Investigation of Autonomous Truck Platoons in Work Zones

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Should Truck Platoons "Talk"?

To themselves (internal communication)

To surrounding traffic

Extra communication needed near work zones?

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Presentation Structure

- Introduction
  - Motivations
  - Objectives
  - Autonomous truck platoon
- Methodology
- Results
- Conclusions and Discussions

Motivations

- Autonomous truck platoon (TP) is expected to be widely deployed in the near future
- How TP impacts surrounding vehicles remains unknown
- Work zones have elevated risk due to atypical driving environment
- Few regulation and guidance is presented

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Objectives

- Investigate the potential impacts of autonomous truck platoon toward surrounding traffic
- Provide suggestions for autonomous truck platoon manufactures regarding external displays
- Provide suggestions for policy makers regarding guidance and regulations

Autonomous truck platoon

- Multiple trucks follow one leading truck
- Autonomously or via technologies such as cooperative adaptive cruise control (CACC)
- Anticipated benefits:
  - Less labor required
  - Shorten headway -> higher efficiency use of existing capacity
  - Reduce fuel usage via drafting

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Presentation Structure

- Introduction
- Methodology
  - Simulator Study
    - Scenario Development
    - Psychophysics
  - Post-Simulator Survey
- Results
- Conclusions and Discussions

Why simulator studies?

- Safe - human subjects encounter minimal risk
- Controlled environment – eliminates potential bias brought by other factors; allows every human subject to experience the same scenario
- Cost-effective – multiple options tested at once; do not need to wait until a physical unit is available

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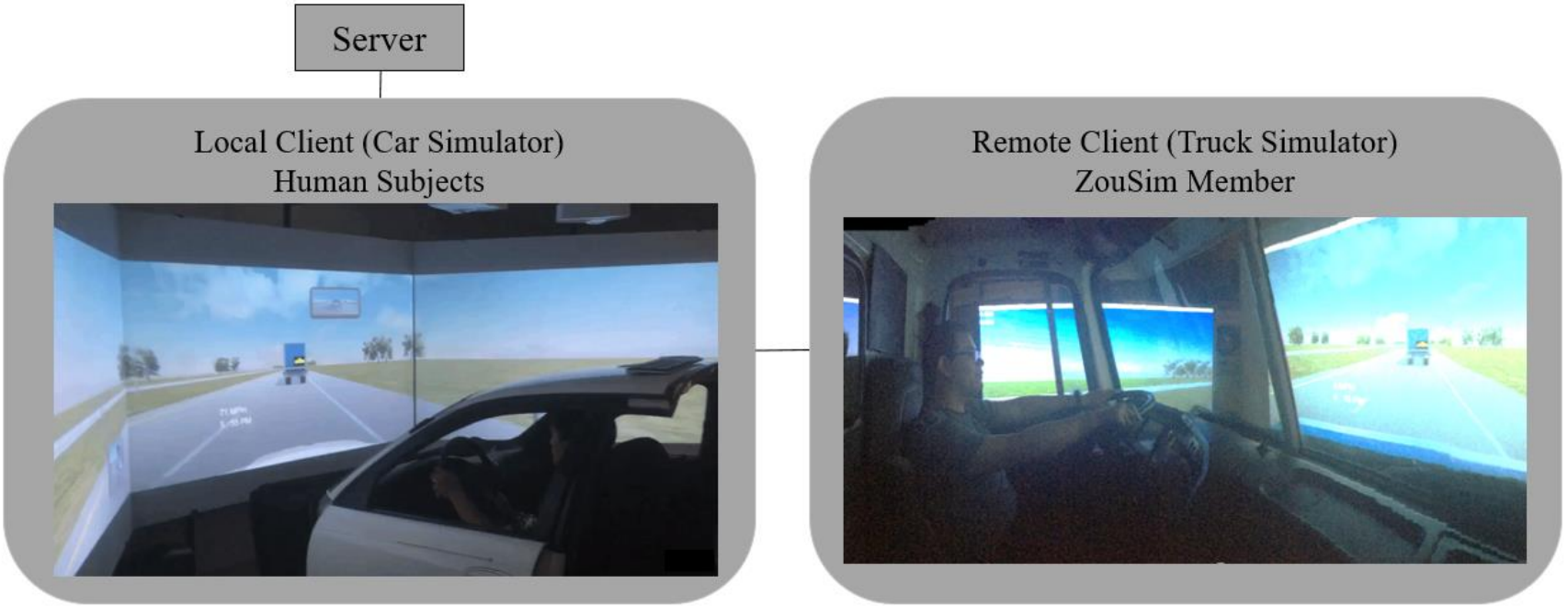
ZouSim Truck Simulator



- Mid-level Truck Simulator: Truck cab outfitted with electronic inputs
- Federated Simulator System – truck connected with car

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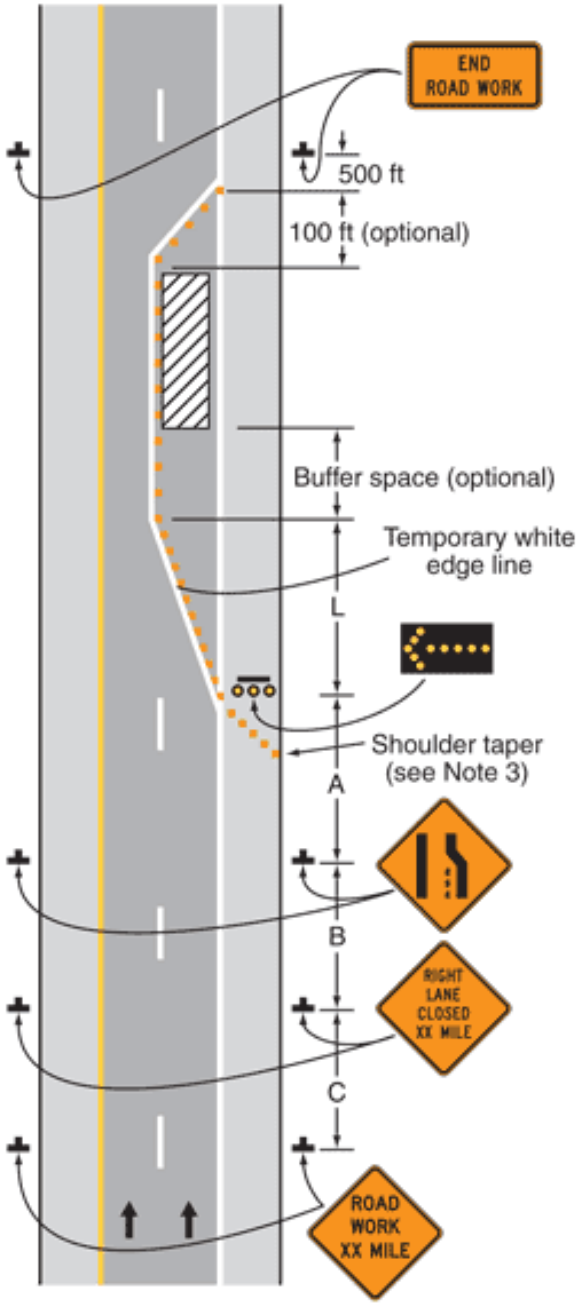
Work Zone Layout

MUTCD Typical Application 33 (FHWA 2009)



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Scenarios

Scenario	Education	Number of Trucks	Sign	Order
1	No	2	No	Randomized
2	No	4	No	
3	No	2	Truck Platoon	Randomized
4	No	4	Truck Platoon	
5	No	2	2 Trucks	
6	No	4	4 Trucks	
7	Yes	2	Truck Platoon	Randomized
8	Yes	4	Truck Platoon	
9	Yes	2	2 Trucks	
10	Yes	4	4 Trucks	

Education

- The following paragraph was read to the human subject after Scenario 6.

> "A platoon means the vehicles are travelling together as a group, and they interact with each other. Please do not cut in or interrupt the truck platoon."

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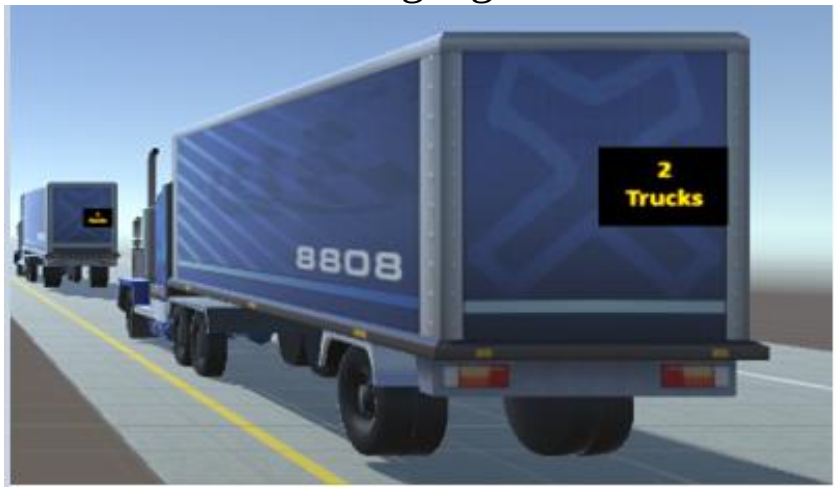
Truck Signs

No signage

Truck Platoon



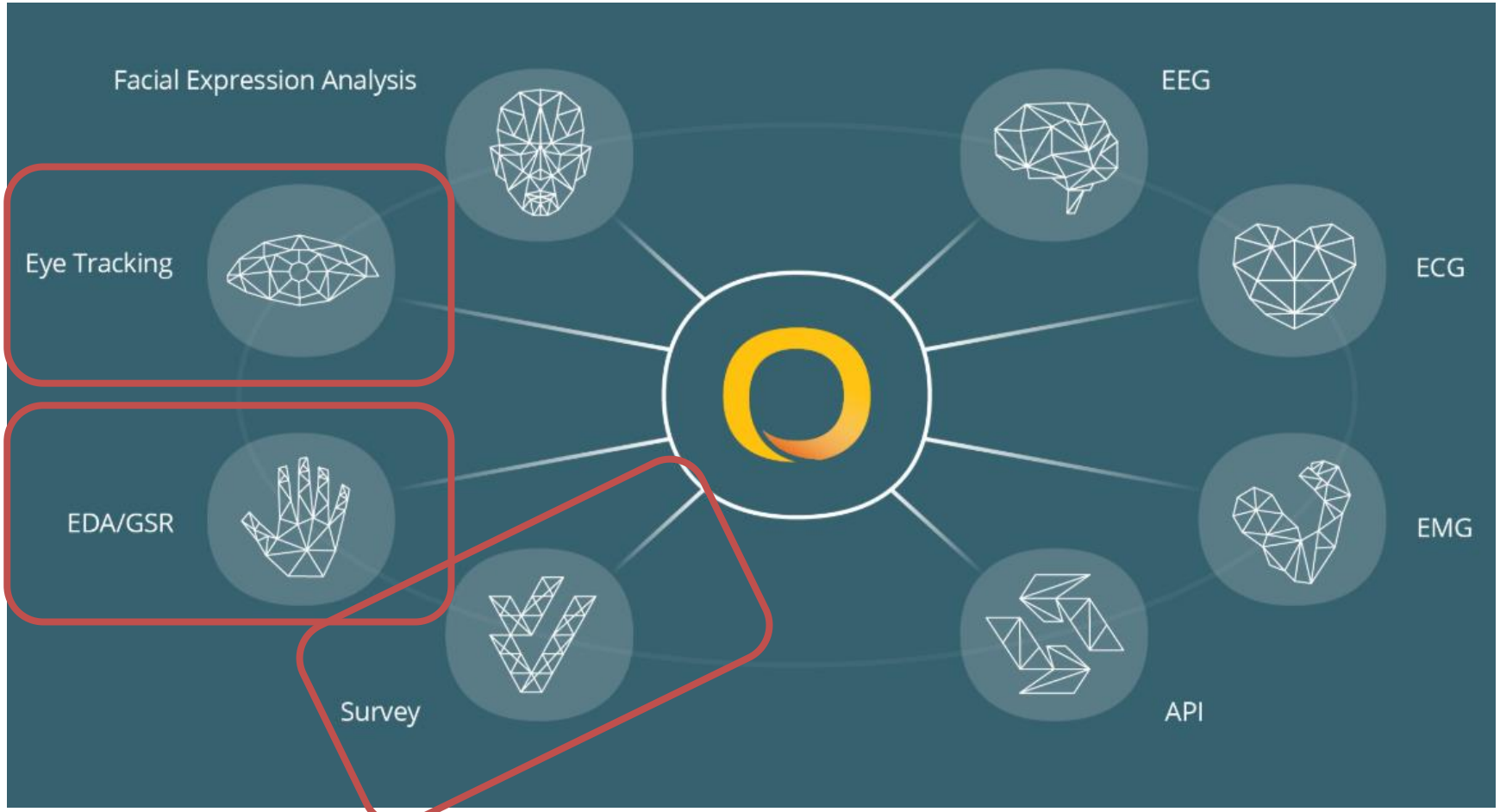
2 Trucks

4 Trucks

Measure of Effectiveness (MOE)

- MOE 1: driver behavior – follow/bypass/cut in
- MOE 2: distance between work zone and car when it merges (ft.)
- MOE 3: speed of car when it merges (mph)
- MOE 4: distance between car and the back of the last truck in the platoon when the car merges (ft.) when follow
- MOE 5 is the distance between car and the head of the leading truck in the platoon when the car merges to bypass
- MOE 6: record of braking of the car
- MOE 7: record of blinker use by the car

Psychophysics Utilization



Psychophysical Devices Utlized

- Tobii eye tracker – mounted on top of car dashboard

- Empatica E4 wristband – worn by human subjects

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Psychophysics Measurement

- Frequency and time of participants looking at specific spots (from eye tracker)
- Electrodermal activity (EDA)
- Blood volume pulse (BVP)
- Heart rate (HR)
- Skin temperature
- Acceleration

Stress Level

Psycho-physiological data was discarded in this study as it did not provide definitive insights

Post-Simulator Survey

- Key parts:
  - Importance of public education
  - Helpfulness of signage on the back of trucks
  - Impacts of the number of trucks in a truck platoon
- Demographic information
- Simulator Sickness Questionnaire (SSQ)

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Simulator Results

Number of Follows and Bypasses

		2 Truck		4 Truck	
		Count	%	Count	%
No Education	Follow	56	65.9%	58	64.4%
	Bypass	29	34.1%	32	35.6%
Education	Follow	39	67.2%	43	71.7%
	Bypass	19	32.8%	17	28.3%

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Level of Education Results Comparison

			2 Truck		4 Truck	
			Car Speed (mph)	Distance (ft.)	Car Speed (mph)	Distance (ft.)
No Education	Follow	Mean	39.27	933.71	39.26	943.02
	Bypass	Mean	47.10	-611.45	56.25	-315.69
Education	Follow	Mean	44.33	653.08	42.63	891.60
		% Difference	**12.90%**	**-30.06%**	**8.58%**	-5.45%
		p-value	**0.000**	**0.002**	**0.038**	0.343
	Bypass	Mean	51.00	-435.53	59.35	-279.59
		% Difference	8.27%	-28.77%	5.52%	-11.44%
		p-value	0.074	0.103	0.116	0.383

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Number of Trucks Results Comparison

			2 Truck		4 Truck	
			Car Speed (mph)	Distance (ft.)	Car Speed (mph)	Distance (ft.)
No Education	Follow	Mean	39.27	933.71	39.26	943.02
		% Difference			-0.02%	1.00%
		p-value			0.498	0.467
	Bypass	Mean	47.10	-611.45	56.25	-315.69
		% Difference			**19.42%**	**-48.37%**
		p-value			**0.001**	**0.038**
Education	Follow	Mean	44.33	653.08	42.63	891.60
		% Difference			-3.85%	**36.52%**
		p-value			0.142	**0.020**
	Bypass	Mean	51.00	-435.53	59.35	-279.59
		% Difference			**16.38%**	**-35.80%**
		p-value			**0.001**	**0.032**

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Number of Follows and Bypasses by Categories

		No Sign		Truck Platoon		# of Trucks	
		Count	%	Count	%	Count	%
No Education	Follow	43	75.4%	34	57.6%	34	58.6%
	Bypass	14	24.6%	25	42.4%	24	41.4%
Education	Follow	-	-	39	65.0%	40	69.0%
	Bypass	-	-	21	35.0%	18	31.0%

		No Sign		Truck Platoon		# of Trucks	
		Count	%	Count	%	Count	%
2 Trucks	Follow	23	82.1%	36	61.0%	36	64.3%
	Bypass	5	17.9%	23	39.0%	20	35.7%
4 Trucks	Follow	20	69.0%	37	61.7%	38	63.3%
	Bypass	9	31.0%	23	38.3%	22	36.7%

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Type of Signage and Level of Education Results Comparison

Comparing signs vs. no sign			No Sign		Truck Platoon		# of Trucks	
			Car Speed (mph)	Distance (ft.)	Car Speed (mph)	Distance (ft.)	Car Speed (mph)	Distance (ft.)
No Edu	Follow	% Diff	baseline	baseline	**8.66%**	-12.88%	6.74%	-13.13%
		p-value			**0.035**	0.140	0.081	0.113
	Bypass	% Diff	baseline	baseline	1.96%	-17.08%	0.68%	-25.85%
		p-value			0.407	0.355	0.465	0.269

No Education vs. Education			No Sign		Truck Platoon		# of Trucks	
			Car Speed (mph)	Distance (ft.)	Car Speed (mph)	Distance (ft.)	Car Speed (mph)	Distance (ft.)
No Edu	Follow	% Diff	-	-	baseline	baseline	baseline	baseline
		p-value	-	-				
	Bypass	% Diff	-	-	baseline	baseline	baseline	baseline
		p-value	-	-				
Edu	Follow	% Diff	-	-	**7.57%**	-16.47%	6.22%	**-21.20%**
		p-value	-	-	**0.033**	0.085	0.080	**0.033**
	Bypass	% Diff	-	-	2.11%	-16.79%	**10.99%**	-8.26%
		p-value	-	-	0.358	0.267	**0.028**	0.295

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Type of Signage and Number of Trucks Results Comparison

Comparing signs vs. no sign			No Sign		Truck Platoon		# of Trucks	
			Car Speed (mph)	Distance (ft.)	Car Speed (mph)	Distance (ft.)	Car Speed (mph)	Distance (ft.)
2 Trucks	Follow	% Diff	baseline	baseline	**17.76%**	**-24.85%**	**14.29%**	**-30.79%**
		p-value			**0.003**	**0.048**	**0.010**	**0.017**
	Bypass	% Diff	baseline	baseline	-7.10%	-13.34%	-3.81%	-22.93%
		p-value			0.246	0.401	0.353	0.321
4 Trucks	Follow	% Diff	baseline	baseline	**8.11%**	-16.29%	6.05%	-15.70%
		p-value			**0.028**	0.093	0.090	0.111
	Bypass	% Diff	baseline	baseline	10.49%	-31.62%	11.80%	-32.24%
		p-value			0.168	0.303	0.140	0.300

Survey Results

Demographic information

- Fairly diverse with respect to age and gender
- Age: 28% for 18 - 25, 44% for 26 - 40, 9% for 41 - 55, and 19% for 56 - 70 (Skewed towards younger participants)
- ~ 53% female
- 84% of participants claimed to be unfamiliar with truck platoons before the study

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Survey Results for Education, Number of Trucks Preference, and Reaction

Education was…	n	Mean	Median		
…helpful to understand the sign displayed on the truck.	30	4.23	5		
…to clarify how to react with the truck platoon.	32	4.75	5		
Reaction to truck platoons	n	Mean	Median		
more pressure felt when there are more trucks in the platoon	32	3.59	4		
Preference	n	Fewer trucks	More trucks		
	32	93.75%	6.25%		
Reaction to truck platoons	n	follow	bypass	merge between	follow others/ don't know
Safest	32	90.63%	9.38%	0.00%	0.00%
Would perform	32	62.50%	34.38%	0.00%	3.13%
From simulator data	293	66.89%	33.11%	0.00%	0.00%

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Survey Results for Preference Towards Type of Sign

		n	No Sign	Truck Platoon	"# of Trucks"
Identified correct meaning		32	-	100.00%	93.75%
Most preferred		32	6.25%	15.63%	78.13%
Easily understandable	Mean	32	-	3.81	4.06
	Median	32	-	5	5
	Diff	32		0.25	
	p-value	32		0.159	

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Summary of results

- Post-education vehicle speeds increased between 8.6% and 12.9% across scenarios and the distance headways decreased between 28.8% and 30%. (Higher efficiency under the work zone speed limit)
- 94% of the subjects believed it was safer not to bypass and yet around 34% chose to do so nonetheless.

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Conclusions

- The importance of education and revealed driver tendencies after learning about truck platooning is confirmed
- Signs are effective in changing driver behavior
- Significant differences in behavior while encountering two versus four trucks in a platoon

Discussions

- This study provided some initial guidance:
- Design and development of effective educational material -> promote safe and efficient driving near platoons
- Continued exploration of truck signage -> improve safety and efficiency
- Further investigate the tradeoffs in the number of trucks and to develop policies and guidelines -> balance logistical needs with work zone operations