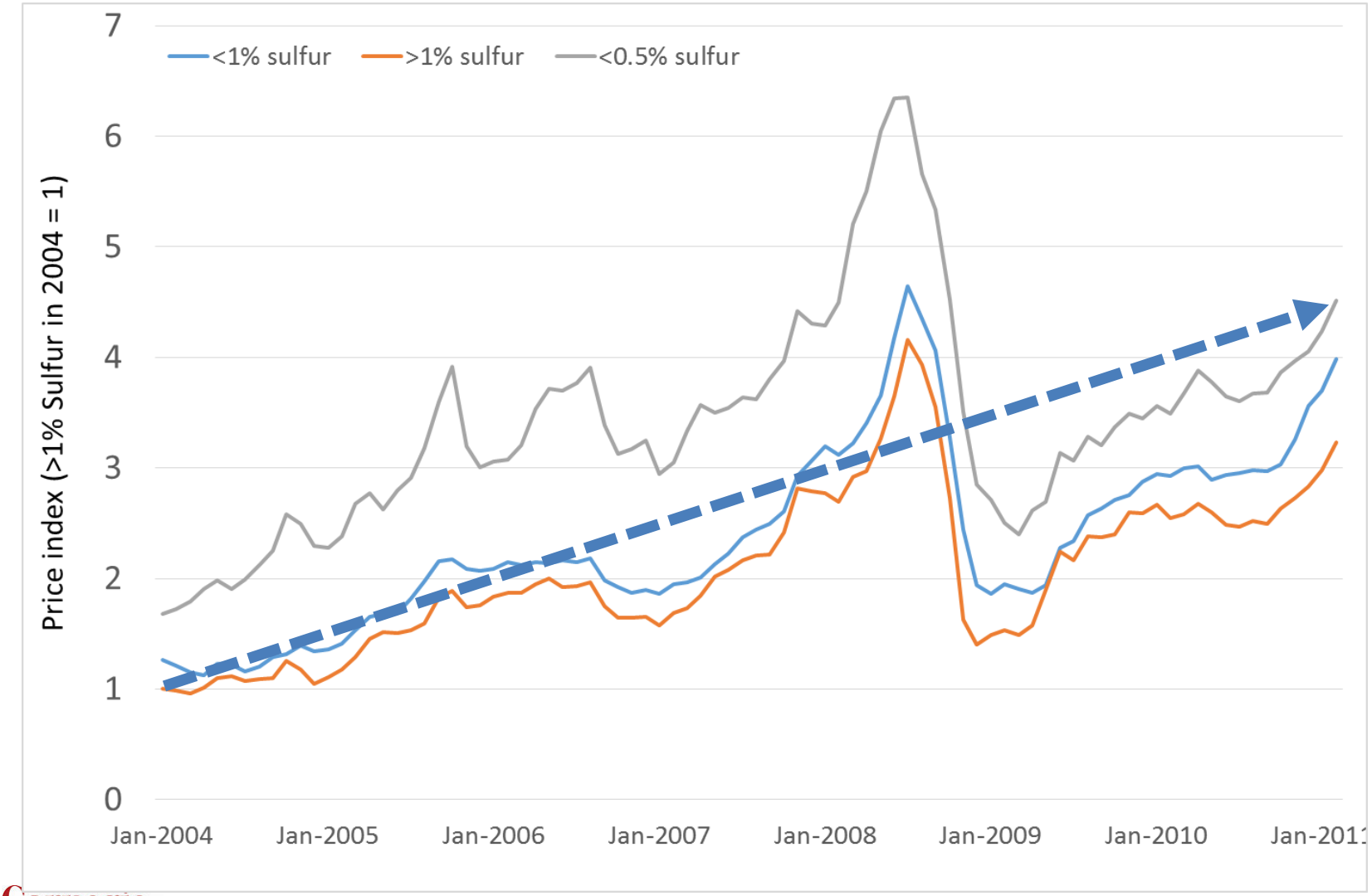
Shippers face >4x the fuel prices they did in 2004



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Shore power had to be justified on the basis of air quality benefits

		Container ship	Cruise ship
Installed power	kW	81000	63000
Hotelling load factor		0.05	0.16
Hotelling power	kW	4000	10000
Port calls per year		10	70
Hours per call		50	10
Hours per year	hrs/y	500	680
Electricity used by ship at berth	kWh per year	2,025,000	6,890,848
Price of shore power	$ / kWh	0.15	0.15
Cost of electricity	$ per year	303,750	1,033,627
Efficiency of diesel generation		0.25	0.25
Quantity of diesel needed	MJ per year	29,160,000	99,228,211
Diesel energy content	MJ/kg	43	43
Quantity of diesel needed	tonnes	678	2,308
Price of marine diesel	$ per tonne	400	400
Cost of diesel	$ per year	270,000	920,000
Savings in diesel cost per year		(32,000)	(110,000)
Cost of retrofitting the ship		1,000,000	1,000,000
Cost of retrofitting the berth		5,000,000	5,000,000
Utilization of berth		0.2	0.2
Cost of retrofitting attributed to berth		1,426,941	1,940,639
Years to payback (undiscounted)	years	-	-

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Quantity of diesel needed	tonnes	678	2,308
Price of marine diesel	$ per tonne	1000	1000
Cost of diesel	$ per year	680,000	2,300,000
Savings in diesel cost per year		370,000	1,300,000
Cost of retrofitting the ship		1,000,000	1,000,000
Cost of retrofitting the berth		5,000,000	5,000,000
Utilization of berth		0.2	0.2
Cost of retrofitting attributed to berth		1,400,000	1,900,000
Years to payback (undiscounted)	years	6.5	2.3

This may no longer be the case.

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Some pretty exotic solutions are being proposed

Image source: http://innovations.oceanhub.com/hybrid-energy-solution-for-ships-in-port/

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Acknowledgements

This work is supported by

- The center for Climate and Energy Decision Making (SES-0949710), through a cooperative agreement between the National Science Foundation and Carnegie Mellon University and by Academic Funds through the Department of Engineering and Public Policy from the CIT Dean's Office.
- A grant from the Transportation Research Board (TRB) under the Airport Co-operative Research Program (ACRP).
- The research benefited from the constant guidance of my supervisors, Prof. Granger Morgan and Prof. Paul Fischbeck, and numerous aviation professionals who took the time to speak to me, including members of a panel constituted by the TRB to guide me in my research for the ACRP.

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Thank you

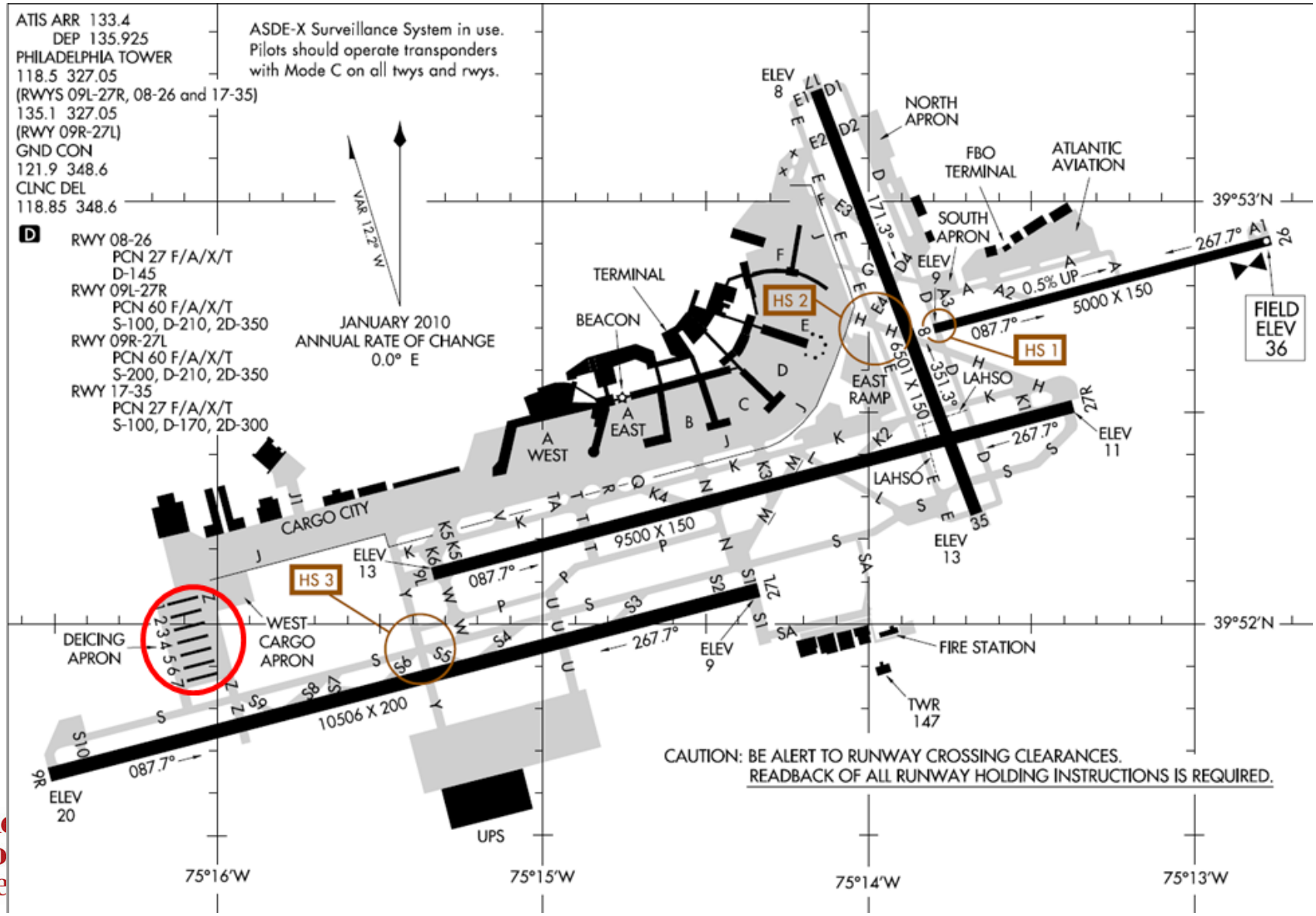
Back-up

There are significant operational concerns…

- Rules may simply prohibit dispatch taxi

  "Non-Port Authority vehicles are prohibited from operating on any runway, taxiway and safety area unless under escort by the Port Authority or FAA maintenance. All vehicles shall obtain permission from the Control Tower before entering or operating on the movement areas." (PANYNJ 2009, p.37)

...and addressing them may be more or less difficult.



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