Impact of Coal Train Movement on Street Traffic Flows: A Case Study

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The impact of increased train movements through the city of Wilmington, North Carolina, on street traffic flows is evaluated. A comprehensive analysis involved a computer simulation of the city traffic flows based on traffic counts and other street geometric parameters secured by the Wilmington planning department. Sixteen critical railroad and street intersections plus major feeder streets were investigated in detail against three scenarios of train operations. These scenarios took into account train speeds, train lengths, and operating frequencies to transport an estimated 9 million tons of coal annually. Hourly delay figures were derived from the computer simulation runs, and total daily hours of vehicle delays were estimated. It was found that if unit trains are placed on the Belt Line, 453 to 730 vehicle-hr of delay daily will be added to the existing traffic-flow conditions depending on train speeds, lengths, and frequencies tested in the operating scenario. An estimate of public costs due to increased driving times for motorists was made. The result of the traffic simulations indicated a substantial yearly cost in vehicle delays to the public and that the speed of the trains is critical to minimizing delays in the traffic network.

The recent behavior of the international coal market--its steady rise followed by a quick retreat--points to the problem of making predictions on future demands for export products. During the past 2 yr, six firms announced plans to develop coal-shipping facilities along the Cape Fear River in Wilmington, North Carolina; most have cancelled these plans or at best are much more uncertain about following through on the investment.

In the long run, there seems to be no disagreement that the demand for coal will grow far in excess of any other energy commodity. The potential coal market export for Wilmington between now and the turn of the century is probably far less than indicated by prompters of export facilities during the past several years. Determining that market involves a great deal of uncertainty. Two major factors that help to define the city's potential as a location for coal exports are the effectiveness of the transportation system and the availability of coal export sites.

Previous studies conducted by the State Coastal Management Program estimated coal storage and loading capacities at the State Port to have a range of 4 to 9 million tons. Site visits conducted during this research generally confirmed the upper limit of this range.

THE PROBLEM

If the State Port is to be considered for coal export, the Seaboard Coast Line would serve their facilities with 70-car unit trains; each car would have a hauling capacity of 100 tons. In order to serve an export facility of 9 million tons, an average of four trains per day would be required on a 365-day/yr schedule. The Wilmington Belt Line (Figure 1) is a semiclosed loop that crosses many city streets. The introduction of unit trains on the Wilmington Belt Line will substantially increase the amount of rail traffic through the city, which will cause vehicular traffic delays that are not now factors in street traffic flow. It is the main objective of this study to evaluate the impact on vehicle hours of delay of the increased unit-train movements through the city of Wilmington.

DELAY-ESTIMATION METHODOLOGY

The uniqueness of the semiclosed railroad loop of the Belt Line and the fact that some streets extend over a significant portion of the loop width require an analysis with a systemwide approach; this means that the street network of Wilmington is dealt with as one unit, in which a queue buildup on one artery is assumed to delay traffic on other connecting streets.

The immense data analysis of the traffic flow on the street network requires computer simulation methods. The NETSIM network simulation model, formerly called UTCS-1, was adapted and then used for the traffic-flow analysis of this research (1). This program is used widely in urban traffic evaluation studies because it has the capacity to make systemwide evaluations of city traffic flows. Given street designs and traffic counts, the model moves each individual vehicle through the street network based on its type (automobile, bus, or truck), average speed, average discharge headway, average acceptable gap, and so on.

The adaptation of the NETSIM model to Wilmington was accomplished by treating the unit train as a vehicle that always has a green light at all the city's street crossings. Thus, in the case of a 4,000-ft train traveling 10 mph, the train occupies the crossing for 272 sec, which has the same effect as a red light that lasts 4.5 min. Because it takes a unit train traveling 10 mph more than 0.5 hr to cover the Belt Line distance, it can be assumed that no more than one train per hour will be in operation on the Belt Line (also considering the track capacities at the State Port). An increase in train speed to 20 mph does not significantly affect this assumption. Once the train clears the intersection after the 4.5-min delay, the intersection vehicle traffic flow is treated as though it has a green signal for the remaining 55.5 min of the hour.

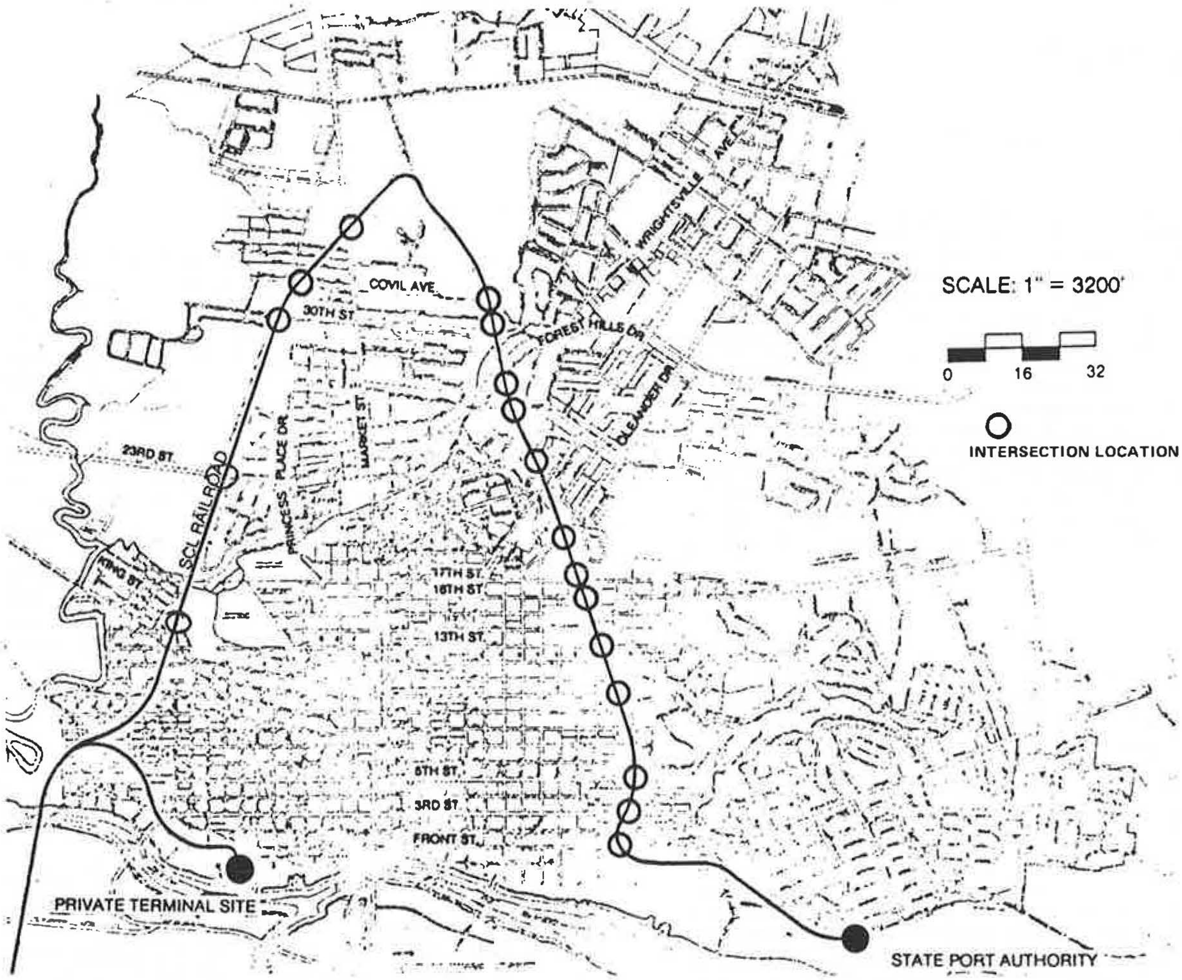
TRAIN CHARACTERISTICS

As mentioned earlier, operating procedures of the Seaboard Coast Line indicate that a 70-car unit train will be used to serve the coal export facility. The total train length, including four diesel engines and an allowance for slack, would be approximately 4,000 ft. Given the physical configuration of the Belt Line loop and assuming necessary track upgrading to accommodate the heavier unit train, it is estimated that speeds are limited to 10 to 20 mph. The use of 70-car trains would require an average of four trains per day to serve a 9-million-ton (annual) coal export facility at the State Port.

STREET TRAFFIC CHARACTERISTICS

The street traffic data used in the NETSIM model concentrate on major arterials in the city identified by the Wilmington Planning Department as the most critical to street traffic flows. These are shown in Figure 1.

Figure 1. Wilmington Belt Line layout.



For each railroad crossing and adjacent street intersections, data were collected by the planning department on approach lengths, number of street lanes, lane configurations, speed limits, signal timings, and turning percentages. Daily traffic counts were made by the planning department for each of the primary streets that cross the Belt Line and for feeder streets.

The traffic counts indicated that the peak hours constituted between 10 and 12 percent of the daily counts. Assuming that the a.m.-peak (7:30 to 8:30) flow and the p.m.-peak (4:30 to 5:30) flow are equal and that each amounts to 11 percent of the average daily traffic (ADT), the remaining 78 percent of the daily traffic will be equal to the sum of the off-peak flows. It was assumed that the vehicular traffic was concentrated between 6:00 a.m. and 10:00 a.m. and between 6:00 p.m. and 10:00 p.m. Therefore, the off-peak period amounts to a total of 14 hr. The average off-peak hour thus constitutes approximately 5.5 percent of the ADT (i.e., one-half of the peak-period flow). The peak hourly flow rates for the 16 major streets at the railroad crossings are shown in Table 1.

OPERATIONAL SCENARIOS

Three operational models were designed to evaluate the impact of unit trains on street traffic flows. The options listed below provide a reasonably comprehensive testing of traffic effects due to number of trains, length, and speed given the physical characteristics of the Belt Line. Each scenario assumes the continued operation of the current 2,000-ft mixed-freight train that travels daily on the Belt Line:

Scenario 1: Daily operation of four 4,000-ft

Table 1. Hourly flow rates during p.m.-peak hour at railroad crossings.

Intersection	Flow Rate (vehicles/hr) Inbound	Outbound
King Street	52	52
23rd Street	616	420
30th Street	250	282
Princess Place Drive	522	347
Market Street	757	1,347
Covil Avenue[a]	93	93
Forest Hills Drive	240	240
Colonial Drive	100	100
Wrightsville Avenue	974	541
Oleander Drive	660	1,340
17th Street[b]	1,002	-
16th Street[b]	-	931
13th Street[b]	220	220
5th Street[b]	130	130
3rd Street	484	616
Front Street	301	502

[a]Peak-hour counts were not available and a fixed percentage of ADT was assumed.
[b]One-way street.

unit trains traveling 10 mph for a total of 10 one-way trips. It is assumed that a single trip will occur during the morning and the evening rush hours.

Scenario 2: Daily operation of one 2,000-ft train (i.e., a split unit train) at a speed of 20 mph during the morning and the evening rush hours. The remaining trips per day will consist of two 2,000-ft trains and three 4,000-ft trains traveling at speeds of 10 mph. This operation will require a total of 12 one-way trips.

Scenario 3: Daily operation of four 4,000-ft trains traveling at speeds of 20 mph for a total of 10 one-way trips. It is assumed that a single trip occurs in the morning and in the evening rush hours.

DELAY RESULTS

The total vehicular delay, average delay per vehicle, and changes in total delay were provided from the NETSIM runs for 16 streets crossed by the railroad track. The results are shown in Tables 2, 3, and 4 for each scenario of train operations.

The analysis was extended to an evaluation of the effects of the operating scenarios on nine other critical intersections connected to the major streets that cross the railroad. The vehicular flow rates, total delay, and average delay per vehicle for those intersections are shown in Table 5. The intersection of Market Street and 30th Street and the intersection of 16th Street and Dawson Street were found to be two bottlenecks in the system under the existing conditions. The introduction of a unit train on the Belt Line would substantially worsen traffic flows at these intersections.

To evaluate what would happen to traffic delays if train speeds were increased, an incremental analysis was conducted between scenarios 1 and 3 as shown in Table 6. The results indicated that for most intersections, even a 10-mph increase in train speeds would result in significant decreases in traffic delays.

The results of the off-peak traffic simulation delays are shown in Tables 7 and 8. A comparison between the increase in total delay for the p.m.-peak (Tables 2, 3, and 4) and the off-peak hours (Table 7) shows that the peak delay will be much greater than would be expected solely on the basis of differences in traffic volumes during the two travel periods.

The delay impacts for scenario 1 and scenario 3 are the same for off-peak traffic flows because train lengths and speeds for these scenarios were varied only during the peak traffic hours. The incremental total delay results for off-peak traffic due to the strategy of increasing train speeds are shown in Table 8. It is important to point out that most of the observed percentages of decrease in total delay due to the strategy of increasing speed from 10 mph to 20 mph are higher for the off-peak hours than for the peak hours. This finding may be

Table 2. Changes in vehicular delays with scenario 1 during p.m.-peak hour at railroad crossings.

Intersection	Existing Conditions: Total Delay (vehicle-min)	Existing Conditions: Avg Delay per Vehicle (sec)	Scenario 1[a]: Total Delay (vehicle-min)	Scenario 1[a]: Avg Delay per Vehicle (sec)	Increase in Total Delay (vehicle-min)
King Street	1.80	1.00	17.37	9.65	15.57
23rd Street	401.90	19.36	893.80	43.07	491.90
30th Street	18.40	2.33	161.00	20.42	142.60
Princess Place Drive	72.00	4.86	223.80	15.12	151.80
Market Street	242.40	8.31	902.00	30.94	659.60
Covil Avenue	17.40	5.49	44.90	14.17	27.50
Forest Hills Drive	43.70	4.61	206.40	21.06	162.70
Colonial Drive	10.40	2.66	43.70	11.20	33.30
Wrightsville Avenue	84.60	3.55	450.20	18.91	365.60
Oleander Drive	213.30	6.40	859.20	25.78	645.90
17th Street	15.40	0.88	222.60	12.72	207.20
16th Street	42.00	3.82	192.10	17.51	150.10
13th Street	25.50	3.11	129.60	15.83	104.10
5th Street	10.40	2.73	72.30	18.22	61.90
3rd Street	8.30	0.45	166.80	9.21	158.50
Front Street	27.90	2.10	178.70	13.48	150.80

[a]A 4,000-ft train traveling 10 mph.

Table 3. Changes in vehicular delays with scenario 2 during p.m.-peak hour at railroad crossings.

Intersection	Existing Conditions: Total Delay (vehicle-min)	Existing Conditions: Avg Delay per Vehicle (sec)	Scenario 2[a]: Total Delay (vehicle-min)	Scenario 2[a]: Avg Delay per Vehicle (sec)	Increase in Total Delay (vehicle-min)
King Street	1.80	1.00	3.60	2.00	1.80
23rd Street	401.90	19.36	540.20	26.00	138.30
30th Street	18.40	2.33	78.70	10.13	60.30
Princess Place Drive	72.00	4.86	109.30	7.49	37.30
Market Street	242.40	8.31	431.90	14.63	189.50
Covil Avenue	17.40	5.49	21.20	6.50	3.80
Forest Hills Drive	43.70	4.61	83.10	8.82	39.40
Colonial Drive	10.40	2.66	16.00	4.19	5.60
Wrightsville Avenue	84.60	3.55	123.70	5.23	39.10
Oleander Drive	213.30	6.40	401.90	12.04	188.60
17th Street	15.40	0.88	32.20	1.84	16.80
16th Street	42.00	3.82	50.70	4.71	8.70
13th Street	25.50	3.11	33.00	4.03	7.50
5th Street	10.40	2.73	16.70	4.21	6.30
3rd Street	8.30	0.45	42.20	2.32	31.80
Front Street	27.90	2.10	60.10	4.52	32.20

[a]A 2,000-ft train traveling 20 mph only during the peak hour.

Table 4. Changes in vehicular delays with scenario 3 during p.m.-peak hour at railroad crossings.

	Existing Conditions		Scenario 3[a]		
Intersection	Total Delay (vehicle-min)	Avg Delay per Vehicle (sec)	Total Delay (vehicle-min)	Avg Delay per Vehicle (sec)	Increases in Total Delay (vehicle-min)
King Street	1.80	1.00	4.23	2.35	2.43
23rd Street	401.90	19.36	589.80	28.42	187.90
30th Street	18.40	2.33	91.60	11.61	73.20
Princess Place Drive	72.00	4.86	161.90	10.93	89.90
Market Street	242.40	8.31	587.70	20.16	345.30
Covil Avenue	17.40	5.49	29.20	9.22	11.80
Forest Hills Drive	43.70	4.61	118.60	12.52	74.90
Colonial Drive	10.40	2.66	17.50	4.48	7.10
Wrightsville Avenue	84.60	3.55	194.20	8.15	109.60
Oleander Drive	213.30	6.40	521.60	15.63	308.30
17th Street	15.40	0.88	76.80	4.38	61.40
16th Street	42.00	3.82	79.20	7.22	37.20
13th Street	25.50	3.11	58.40	7.13	32.90
5th Street	10.40	2.73	34.40	9.05	24.00
3rd Street	8.30	0.45	135.50	7.48	127.20
Front Street	27.90	2.10	129.10	9.74	101.20

[a]A 4,000-ft train traveling 20 mph.

Table 5. Vehicular delays for p.m.-peak hour at critical intersections on both sides of railroad crossings.

	Existing Conditions			Scenario 1			Scenario 2			Scenario 3		
Intersection	Flow Rate (vehicles/hr)	Total Delay (vehicle-min)	Avg Delay (sec)	Flow Rate (vehicles/hr)	Total Delay (vehicle-min)	Avg Delay (sec)	Flow Rate (vehicles/hr)	Total Delay (vehicle-min)	Avg Delay (sec)	Flow Rate (vehicles/hr)	Total Delay (vehicle-min)	Avg Delay (sec)
Princess Place and 23rd Street	1,952	3,094.70	95.12	1,920	4,544.30	142.00	1,977	3,297.80	100.00	1,951	4,782.40	147.07
Princess Place and 30th Street	1,300	516.10	23.28	1,290	522.70	24.31	1,319	524.00	23.83	1,322	542.70	24.63
Market Street and 30th Street	2,038	7,098.40	208.98	1,867	22,097.0	710.13	1,977	15,562.30	708.00	1,973	16,466.6	500.75
Forest Hills Drive and Colonial Drive	701	81.70	6.99	702	209.86	17.93	693	164.90	14.27	701	171.6	14.64
Wrightsville Avenue and Colonial Drive	1,606	173.30	6.47	1,603	299.60	11.21	1,604	257.30	9.62	1,605	289.10	10.80
Oleander Drive and Columbus Circle	2,025	258.10	7.65	2,020	629.40	18.64	2,093	468.70	13.80	2,050	593.70	17.40
Oleander Drive and Dawson Street	939	55.90	3.57	946	305.72	19.40	941	80.20	5.61	961	122.60	7.65
17th Street and Marsteller Street	1,047	87.00	4.98	1,056	398.10	22.61	1,047	346.30	19.04	1,046	326.20	18.71
16th Street and Dawson Street	1,536	4,514.40	176.34	1,509	12,472.10	495.90	1,510	12,283.40	488.08	1,568	11,466.40	438.76

Table 6. Incremental delay results for p.m.-peak hour at major railroad crossings due to increased train speed.

Intersection	Decrease in Total Delay due to Train Speed Increase[a] (vehicle-min)	Percentage of Decrease in Total Delay
King Street	13.14	75.65
23rd Street	304.00	34.00
30th Street	69.40	43.10
Princess Place Drive	61.90	27.65
Market Street	314.30	34.84
Covil Avenue	15.70	34.96
Forest Hills Drive	87.80	42.53
Colonial Drive	26.20	59.95
Wrightsville Avenue	256.00	56.86
Oleander Drive	337.60	39.29
17th Street	145.80	65.49
16th Street	112.90	58.77
13th Street	71.20	54.93
5th Street	37.90	52.42
3rd Street	31.30	18.76
Front Street	49.60	27.75

[a]Total vehicular delay of scenario 1 minus total vehicular delay of scenario 3.

attributed to the differences in size of queues during the peak and off-peak hours.

To evaluate the three operational scenarios, it was found necessary to estimate the total vehicle delays on a networkwide basis and to combine the peak-hour and off-peak-hour results to produce daily delay results. The total traffic network delay statistics for the peak and off-peak hours were generated by the NETSIM computer model. These are shown in Table 9. The results of these calculations are much higher than the sum of the individual intersection values shown in Tables 2, 3, 4, and 7 because the delay due to vehicle acceleration on the links leaving the intersections was not accounted for in those tables. To estimate the average daily delay in vehicle hours, it was assumed that train arrivals to the Belt Line follow a Poisson probability distribution. The calculations of the average daily delays for the three scenarios are shown below. The average total delay is calculated for the high level of forecast train traffic (five trains):

Table 7. Change in total vehicle delays with three scenarios for off-peak hours at railroad crossings.

Intersection[a]	Existing Conditions (vehicle-min)	Scenario 1 (vehicle-min) Total Delay	Scenario 1 Increase in Total Delay	Scenario 2 (vehicle-min) Total Delay	Scenario 2 Increase in Total Delay	Scenario 3 (vehicle-min) Total Delay	Scenario 3 Increase in Total Delay
23rd Street	153.40	334.50	181.10	334.50	181.10	210.40	57.00
30th Street	9.40	68.90	59.50	68.90	59.50	31.70	22.30
Princess Place Drive	33.00	116.70	83.70	116.70	83.70	56.30	23.30
Market Street	119.60	494.80	375.20	494.80	375.20	235.10	115.50
Covil Avenue	10.90	33.20	22.30	33.20	22.30	13.00	2.10
Forest Hills Drive	20.50	86.30	65.80	86.30	65.80	44.40	23.90
Colonial Drive	5.40	25.40	20.00	25.40	20.00	9.10	3.70
Wrightsville Avenue	34.90	175.20	140.30	175.20	140.30	86.60	33.70
Oleander Drive	90.60	378.70	268.10	378.70	268.10	194.50	103.90
17th Street	4.10	131.20	127.10	131.20	127.10	36.00	31.90
16th Street	32.30	134.70	102.40	134.70	102.40	58.80	26.50
13th Street	11.60	65.10	53.50	65.10	53.50	23.50	11.90
5th Street	5.60	21.10	15.50	21.10	12.00	6.40	6.40
3rd Street	3.60	103.90	100.30	103.90	100.30	57.20	56.30
Front Street	13.20	107.00	93.80	107.00	93.80	60.20	47.00

[a]There was a negligible off-peak impact for King Street.

5 trains/day = 10 one-way trips/day,
16 hr of vehicular traffic daily,
Average number of trains per hour = m = 10/16 = 0.625.

The Poisson probability distribution is

$P(X) = e^{-m}m^X/X!$

$P(X \geq 1) = 0.4647$ = probability that one or more trains will arrive in any given hour.

Scenario 1

Change in peak-hour delay = +30,595.1 vehicle-min,
Change in off-peak delay = +2,361.2 vehicle-min,
Average delay per day = (30,595.1) (2) (0.4647) + (2,361.2) (14) (0.4647) = 43,800 vehicle-min/day = 730.00 vehicle-hr/day.

Table 8. Incremental total delay results for off-peak hours at major railroad crossings due to increased train speed.

Intersection[a]	Decrease in Total Delay due to Train Speed Increase[b] (vehicle-min)	Percentage of Decrease in Total Delay
23rd Street	124.10	37.10
30th Street	37.20	53.99
Princess Place Drive	60.40	51.75
Market Street	259.70	52.48
Covil Avenue	20.20	60.84
Forest Hills Drive	41.90	48.55
Colonial Drive	16.30	64.17
Wrightsville Avenue	106.60	60.84
Oleander Drive	177.50	48.64
17th Street	95.20	75.56
16th Street	75.90	56.34
13th Street	41.60	63.90
5th Street	9.10	43.12
3rd Street	46.70	44.94
Front Street	46.80	45.60

[a]Negligible off-peak impact at King Street.
[b]Total vehicular delay of scenario 1 minus total vehicular delay of scenario 3.

Scenario 2

12 one-way trips/day, $P(X \geq 1) = 0.5276$,
Average delay per day = (18,365.7) (2) (0.5276) + (2,495.7) (14) (0.5276) = 37,816 vehicle-min/day = 630.26 vehicle-hr/day.

Scenario 3

Average delay per day = (21,068.4) (2) (0.4647) + (1,170.1) (14) (0.4647) = 27,192 vehicle-min/day = 453.20 vehicle-hr/day.

TRAVEL-DELAY COSTS

The loss in travel time due to vehicle delays will generate both direct and indirect public costs. Various measures to translate delays into tangible dollar amounts have been used in transportation studies; however, because people value their time differently, it is impossible to assign a value that precisely accounts for each person's delay costs.

A literature review was performed to determine an appropriate value of time (VOT) to convert travel-time delay to an economic cost. The assumed VOT was $6.00/passenger hour of delay. This value was obtained by adjusting the $2.70/passenger-hour value estimated by Stover, Adkins, and Goodknight (2) by using the appropriate consumer-price-index factor, and the adjusted value was found to be $4.38. A vehicle-occupancy factor of 1.37 was used to account for average passenger loads (as developed from city traffic surveys) (3). Annual delay costs were calculated for a period of 250 working days in any given year. The estimated annual costs amounted to $1,095,000, $945,390, and $679,800 for scenarios 1, 2, and 3, respectively.

The totals indicate that unit-train operations will result in substantial public driving-time costs on a yearly basis. Given these costs, if plans are developed that lead to coal export operations at the State Port, it is clearly in the city's interest that track speeds be increased to more than the estimated 10-mph minimum.

Table 9. Total network delay for p.m.-peak hour and single off-peak hour during train movements.

Time Period	Existing Conditions (vehicle-min)	Scenario 1 (vehicle-min) Total	Scenario 1 Change	Scenario 2 (vehicle-min) Total	Scenario 2 Change	Scenario 3 (vehicle-min) Total	Scenario 3 Change
P.M. peak	23,712.1	54,307.2	30,595.1	42,077.8	18,365.7	44,780.5	21,068.4
Off peak	2,854.1	5,215.3	2,361.2	5,349.8	2,495.7	4,024.2	1,170.1

SUMMARY AND FINDINGS

The introduction of unit trains on the Wilmington Belt Line will substantially increase the amount of rail traffic through the city, which will cause traffic delays that are not now factors in street traffic flow. Currently, there is only a single train per day that travels the entire Belt Line loop. Four additional trains, each roughly two to three times the length of the current single train, will be required to move coal tonnage for a 9-million-ton facility at the State Port.

Computer simulation was used to estimate hourly vehicular delay at the 16 major intersections between streets and the railroad in Wilmington during peak hours and off-peak hours. Nine intersections between streets were also evaluated for the same time periods. Average daily delays for three operational scenarios were calculated, and their corresponding annual costs were determined. The major findings of this case study are listed below:

1. The length of the Belt Line, its single-track construction, and the loop configuration and consequent speed restrictions allow under the worst conditions the possibility of no more than one train during the morning and one during the evening rush hour.
2. The intersections of Market Street and 30th Street and 16th Street and Dawson Street will be the areas most severely affected in terms of vehicle delays.
3. On a daily basis, during the Monday through Friday work week, unit-train operations can be expected to cause total traffic delays ranging from 453 to 730 vehicle-hr, depending on train speeds, lengths, and frequencies.
4. The public cost of the delays is assumed to involve, at a minimum, a value for the driver's time and an increased vehicle operating expense due to engine idling. For purposes of analysis, a $6.00/hr value is used for driving time, and it is recognized that individual values of time may vary substantially. Given this value, the annual increase in driving-time costs can be expected to range from $679,800 to $1,095,000. Public costs due to engine idling during delays can be expected to range from $84,839 to $136,656.
5. The higher ranges of potential public costs will result if unit trains are operated at 10-mph averages. An increase to 20-mph average speed for the trains on the Belt Line will reduce street traffic delays by approximately 40 percent.

POLICY RECOMMENDATIONS

If unit trains are placed in service, the city should encourage the Seaboard Coast Line to make improvements necessary to increase average operating speeds to 20 mph. Any increment over 10 mph should not be overlooked in its importance to reducing street traffic delays. The city also should work with the railroad toward avoiding train movements during street rush hours.

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