

Network performance of autonomous vehicles at low market shares

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NETWORK PERFORMANCE OF AVs AT LOW MARKET SHARES

hEART 2017 September 12 – 14 Haifa, Israel

Andrea Papu Carrone Jeppe Rich TRANSPORT MODELLING



DTU Management Engineering Department of Management Engineering



- Motivation
- Model formulation
- Experiment setup
- Simulation framework
- Case Study: Results
- How / What should we plan?
- Conclusions



STAY

FOCUSED!

DON'T DRINI

AND DRIVE!

BUCKLE

UP!

STOP AT RED

LIGHTS!

WATCH

OUT FOR

PEDESTRIANS

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Motivation (I)

- AVs conceived to:
 - Increase safety
 - Reduce pollution
 - Optimize inefficient use of infrastructure
 - Reduce congestion



- Technological advances in sensing technology, wireless communications and data processing.
- AVs already prototyped, car manufacturers working towards deployment.





MICROSCOPIC BEHAVIOR OF TRAFFIC

- Will AVs penetration to the market improve capacity and traffic flow?
- Is this improvement proportional to the % AVs?
 or, will AVs smooth traffic flow even at low rates of penetration?

For 2050: 7 – 61% trips performed in AVs (Milakis et al., 2016)



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IIDM: Improved Intelligent Driver Model

$z_{ji} = \frac{DesS(v_{(j-1)i}, \Delta v_{(j-1)i})}{s_{(j-r_i)i}}$		-	X _{i-1} X _i S _i V _i , a _i V _{i-1} , a _{i-1}	
• if $v \leq v_0$ $a_{free_{ji}} = A \cdot \left[1 - \left(\frac{v_{(j-r_i)i}}{v_{0i}}\right)^{\delta}\right],$	$a_{ji} = \begin{cases} A \cdot \left[1 - z_{ji}^2\right] \\ \end{cases}$	$z_{ji} \ge 1$	$\downarrow I_{i} \qquad \qquad \downarrow_{i-1}$	
	$\left[a_{free_{ji}} \cdot \left[1 - z_{ji}^{(2 \cdot A)/a_{free_{ji}}}\right]\right]$	$z_{ji} < 1$	Cars	AVs
• if $v > v_0$	$\left(a_{free} + A \cdot \left[1 - z_{ii}^2\right]\right)$	$z_{ii} > 1$	Stochastic IIDM	Deterministic IIDM
$\begin{bmatrix} v_{0i} & 4\delta/B \end{bmatrix}$	[3]	J* _	$A = 3 m/s^2$	$A = 3 m/s^2$
$a_{free_{ji}} = -B \cdot \left[1 - \left(\frac{v_{(j-r_i)i}}{v_{(j-r_i)i}}\right)^{n-1/2}\right]$	$\begin{bmatrix} \\ \\ \\ \end{bmatrix}, a_{ji} = \{$		B = 1.67 m/s ²	B = 1.67 m/s ²
	$a_{free_{ji}}$	$z_{ji} < 1$	B _{max} = 7.5 m/s ²	$B_{max} = 7.5 \text{ m/s}^2$
Development			S ₀ = 2 m	$S_0 = 2 m$
Parameters: A = maximum acceleration	T = speed dependent safe gap		T =1.5 s	T = 1 s
B = comfortable deceleration	δ = IDM parameter		δ = 4	$\delta = 4$
B _{max} = maximum deceleration	v ₀ = desired speed		v ₀ = norm(30.56;3.5 ²) m/s	v ₀ = 30.56 m/s
s _o = standstill safe gap	r _i = reaction time		r _i = norm(0.5;0.1 ²) s	$r_i = 0 s$
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Time steps j







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Case Study: AVs different driving behaviours



Validation of	f Base Scenario:	: 0% AV		Xi Si EAM I DARY Vi, ai Vi-1, ai-1	DOWNSTREAM BOUNDARY
Analysis of A	Ws T and v_0 para	ameter sens	itivity	• 13 km	40 1 km 2 km
Analysis of A	AVs at different	penetration	rates	Cars	AVs
50% AV/c	Va	т	Performance	Stochastic IIDM	Deterministic IIDM
50% AVS	80 km/h	1.0 s	Indicators:	$A = 3 m/s^2$	$A = 3 m/s^2$
	, 110 km/h	1.0 s	 Av. Travel time 	B = 1.67 m/s ²	B = 1.67 m/s ²
	145 km/h	1.0 s	 Throughput 	$B_{max} = 7.5 \text{ m/s}^2$	B _{max} = 7.5 m/s ²
50% / \/c	<u>_</u>		Capacity drop	S ₀ = 2 m	S ₀ = 2 m
50% AVS	110 km/h	0.5 s		T =1.5 s	T = 1 s
	110 km/h	1.0 s	 Queue 	δ = 4	δ = 4
	110 km/h	1.3 s		V ₀ = norm(30.56;3.5 ²) m/s	v₀ = 30.56 m/s =110km/h
				r _i = norm(0.5;0.1 ²) s	r _i =0 s

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Case Study: AVs different driving behaviour – 50% AVs



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Case Study: AVs at different penetration rates



Х_{і-1} DRIVING x_i s_i DIRECTION Validation of Base Scenario: 0% AV DOWNSTREAM UPSTREAM BOUNDARY BOUNDARY $v_{i\text{-}1}, a_{i\text{-}1}$ 40 Analysis of AVs T and v_o parameter sensitivity 13 km 10 km 1 km 2 km Analysis of AVs at different penetration rates AVs Cars **Stochastic IIDM Deterministic IIDM** Performance % AVs V₀ Т $A = 3 m/s^{2}$ Indicators: $A = 3 m/s^2$ 0 110 km/h 1.0 s $B = 1.67 \text{ m/s}^2$ $B = 1.67 \text{ m/s}^2$ Av. Travel time 25 110 km/h 1.0 s $B_{max} = 7.5 \text{ m/s}^2$ $B_{max} = 7.5 \text{ m/s}^2$ Throughput 50 110 km/h 1.0 s $S_0 = 2 \text{ m}$ $S_0 = 2 m$ Capacity drop 75 110 km/h 1.0 s T=1.5 s T = 1 s90 110 km/h 1.0 s Queue $\delta = 4$ $\delta = 4$ 100 110 km/h 1.0 s $V_0 = norm(30.56; 3.5^2) m/s$ **v_o = 30.56 m/s = 110km/h** $r_i = 0 s$ $r_i = norm(0.5; 0.1^2) s$

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AVs at different penetration rates – AVERAGE TRAVEL TIME



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AVs at different penetration rates – QUEUE



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AVs at different penetration rates – THROUGHPUT AND CAPACITY



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Flow – Density



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How / What should we plan?





DEDICATED LANES FOR AVS IN MOTORWAYS

AVS IN MOTORWAYS MIXED IN TRAFFIC

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AVs at different penetration rates – Benefit calculations



		Autonomous Car Normal Car		 Scaling of results: –2 peak periods per day –1 year (285 days) 		
	AVS IN MOTORWAYS M IN TRAFFIC	IIXED	DEDICATED LANES FO	R AVS	Penetration rate of AVs	Total benefits M dkk / lane / year
	NORMAL CARS + AVs	33.3%	AVs	100%	0	-
	NORMAL CARS + AVs	33.3%	NORMAL CARS	0%	10	1.6
	NORMAL CARS+ AVs	33.3%	NORMAL CARS	0%	25	4.2
					33.3	5.5
					50	9.2
Π.					75	15.9
I otal Benefits = 5.5 + 5.5 + 5.5		Total Benefits $= 35.2 + 0 + 0$		90	22.5	
То	tal Benefits = 16 . 5 M	dkk/year	Total Benefits $=$ 35 .	2 Mdkk/year	100	35.2

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The potential network benefits do not follow a linear relation to the market penetration rate of

Po	Potential Benefits with respect to current situation		
Penetration rate of AVs	Time saving	Capacity increase	
50%	12	6	
75%	20	12	
100%	45	25	

Benefits at low market shares could be difficult to perceive.

 At early implementation stages beneficial to plan towards motorways with dedicated lanes for AVs rather than AVs mixed in traffic. However, several practical problems could arise when implementing into real-world.

 Work is limited to analyze changes in vehicle dynamics and does not consider potential induced demand.



THANK YOU FOR LISTENING

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