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CAN AUTONOMOUS DELIVERY ROBOTS REDUCE LAST MILE ENERGY CONSUMPTION AND CO₂ EMISSIONS?

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Problem Context:

- E-commerce purchases increase by 16% each year in the United States
- Low efficiency of last-mile of deliveries



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

Solution: Autonomous Delivery Robots (ADRs)

- Deliver items to customers
- Travels on road / sidewalk
- NO delivery person
- SADR vs RADR



Starship SADR with Mothership Van



Nuro RADR

Contents of Our Paper



AutoX RADR

- Capabilities of existing ADRs
- Energy consumption of ADRs
- Determined change in VMT for different customer densities
- Determined ideal vehicle fleets for different customer densities
- CO₂ emissions for different ADRs

Figure Source: <https://www.businessfleet.com/323140/were-learning-very-quickly-using-autonomous-vehicles-for-grocery-delivery>

Capabilities of Starship Technologies' SADR

Speed, mph (kph)	Capacity, lbs (kg)	Capacity, chambers	Range, mi (km)
4 (6.4)	40 (18.1)	1	2 (3.2)



Small Sidewalk ADR

1 chamber, can hold about 6 parcels

Figure Source: <https://i7.pngguru.com/preview/613/627/675/starship-technologies-robot-technology-delivery-drone-robot.jpg>

Capabilities of Starship's Prototype Mothership



Diesel Mercedes-Bens Sprinter Cargo Van
Carries up to 8 SADRs
Human driven

Capabilities of analyzed RADRs

RADR Company	Capacity, lb (kg)	Capacity, chambers	Max Speed, mph (kph)	Range, mi (km)
Nuro	243 (110)	2	35 (56)	10 (16.1)
Udelv	1300 (590)	32	60 (97)	60 (97)



Nuro RADR



Udelv RADR

Energy Consumption of ADRs

Vehicle	Energy Consumption wh/km	% of baseline
Conventional Van	1000	488%
Electric Van*	205	100%
Udelv Van	194	95%
Nuro Van	140	68%
SADR	24.7	12%

*E-Van is our baseline vehicle

Customer Densities

- Four different density scenarios
- Customers per mile² (customers per km²)
- Low density: 1.1 (0.43)
- Medium density: 4.4 (1.70)
- High density: 17.6 (6.81)
- Very high density: 70.6 (27.26)

Results

Mothership (SADRs) Reduction in VMT

- Lower VMT than baseline E-Van for all scenarios
- Delivery work is spread between many small “drone workers” (SADRs)
- Up to 18% reduced VMT for small distances from depot to service area
- Drawback: increased sidewalk travel from robots

Nuro & Udelv (RADR) Increase in VMT

- Udelv equivalent with E-Van except when range of Udelv is exceeded
- Nuro range is 10 miles, so makes many tours
- Nuro VMT is then 2 to 3 times E-Van VMT

SADR Energy Consumption

SADR's energy consumption is much lower than diesel vans that transport them. Units: Kwh

Long-haul travel <i>d</i> (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

RADR Energy Consumption

- RADRs have lower energy consumption because they are electric vehicles
- Nuro is better in very high density scenarios

Long-haul travel 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

Ideal Vehicle Fleets

- Based on energy consumption
- SADR best at $d=0$ if no mothership involved

	Low Density	High Density
Depot Close to Service Area	SADR/Udelv	SADR/Nuro
Depot Far from Service Area	E-Van	Udelv

Best energy consumption (ideal fleet)

- Low energy consumption: high density & low d
- High energy consumption: low density & high d
- *Not including SADR

d (kms)	Density			
	Low	Med.	High	Very High
0*	8.8	4.4	1.6	0.8
5	10.7	6.3	4.1	2.2
10	12.6	8.3	6.1	5
15	14.6	10.2	8	7
20	16.5	12.1	9.9	8.9
25	18.5	14.1	11.9	10.8
30	21.6	16	13.8	12.8
35	23.6	18	15.8	14.7
40	25.7	21	17.7	16.6

Typical Example Uses for ADRs

Where is each vehicle the ideal fleet vehicle?



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Typical Example Uses for ADRs

Rural Service Area



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Depot Near Service Area



SADR



Udelv RADR

Typical Example Uses for ADRs

Rural Service Area



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Depot Far from Service Area



Electric Van

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Typical Example Uses for ADRs

Urban Service Area



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Depot Near Service Area



SADR



Nuro RADR

Typical Example Uses for ADRs

Urban Service Area



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Depot Far from Service Area



Udelv RADR

CO₂ Emissions Comparison

- Diesel vehicles create 22.5 times CO₂ as electric vehicles
- Internal combustion engines are less CO₂ efficient than electric engines in any situation
- Introduction of ADRs would substantially reduce CO₂ emissions

CO₂ Emissions Comparison

- E-vans produce 4% the emissions of a conventional combustion engine van
- RADRs produce 3% the emissions
- SADR without a mothership produce 0.7% the emissions

Acknowledgment

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QUESTIONS?

Additional Sources

Slide 7 Figure Sources:

www.nuro.ai

<https://www.transportmedia.be/wp-content/uploads/2019/01/Udelv-1024x576.jpg>