Table 1. Travel time and delay for the test vehicle shown in Figure 2

	Direction	Trip 1	Trip 2	Trip 3	Trip 4	Trip 5	Trip 6	Trip 7	Trip 8	Average
Travel time (sec) - base condition	EB	447	585	408	459	365	461	431	354	439
	WB	390	445	514	415	549	367	409	427	440
Travel time (sec) - connected environment	EB	250	328	348	256	333	262	311	254	293
	WB	297	293	259	283	304	238	267	304	281
Difference in travel time (sec)	EB	-197	-257	-60	-203	-32	-199	-120	-100	-146
	WB	-93	-152	-255	-132	-245	-129	-142	-123	-159
% difference	EB	-44	-44	-15	-44	-9	-43	-28	-28	-32
	WB	-24	-34	-50	-32	-45	-35	-35	-29	-35

Note: Difference in travel time (an indicator of delay) is travel time in the connected environment minus travel time in the base condition. % difference is the difference in travel time divided by travel time in the base condition multiplied by 100.

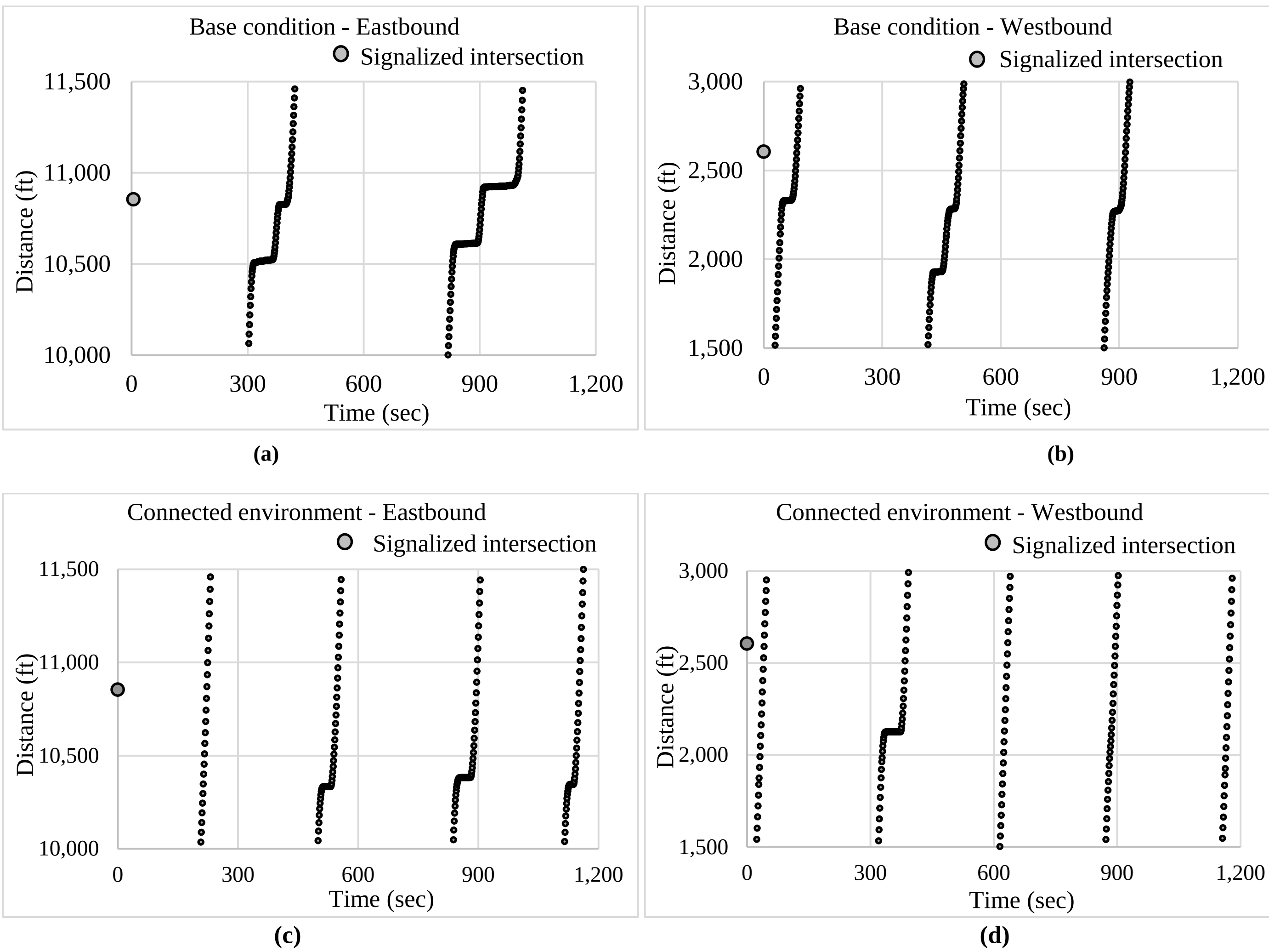

Figure 3. Distance-time plots for a test vehicle in the base condition and the connected environment at a signalized intersection

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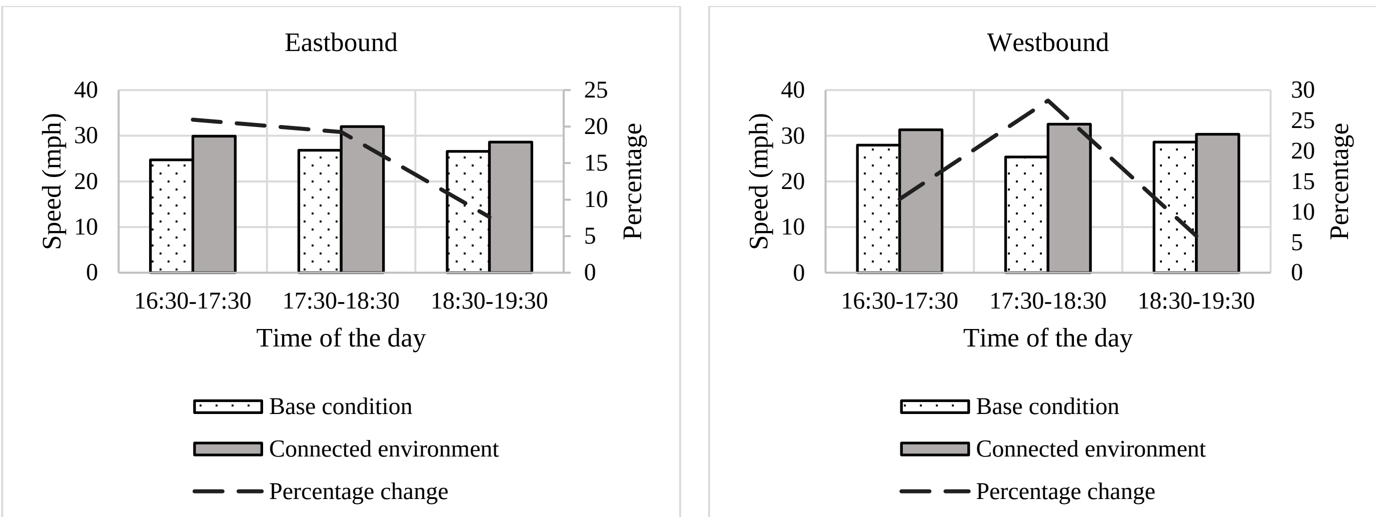
Table 2. Summary of speed (mph) - base condition and the connected environment

Vehicle	Direction	Time of the day 16:30-17:30		Time of the day 17:30-18:30		Time of the day 18:30-19:30	
		Base condition	Connected env.	Base condition	Connected env.	Base condition	Connected env.
Vehicle 1	EB	28.86	30.69	29.36	36.11	29.65	26.94
Vehicle 2	EB	18.49	28.63	20.72	30.84	21.18	30.67
Vehicle 3	EB	26.79	30.36	30.41	29.03	28.94	28.24
Vehicle 1	WB	26.89	33.46	28.98	34.73	27.89	31.80
Vehicle 2	WB	20.85	33.29	21.58	34.49	24.19	32.79
Vehicle 3	WB	36.08	27.20	25.51	28.35	33.76	26.42
Average	EB	24.71	29.89	26.83	31.99	26.59	28.61
	WB	27.94	31.32	25.36	32.53	28.61	30.34



(a) **(b)**

Figure 4. Average speed and percentage change in the speed - base condition compared to the connected environment

A one-tailed t-test was conducted to examine the statistical significance of an increase in the average speed in the connected environment. The null hypothesis is defined as the average speed in the base condition is greater than or equal to the average speed in the connected environment while the alternate hypothesis is defined as the average speed in the base condition is less than the average speed in the connected environment. The computed hourly average speeds in the base condition and the connected environment (irrespective of the direction of travel or time of the day) are 26.7 mph and 30.8 mph, respectively. The computed p-value is 0.007 (t-statistic = -2.73), indicating a significant increase in the average speed in the connected environment compared to the base condition. A similar analysis of speeds comparing trips that were departing within ±2-min also indicate a significant increase in the speed in the connected environment compared to the base condition.

CONCLUSION

In this research, the effectiveness of the connected vehicle environment was evaluated using real-world test vehicle data gathered from a connected vehicle testbed, MMITSS, located in Arizona, United States. DSRC technology (5.9 GHz) was used to communicate between roadside equipment and the test vehicles. The data stored in the server was used to optimize the signal phase/time.

The vehicle trajectories in the connected environment and base condition were plotted and analyzed. Lower variation in travel speeds and relatively fewer number of stops were observed in the connected environment compared to the base condition. The results show a 12% to 18% increase in the average speed of the test vehicles along the considered arterial corridor with six signalized intersections in the connected environment compared to the base condition. The increase in speeds or decrease in travel time from the trajectory data differed by the direction of travel and time of the day.

The underlying factors that influence the effectiveness of a connected vehicle environment should be further explored in the future. Further, the effectiveness by vehicle type and priority scenario like emergency vehicle, transit vehicle, or truck compared to a passenger car by time of the day and different traffic conditions should be explored using larger datasets in the future.

Also, the influence of the connected and automated environment on the operational performance at each individual intersection, along the corridor, and on the cross-streets merits an investigation. The data from other testbeds and technologies should also be compared to check how the effectiveness varies with the facility type, built environment, and technology.

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