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Autonomous Delivery Robots and their Potential Impacts on Urban Freight Travel, Energy, and Emissions

Miguel Figliozzi
Dylan Jennings

Portland State UNIVERSITY
Maseeh College of Engineering and Computer Science
PORTLAND STATE UNIVERSITY
TTP Lab

Problem Context:

- E-commerce purchases increase by 16% each year in the United States
- Congested streets and lack of parking

- Low efficiency of last-mile of deliveries

Figure Source: https://www.augment.com/blog/evolution-ecommerce-last-decade/

Acronyms

Autonomous Delivery Robots (ADRs)

Sidewalk ADR (SADR) and Road ADR (RADR)

Typical (US) SADR Regulations

- Weight limit up to 80 lbs (36kg)
- Speed limit of 10 mph (16kph)
- Follows pedestrian laws
- Insurance policy
- Headlights
- Brakes

Why are we only focusing on US regulations?

Regulatory Extremes

- San Francisco, CA:
- 3 mph (5 kph) speed limit
- Requires permits
- 9 SADRs in all of SF
- Must emit warning noise for pedestrians

- Arizona:
- 10 mph (16 kph) speed limit
- Brakes, lights, & insurance not required

Washington State (May 2019)

A personal delivery device (PDD) electrically powered, weighing less than 120 pounds and intended primarily to transport property on a sidewalk or crosswalk at speeds of 6 miles per hour (mph) or less. The operation of the PDD is supported by a remote operator who may either monitor or exercise active control of the device with insurance policy liability coverage of at least $100,000 for damages.

New robots

- FedEx
- Amazon
- Postmates

Credits: FedEx https://thefuturefedex.com/?search=true&spterm=bot ,
Postmates https://blog.postmates.com/meet-serve-the-newest-member-of-the-postmates-fleet-e3884825b94c

SADRs Specifications

	Weight (lbs)	Speed (mph)	Capacity (lbs)	Capacity (chambers)	Range (miles)
Starship Technologies	40	4	40	1	4
Domino's DRU	Unknown	12	21 (approx.)	4*	12
Dispatch's Carry	Unknown	4	100	4	12 hr battery, up to 48 miles
Thyssenkrupp's TeleRetail	60	35	77	1	10
Marble	80	4	Unknown	1	Unknown
Robby	60	Unknown	Unknown	1	20
KiwiBot	Unknown	Unknown	Unknown	1	Unknown

Road ADRs (regulated as Avs)

Nuro (Wired, 2018), uDelv (Cnet, 2019)

RADRs Specifications

	Capacity (parcels)	Capacity (lbs)	Max Speed (mph)	Approx. Size L x W x H in feet	Vehicle Weight (lbs)	Range (miles)
Nuro	40 parc. (*,**) or 12 large grocery bags	250	25	8’x.3,6’ x 6’	1,500	10
uDelv	32 parc.	700	25	15’x 6’x 6’	4,167	60
AutoX	11.1 to 15.4 cuft	Unknown	80 (*)	16’ x 6’ x 5’	3,900	560

More news

- Amazon announced that it will spend $800 million to make one-day shipping the new standard for Prime members across the country (April 2019).
- In Snohomish, Washington six Amazon Scout robots have been delivering packages to customers since January 2019.
- A United States Postal Service survey found that a majority of Americans embrace the idea of robot delivery

Literature Review: new topic

Few publications, no studies focusing on emissions

Vleeshouwer, T., Duin, R. V., and Verbraeck, A (2017). Implementatie van autonome bezorgrobots voor een kleinschalige thuisbenzorgdienst. *ResearchGate*. Accessed November 1, 2018.

Jennings, D., & Figliozzi, M. (2019). Study of Sidewalk Autonomous Delivery Robots and Their Potential Impacts on Freight Efficiency and Travel. *Transportation Research Record*

More publications related to

- Optimization (joint planning or scheduling of robots and/or vans/trucks)
- Software and hardware design

Methodology I

- Distance/range constrained vehicles
- Continuous approximations to estimate average distance traveled by different vehicle types
- VMT Changes, emissions rates
- Different scenarios: delivery density

Delivery density

(a) 48 customers distributed in an area of 86.7 km^2
(b) 48 customers distributed in an area of 21.7 km^2
(c) 48 customers distributed in an area of 5.4 km^2
(d) 48 customers distributed in an area of 1.4 km^2

- Eight Starship SADRs can serve 48 customers in case (a) using up all its energy/range
- Cases (b), (c) and (d) utilize ½, ¼ , and $1/8$ of the Starship's range respectively. NOTE: numbers rounded up

Delivery density

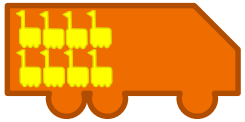
(a)	0.43 customers per km^2	Low
(b)	1.70 customers per km^2	Medium
(c)	6.81 customers per km^2	High
(d)	27.26 customers per km^2	Very high

NOTE: numbers rounded

Methodology II

- Apply Most Common US Regulations for SADRs (Starship)
- Nuro and Udelv RADRs
- Compare energy rates with other vehicles:
  - Mothership: ICE vs EV
  - Electric vans

Assumptions: SADR Van “mothership”



- Combine Standard Van with SADRs
- Human driver
- 8 SADRs

Mercedes Benz SADR Van

Figure Source: Daimler Media

VMT Reduction by using SADR Vans*

d (kms)	Density			
	Low	Med.	High	Very High
5	15.0%	12.7%	9.7%	6.6%
10	12.7%	9.7%	6.6%	4.0%
15	11.0%	7.9%	5.0%	2.9%
20	9.7%	6.6%	4.0%	2.3%
25	8.7%	5.7%	3.4%	1.9%

d (kms): distance from the van depot to the customer service area

* On road VMT, not counting sidewalk VMT

SADR Energy Consumption in Kwh*

d (kms)	Low Density		Very High Density	
	SADR	Van (mothership)	SADR	Van (mothership)
0	1.3	36.9	0.2	4.6
5	1.3	46.9	0.2	14.6
10	1.3	56.9	0.2	24.6
15	1.3	66.9	0.2	34.6
20	1.3	76.9	0.2	44.6
25	1.3	86.9	0.2	54.6

d (kms): distance from the van depot to the customer service area

* To serve 48 customers, mothership with conventional ICE reduce by~ 4 with electric engine

RADR Energy Consumption in Kwh*

d (kms)	Low Density		Very High Density	
	NURO	UDelv	NURO	UDelv
0	10.9	8.8	0.8	1.1
5	29.0	10.7	2.2	3.0
10	*NA*	12.6	*NA*	5.0
15	*NA*	14.6	*NA*	6.9
20	*NA*	16.5	*NA*	8.9
25	*NA*	18.5	*NA*	10.8

d (kms): distance from the van depot to the customer service area

* To serve 48 customers

Energy Consumption Kwh (low density)

d (kms)	SADR (no van)	SADR MS ICE	SADR MS EV	E-van	NURO	Udelv
0	1.3	38.1	10.5	9.3	10.9	8.8
5	*NA*	48.1	13.0	11.3	29.0	10.7
10	*NA*	58.1	15.5	13.4	*NA*	12.6
15	*NA*	68.1	18.0	15.4	*NA*	14.6
20	*NA*	78.1	20.5	17.5	*NA*	16.5
25	*NA*	88.1	23.0	19.5	*NA*	18.5
30	*NA*	98.1	25.5	21.6	*NA*	35.7
35	*NA*	108.1	28.0	23.6	*NA*	39.5
40	*NA*	118.1	30.5	25.7	*NA*	61.7

Best Fleet (lowest energy)

d (kms)	Density			
	Low	Med.	High	Very High
0	SADR*	SADR*	SADR*	SADR*
5	Udelv	Udelv	Udelv	NURO
10				Udelv
15				
20				
25				
30	E-van			
35				
40		E-van		

d (kms): distance from the van depot to the customer service area

* SADR without a mothership van

Time constrained

Deliveries must be completed in 8 hrs

Average speeds

SADR: 2 km/h, mothership van 20 km/h

Nuro and Udel: 10 km/h

E-van: 20 km/h

Time constrained

Deliveries must be completed in 8 hrs

Time per customer

SADR: 5 min.

Nuro and Udel: 5 min.

E-van: 3 min.

Vehicles required (8 hs –low density)

d (kms)	SADRs	SADR Motherships	E-van	NURO	Udelv
0	10	2	1	2	2
5	43	6	1	2	2
10	*NA*	*NA*	1	*NA*	2
15	*NA*	*NA*	1	*NA*	3
20	*NA*	*NA*	1	*NA*	*NA*
25	*NA*	*NA*	1	*NA*	*NA*
30	*NA*	*NA*	1	*NA*	*NA*
35	*NA*	*NA*	2	*NA*	*NA*
40	*NA*	*NA*	2	*NA*	*NA*

Best vehicle (lowest energy)

d (kms)	Density			
	Low	Med.	High	Very High
0	SADR*	SADR*	SADR*	SADR*
5	NURO	NURO	NURO	NURO
10	E-van	E-van	Udelv	Udelv
15			E-van	
20				E-van
25				
30				
35				
40				

d (kms): distance from the van depot to the customer service area

* SADR without a mothership van

Key findings

- SADRs are energy efficient without mothership and have potential VMT reductions (on road) but increased sidewalk utilization
- RADRs most energy efficient when the delivery density is not near the depot
- E-vans more efficient in lower density areas (range)
- Regulations and economic viability (other paper)

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Portland State UNIVERSITY

THE UNIVERSITY OF MEMPHIS

FAU FLORIDA ATLANTIC UNIVERSITY

Portland State UNIVERSITY

Maseeh College of Engineering and Computer Science
PORTLAND STATE UNIVERSITY

TTP Lab

QUESTIONS?