Challenges for the Remote Operation of Vehicles

Poster number: 20-05779

Noah J. Goodall, Ph.D., P.E.

VTRC Virginia Transportation Research Council

VDOT Virginia Department of Transportation

BACKGROUND

BACKGROUND

- **Vehicles can be operated from a remote location**
  - ⇒ First done in 1925 by radio control
  - ⇒ Used in mining, agriculture, drone warfare, and dockless scooters
  - ⇒ At least six AV developers and five startups can remotely operate road vehicles
  - ⇒ Allows Level 4 AVs to operate as Level 5
- **Questions remain for remote operation of vehicles on public roads in the United States**
  - ⇒ Is it legal?
  - ⇒ Is it technically feasible?
  - ⇒ Is it practical?

LEGAL ASPECTS

- **Driver's Physical Presence in the Vehicle**
  - ⇒ No state statutes expressly require physical presence of a driver as of 2014
  - ⇒ Other rules *imply* presence
    - ♦ Unattended vehicles, abandoned vehicles, crash obligations, safety belts, driver sight, driver interference
  - ⇒ Uniform Vehicle Code (basis for many state motor vehicle codes) states that "no person … shall drive … without a valid driver's license" but do not make the opposite requirement that vehicles must be driven by person with valid license. Without opposite requirement, there is no driver to regulate and rules of the road may not apply.
- **Remote Operator's Physical Presence within the United States**
  - ⇒ States recognize driver's licenses from other states.
  - ⇒ Driver's licenses from foreign countries are generally recognized. Some states require an International Driver's License.

State	Title	Driver's License	Physical Location
California	Testing of Autonomous Vehicles	Valid driver's license required, jurisdiction not specified.	Not specified.
Florida	House Bill 311	U.S. driver's license required.	United States.
Alabama	Senate Bill 47	Valid driver's license required, jurisdiction not specified.	Not specified.
Vermont	Senate Bill 149	Valid driver's license required, jurisdiction not specified.	Not specified.
Utah	House Bill 101	Valid driver's license required, jurisdiction not specified.	Not specified.

State laws and regulations addressing remote operation of road vehicles

REFERENCES

1. Saeed, U., J. Hämäläinen, M. Garcia-Lozano, and G. David González. On the Feasibility of Remote Driving Application over Dense 5G Roadside Networks. Presented at the 2019 16th International Symposium on Wireless Communication Systems (ISWCS), 2019.
2. Kang, L., W. Zhao, B. Qi, and S. Banerjee. Augmenting Self-Driving with Remote Control: Challenges and Directions. Presented at the 19th International Workshop on Mobile Computing Systems & Applications, New York, NY, USA, 2018.

MODEL

TECHNICAL FEASIBILTY

- **LTE networks *barely* support demonstrations**
  - ⇒ 100ms delay
  - ⇒ Field tests require more than one provider
- **5G networks supports demonstrations**
  - ⇒ A few successful demos
  - ⇒ 10ms delay
- **Large deployments might not be feasible *(1)***
  - ⇒ Require 20 Mbps upload rate with 99.999% probability
  - ⇒ Interference becomes an issue in dense deployments
  - ⇒ Could be restricted to high-value corridors

Network	Delay	Details
LTE	100ms	MPEG-4, frame rate 10, 640p
Wi-Fi	50ms	MPEG-4, frame rate 10, 640p

LTE and Wi-Fi latency *(2)*

Demonstration	Year	Network	Range	Details
Huawei and Shanghai Automotive Industry Corporation	2017	5G	30 km	240 degree HD video, 10ms delay
Telefonica and Ericsson	2017	5G	70 km	Mobile World Congress
Phantom Auto	2018	LTE	600 km	Simultaneous AT&T and Verizon networks

Road vehicle remote operation demonstrations

REMOTE OPERATION STAFFING MODEL

Erlang C Formula

Used in queueing theory to predict number of operators needed to manage a call load while meeting a performance target.

$$P_C(m,a) = \frac{\frac{a^m m}{m!\,(m-a)}}{\sum_{i=0}^{m-1} \frac{a^i}{i!} + \frac{a^m m}{m!\,(m-a)}}$$

$$a = \frac{\lambda}{\mu} \qquad \lambda = r_v n_v$$

$P_C(m,a)$ = probability that an incoming request cannot be immediately served
a = request load
m = number of agents
λ = average number of requests per unit time
μ = average number of requests that can be serviced by a single operator per unit time
r_v = disengagement rate of automated driving system
n_v = number of vehicles in the fleet

Parameter	Symbol	Value	Source
Requests	a	Varies	Calculated
Operators	m	Varies	Calculated
Request rate	λ	$r_v n_v$	CA DMV
Service rate	μ	6, 12, 60 / hr	Assumption
Target failure rate	r_t	2.53×10^{-7}	Medical event rate
Vehicles on road during shift peak hour	n_v	25.3 million day 17.7 million night	FHWA, Urban Mobility Report

Erlang C model parameters

Performance Target Selection

Ensure that *combined* ADS and remote operator *at least as reliable* as a dedicated human driver.

Assistance Request Rate × Prob. Missed Call ≤ Human Driver Failure Rate

$$r_v \times P_C(m,a) \le r_t$$

- **Assistance Request Rate, r_v:** No available data. Can use California DMV disengagement reporting as surrogates, supplementing with potential rates.
- **Human driver failure rate, r_t** = probability of human medical event
  - ⇒ Commercial airline pilots have 0.058 incapacitating medical event per 100,000 flight hours
  - ⇒ At 2.5 pilots per flight, medical event rate **r_t = 2.32×10^{-7} / hour**

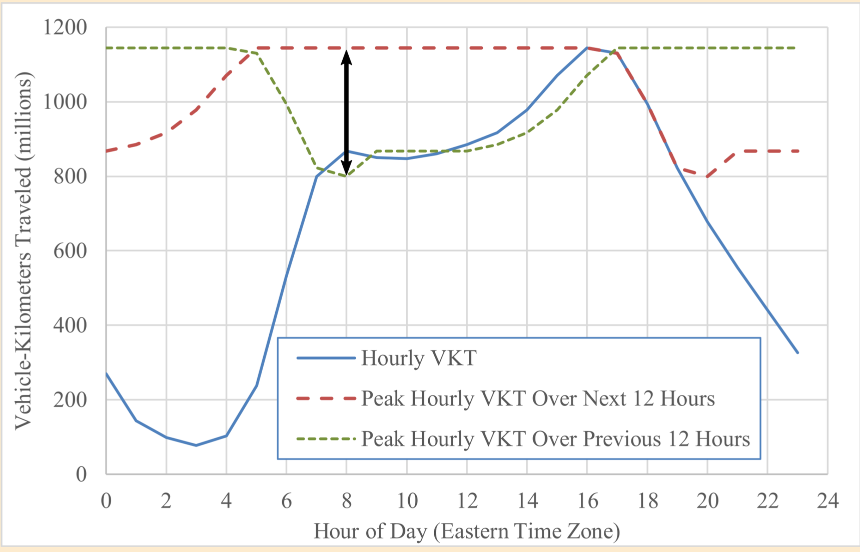
Description	Average hours between disengagements[a]	Disengagement rate per hour per vehicle, r_v
Once per hour	1	1
Once per 10 hours	10	10^{-1}
Waymo 2017	44	2.27×10^{-2}
GM Cruise 2018	185	5.41×10^{-3}
Waymo 2018	397	2.52×10^{-3}
Once per year for average driver	480	2.08×10^{-3}
Once per 1,000 hours	1,000	10^{-3}
Once per 10,000 hours	10,000	10^{-4}
Once per 100,000 hours	100,000	10^{-5}

[a] Converted from distance using National Household Travel Study average speed of 45 km/hr.

ADS disengagement rates as surrogates for assistance request rates

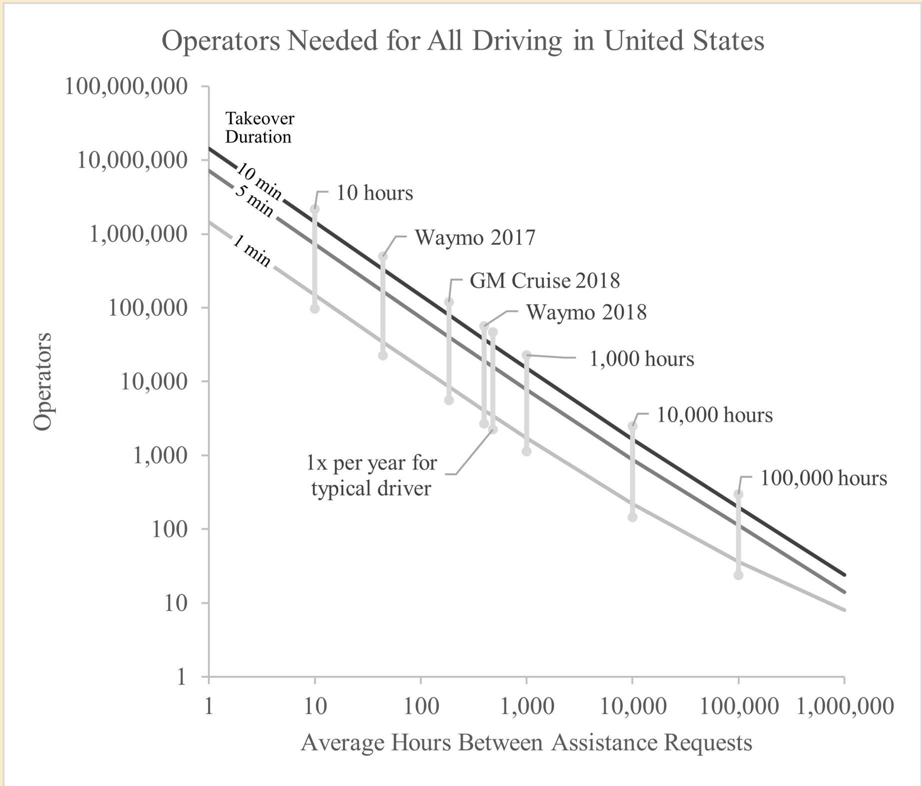
RESULTS

STAFFING REQUIREMENTS



Hourly vehicle-kilometers traveled (VKT) for a typical Friday in the United States.

Average Hours Between Disengagement Requests	Operators Needed to Manage all U.S. Driving		
	1 min/request	*5 min/request*	*10 min/request*
1	1,445,392	7,193,604	14,371,422
10	146,812	724,424	1,444,296
(Waymo 2017) 44	34,126	166,328	330,628
(GM Cruise '18) 185	8,452	40,298	79,676
(Waymo 2018) 397	4,074	19,072	37,538
(1x/driver/year) 480	3,402	15,846	31,150
1,000	1,710	7,772	15,184
10,000	220	878	1,658
100,000	36	112	198
1,000,000	8	14	24



Operators needed to manage all remote driving in the United States

Staffing assumptions

Rotating 12-hour shifts
Four days on, four days off
Staff needed = (Night shift + Day Shift) × 2

CONCLUSIONS

- Remote operation of vehicles on public roads is somewhat common in industry, yet has received little attention from regulators and researchers.
- Remote operation is not prohibited by most state motor vehicle codes, nor is it prohibited under most definitions of driver/operator. Other state laws imply a driver's physical presence.
- Of five reviewed states that address remote operation in their AV laws, only one requires that a remote operator must be physically located in the United States.
- Queueing theory was used to estimate the number of remote operators needed to manage a large fleet of AVs requesting occasional takeover. **At Waymo's 2018 disengagement rate, all driving in the United States could be managed by 4,000 to 37,000 operators working in shifts.** For comparison, 4.4 million are employed as drivers in the United States.

ACKNOWLEDGEMENTS

Michael Fontaine and Ramkumar Venkatanarayana reviewed drafts of this paper. Joseph Keogh contributed analysis.