Connecting Industry to Mathematics Instruction

NSF ATE Award # 1954291

Student Activity Sheet

In partnership with

WAKE TECH

WAKE COUNTY PUBLIC SCHOOL SYSTEM

WakeEd PARTNERSHIP

SEPI, Inc is an Engineering company started by Sepi Saidi in 2001 in Wake County. In this activity, you will determine how a stretch of highway in Wake County functions now and how it will function in the future.

Initial thought questions:

1. Have you ever been stuck in traffic?
2. List two or three reasons that traffic occurs.
3. List two or three ways to alleviate traffic issues.
4. Describe when roads are functioning at optimal level or traffic conditions are ideal.

Scenario:

As more people are moving to Wake County, our roads are becoming busier and are no longer functioning at an optimal level. Today, you are a civil engineer at SEPI, Inc. Your job is to analyze the traffic on a 1.25 mile stretch of I-40 in Wake County. This stretch of I-40W is a 4-lane highway (2 lanes in each direction) and has 3 interchanges (exit ramps) in each direction per 6 miles. A survey of the highway has found that the lanes are 12 feet wide with a 4 foot left shoulder, 10 foot right shoulder, and a 2.5% grade. We are going to analyze just the traffic flow traveling eastbound on I-40. The Traffic traveling eastbound during the morning peak (DDHV) is found to be 2,400 vehicles per hour. The peak hour factor is 0.9. Trucks are 6% of the peak hour traffic.

Vocabulary:

Free Flow Speed (FFS): the speed drivers drive on a segment of roadway when they feel free to travel at their desired speed and their speed is not impacted by the presence of other vehicles. This would be a low traffic situation.

Base Free Flow Speed (BFFS): measured during a time of day with relatively low volume. In practice, most times, Base Free Flow Speed is determined by either the roadway design speed, or by adding 5 mph to the speed limit if it is over 50 mph or adding 7 mph if the speed limit is under 50 mph.

Lane Width Adjustment (f_{LW}): The effect lane widths have on free flow speed. The narrower a lane, the more the free flow speed is reduced.

Right-Side Lateral Clearance (f_{RLC}): The effect that right shoulder width and the number of lanes in one direction has on free flow speed.

Formulas:

Free Flow Speed: FFS = BFFS - f_{LW} - f_{RLC} - 3.22(TRD)$^{0.84}$

Capacity: c (basic freeway segment) = 2,200+10(FFS - 50)

Demand Flow Rate: $v_p = \frac{V}{PHF \cdot N \cdot f_{HV}}$, where:

V = DDHV, demand volume under prevailing conditions, (vehicles/hr)

PHF = peak hour factor

N = number of lanes in analysis direction

Heavy Vehicle Adjustment Factor: $f_{HV} = \frac{1}{1+P_T(E_T-1)}$, where:

P_T = proportion of trucks in the traffic

E_T = passenger car equivalent for trucks

Density: $D = \frac{v_p}{S}$, where:

S = mean speed of traffic stream under base conditions (FFS)

Task 1: Determine the level of service for this stretch of roadway

1. Using the definition above, and the fact that the speed limit on the stretch of I-40 in question is 55 mph, what is the Base Free Flow Speed?

2. The table below shows the lane width adjustment (mi/h) given the average lane width.

Average Lane Width (ALW)	Reduction in FFS, (mi/hr)	Exhibit 12-20: Adjustment to FFS for Average Lane Width for Basic Freeway and Multilane Highway Segments
$ALW \geq 12$	0.0	
$11 \leq ALW < 12$	1.9	
$10 \leq ALW < 11$	6.6	

   a. What relationship do you notice between the Average Lane Width and the Reduction in FFS?

   b. Explain in a couple of sentences why you think this is the case?

   c. What is the Reduction in Free Flow Speed for our stretch of I-40?

3. The table below shows the right side lateral clearance (mi/h) given the number of lanes and width of the shoulder.

Right Side Lateral Clearance	Lanes in One Direction				Exhibit 12-21
	2	3	4	≥5	Adjustment to FFS for Right Side Lateral Clearance (mi/hr) for basic Freeway Segments
≥6	0.0	0.0	0.0	0.0	
5	0.6	0.4	0.2	0.1	
4	1.2	0.8	0.4	0.2	
3	1.8	1.2	0.6	0.3	
2	2.4	1.6	0.8	0.4	
1	3.0	2.0	1.0	0.5	
0	3.6	2.4	1.2	0.6	

   a. What relationship do you notice between the width of the shoulder, number of lanes, and the right-side lateral clearance?

   b. Explain in a couple of sentences why you think this is the case?

   c. What is the reduction in Free Flow Speed for our stretch of I-40?

4. The total ramp density, TRD, gives is the number of ramps per mile of a stretch of highway.
   a. How many exit ramps are there per 6 miles in each direction?

   b. How many total exit ramps are there in 6 miles?

   c. What is the total ramp density of our stretch of I-40?

5. Calculate the Free Flow Speed for this stretch of highway.

6. Determine the capacity (in pieces per hour per lane) for this stretch of highway.

7. Answer the following questions to determine the Demand Flow Rate.
   a. What are the units for Demand Flow Rate, v_p?

   b. In order to calculate the Demand Flow Rate, we need to determine the Heavy Vehicle Adjustment Factor.
      i. If we know from the problem set up that our stretch of highway has a 2.5% grade, the percentage of trucks is 6%, and the length of the highway is 1.25 miles, use Exhibit 12-26 to determine the Passenger Car Equivalent for Trucks.

      ii. What is the proportion of trucks in the traffic?

      iii. Determine the Heavy Vehicle Adjustment Factor.

   c. Using the information gathered from parts a and b, along with relevant information from the problem set up, determine the Demand Flow Rate.

Exhibit 12-26: PCEs for a mix of 30% SUTs and 70% TTs										
% Grade	**Length (mi)**	**Percentage of Trucks (%)**								
		2%	**4%**	**5%**	**6%**	**8%**	**10%**	**15%**	**20%**	**>25%**
-2	**0.125**	2.62	2.37	2.30	2.24	2.17	2.12	2.04	1.99	1.97
	0.375	2.62	2.37	2.30	2.24	2.17	2.12	2.04	1.99	1.97
	0.625	2.62	2.37	2.30	2.24	2.17	2.12	2.04	1.99	1.97
	0.875	2.62	2.37	2.30	2.24	2.17	2.12	2.04	1.99	1.97
	1.25	2.62	2.37	2.30	2.24	2.17	2.12	2.04	1.99	1.97
	1.5	2.62	2.37	2.30	2.24	2.17	2.12	2.04	1.99	1.97
0	**0.125**	2.62	2.37	2.30	2.24	2.17	2.12	2.04	1.99	1.97
	0.375	2.62	2.37	2.30	2.24	2.17	2.12	2.04	1.99	1.97
	0.625	2.62	2.37	2.30	2.24	2.17	2.12	2.04	1.99	1.97
	0.875	2.62	2.37	2.30	2.24	2.17	2.12	2.04	1.99	1.97
	1.25	2.62	2.37	2.30	2.24	2.17	2.12	2.04	1.99	1.97
	1.5	2.62	2.37	2.30	2.24	2.17	2.12	2.04	1.99	1.97
2	**0.125**	2.62	2.37	2.30	2.24	2.17	2.12	2.04	1.99	1.97
	0.375	3.76	2.96	2.78	2.65	2.48	2.38	2.22	2.14	2.09
	0.625	4.47	3.33	3.08	2.91	2.68	2.54	2.34	2.23	2.17
	0.875	4.8	3.5	3.22	3.03	2.77	2.61	2.39	2.28	2.21
	1.25	5.00	3.60	3.30	3.09	2.83	2.66	2.42	2.30	2.23
	1.5	5.04	3.62	3.32	3.11	2.84	2.67	2.43	2.31	2.23
2.5	**0.125**	2.62	2.37	2.30	2.24	2.17	2.12	2.04	1.99	1.97
	0.375	4.11	3.14	2.93	2.78	2.58	2.46	2.28	2.19	2.13
	0.625	5.04	3.62	3.32	3.11	2.84	2.67	2.43	2.31	2.23
	0.875	5.48	3.85	3.51	3.27	2.96	2.77	2.50	2.36	2.28
	1.25	5.73	3.98	3.61	3.36	3.03	2.83	2.54	2.40	2.31
	1.5	5.80	4.02	3.64	3.38	3.05	2.84	2.55	2.41	2.32
3.5	**0.125**	2.62	2.37	2.30	2.24	2.17	2.12	2.04	1.99	1.97
	0.375	4.88	3.54	3.25	3.05	2.80	2.63	2.41	2.29	2.22
	0.625	6.34	4.3	3.87	3.58	3.20	2.97	2.64	2.48	2.38
	0.875	7.03	4.66	4.16	3.83	3.39	3.12	2.76	2.57	2.46
	1.25	7.44	4.87	4.33	3.97	3.50	3.22	2.82	2.62	2.50

Exhibit 12-26: PCEs for a mix of 30% SUTs and 70% TTs										
% Grade	**Length (mi)**	**Percentage of Trucks (%)**								
		2%	**4%**	**5%**	**6%**	**8%**	**10%**	**15%**	**20%**	**>25%**
4.5	**0.125**	2.62	2.37	2.30	2.24	2.17	2.12	2.04	1.99	1.97
	0.375	5.80	4.02	3.64	3.38	3.05	2.84	2.55	2.41	2.32
	0.625	7.90	5.11	4.53	4.14	3.63	3.32	2.90	2.68	2.55
	0.875	8.91	5.64	4.96	4.50	3.92	3.56	3.07	2.82	2.67
	1	9.19	5.78	5.08	4.60	3.99	3.62	3.11	2.85	2.70
5.5	**0.125**	2.62	2.37	2.30	2.24	2.17	2.12	2.04	1.99	1.97
	0.375	6.87	4.58	4.10	3.77	3.35	3.09	2.73	2.55	2.44
	0.625	9.78	6.09	5.33	4.82	4.16	3.76	3.21	2.93	2.27
	0.875	11.20	6.83	5.94	5.33	4.56	4.09	3.45	3.12	2.93
	1	11.60	7.04	6.11	5.47	4.67	4.18	3.51	3.17	2.97
6	**0.125**	2.62	2.37	2.30	2.24	2.17	2.12	2.04	1.99	1.97
	0.375	7.48	4.90	4.36	3.99	3.52	3.23	2.83	2.63	2.51
	0.625	10.87	6.66	5.79	5.21	4.46	4.01	3.39	3.08	2.89
	0.875	12.54	7.54	6.51	5.81	4.94	4.40	3.67	3.30	3.08
	1	13.02	7.78	6.71	5.99	5.07	4.51	3.75	3.37	3.14

8. What are the units for Density?

9. Determine the Density of this stretch of highway.

10. Determine the Level of Service for our stretch of highway. Explain what that means in complete sentences.

Level of Service	Density (pc/mi/in)	Exhibit 12-15 LOS Criteria for Basic Freeway and Multilane Highway Segments
A	≤ 11	
B	> 11 - 18	
C	> 18 - 26	
D	> 26 - 35	
E	> 35 - 45	
F	Demand exceeds capacity or density > 45	

Task 2: Traffic Growth and Future Improvement

Eastbound morning traffic is expected to grow in this area at 4% per year. Using the information from task 1, determine the number of lanes needed to improve the level of service to the next level in 10 years.

11. Use the future growth equation, $V_n = V(1 + P)^n$ to determine the volume of traffic in 10 years.

12. If no improvements are made, what is the level of service for this volume in 10 years?

13. How many lanes will be needed to improve the level of service to the next level?

14. How many lanes will be needed to improve the level of service to level A based on this growth?

15. Why might it not be the best idea to improve the level of service to level A?