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EFFECTS OF RESTRAINED HIGHWAY SPEEDS ON PROJECTIONS OF TRAVEL PATTERNS AND MODAL CHOICE

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This paper discusses the impact that use of restrained highway speeds may have in the simulation of future travel patterns. The investigation is made in 3 stages: at the time that choice of mode of travel is made, at the time of trip distribution, and at the time that automobile and transit trips are assigned to their respective networks. The comparison is made against the simulated travel pattern that is based on highway speeds previously determined as policy speeds. A review of the results indicates that a 15 percent increase in transit system accessibility produces approximately a 10 percent increase of transit trips in regions like the Philadelphia SMSA. This 10 percent increase in transit corresponds to approximately a 1.7 percent reduction in highway trips. The major transit diversion occurs in work trips and in central city trips. Most of the diversion (about 70 percent) took place within the central part of the region and along the corridor of the new rapid transit line from Philadelphia to Lindenwold.

AS PART of the work program of the Delaware Valley Regional Planning Commission (DVRPC), an investigation was undertaken to ascertain the impacts of using the restrained highway speeds in projecting the 1985 travel patterns by mode of travel, by type of facility, and by subarea of travel within the region. The task involved the resimulation of the district-level travel projections for 1985 and their comparisons with earlier projections made by using the set of policy speeds that were adopted by the policy committee of the agency. In more specific terms, the resimulation required the resimulation of the modal split projections, distribution of the automobile and transit trips, and submodal split projections, and the reassignment of automobile and transit trips to the corresponding networks. The only phase of simulation process exempted was the trip generation; thus, total person trips generated for the region in 1985 remained unchanged at approximately 14.4 million.

Table 1 gives the differences between the policy speeds and the restrained speeds. The reference to policy speed for each facility of the highway network refers to the speed that was determined during the initial travel projections or the desirable speed on the basis of the type of the facility, its location, and a policy determination of what a desirable speed would be in each subarea and type of facility of the region in 1985. These speeds were developed by the staff and approved as policy inputs by the policy committee of the agency. In contrast, restrained highway speeds were obtained after the trip-assignment program of the DVRPC was run with the 1985 trip matrix. This trip-assignment program already includes a "capacity constraint" for the trip-assignment purposes (1). In some detail, the program accepts the trip interchanges, the link capacities, the policy speeds on each link, and a mathematical function that, at the end of each run, compares volumes to capacities by link and reduces correspond-

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TABLE 1

COMPARISON OF POLICY SPEEDS AND RESTRAINED SPEEDS
OF THE HIGHWAY NETWORK OF THE DVRPC REGION FOR 1985

Route Type	Area Type														
	CBD			Urban			Suburban			Rural			Open Rural		
	I [a]	II [b]	III [c]	I [a]	II [b]	III [c]	I [a]	II [b]	III [c]	I [a]	II [b]	III [c]	I [a]	II [b]	III [c]
Turnpikes	50	0	0	50	58	58	55	44	46	60	58	58	65	0	0
Non-Interstate freeways	37	39	39	44	38	39	50	44	45	55	55	55	60	0	0
Interstate freeways	37	36	35	44	37	40	50	43	45	55	53	54	60	0	0
Multilane, low type	19	12	12	23	15	16	34	23	24	39	34	34	45	0	0
Other	14	9	9	19	13	13	30	20	21	35	28	28	45	31	31
Multilane, high type															
Controlled access	26	20	21	31	24	27	41	34	35	47	41	43	50	0	0
Uncontrolled access	25	0	0	29	19	21	37	27	30	45	40	41	50	50	50

[a] Policy speeds (initial input).
[b] Restrained speeds (output of first round of assignment and input to restrained simulation of travel).
[c] Output speeds (at the final stage of assignments).

ingly the initial policy speeds on each link. The exact form of the function used is as follows:

$$Y = [M \cdot N \cdot (P + p)] + 1 - (M \cdot N \cdot P)$$

where

- Y = average daily restraint speed rate;
- M = daily duration of delay, $[2.5\ (v/c)^{-1}]^2$;
- N = peak-hour fraction, 2KD, obtained from look-up table based on route and area type;
- P = off-peak-hour policy speed rate, 60/off-peak speed in mph yields minutes per mile, obtained from look-up table based on route and area type;
- p = delay rate, $r(v/c)^5$;
- r = 2.5 for turnpikes, 3.0 for multilane high type, and 3.5 for other facilties;
- v = daily assigned volume; and
- c = daily capacity.

The program then repeats the process for the second, third, or fourth time, and so on. Because of numerous isolations of loadings that occur in many links after the third iteration, the impact of capacity constraints (of the form used by DVRPC) is only marginal. The final link loads are then estimated as the average of the loads that were produced by 2 sequential loadings (say, third and fourth iteration). The final link speeds are also the average speeds of the ones produced after the end of the 2 iterations that were used in estimating average loads.

PROJECTION OF TOTAL TRANSIT TRIPS

Modal-split projections involve essentially an estimation of the proportion (and subsequently the number) of future trips that will tend to make use of the public transportation system or the private automobile facilities. This estimation is accomplished usually by the use of a modal-split model. Such models are currently 1 of 2 types, i.e., either a trip-interchange model or a trip-end model (2). A trip-interchange model estimates the proportion of trips between 2 specific districts that would tend to make use of the transit system. This estimation takes place after the distribution of trips between districts. In contrast, a trip-end modal-split model estimates the proportion of total person trips generated in a district that would tend to make use of the transit system as a result of all the highway and transit connections of the district of trip origin. This estimation takes place before the distribution of trips between districts (3). This is the type of model used by DVRPC for reasons explained in other publications (4).

Table 2 gives the form that the DVRPC modal-split model took, together with the variables used and the statistical tests performed in its derivation. Table 2 gives some measures of quality of the model itself such as the correlation coefficient, the standard error, and the F-statistic. The correlation coefficients of the equations varied from 0.807 for non-work—home (NW-H) trips to 0.914 for work-home (W-H) trips from the 3 CBD's of the region. The standard error of estimate of the equations varied from 4.3 percent to 21 percent of the mean values of non-home—non-home (NH-NH) and non-work—home (NW-H) trips respectively. The F-statistic is also significant in all cases.

The statistical test of the significance of each of these variables indicated that not all variables are equally important nor is an important variable in 1 case necessarily important in another case. Nevertheless, the transit accessibility variable was found to be significant in several important cases. In the context of this paper, transit accessibility is defined as a measure of the relative ease of getting from 1 subarea to the entire region by using the transit system. This is also the variable that bears the impact of any major changes in speeds or additions of new major facilities in the highway or transit network.

TABLE 2

GENERATION OF TRANSIT TRIP ORIGINS IN EACH DISTRICT BY USING TRANSIT AND HIGHWAY SYSTEM VARIABLES

Trip Purpose	Area	Equation[a]	Correlation Coefficient R	Standard Error S	Statistic F	1960 Simulation Error	Standard Deviation Y	Mean $\bar{Y}$
Home-work	Cordon	$Y_{385} = 0.1626 - 0.4107 \log X_2 + 0.0709 \log X_{55} + 0.0702 \log X_{43} + 0.0001 X_{54}$	0.902	0.08	149.20	-0.82	0.18	0.26
Home—non-work	Cordon	$\log Y_{387} = -2.1544 - 0.7255 \log X_2 + 0.3314 \log X_{55} + 0.2142 \log X_{56} + 0.3058 \log X_{54}$	0.839	0.20	76.23	-7.19	0.35	0.08
Work-home	CBD[b]	$\log Y_{397} = -1.6234 + 0.1553 \log X_8 + 2.0913 X_{19}$	0.914	0.13	28.01	-0.81	0.21	0.43
	Cordon	$\log Y_{397} = -2.0513 + 0.2285 \log X_8 + 0.5700 X_{19} + 0.3104 \log X_{54}$	0.864	0.16	109.47	+4.17	0.25	0.19
Non-work—home	CBD[b]	$\log Y_{405} = -2.0556 + 0.6244 \log X_8 + 0.6143 X_{24}$	0.909	0.17	26.18	+8.11	0.25	0.32
	Cordon	$\log Y_{405} = -2.3800 + 0.4332 \log X_8 + 0.0371 X_{24} + 0.3198 \log X_{54}$	0.807	0.21	68.25	+3.50	0.35	0.07
Non-home—non-home	Cordon	$Y_{342} = -0.0257 + 0.0007 X_8 + 0.1971 X_{67}$	0.894	0.04	200.17	+4.82	0.09	0.07

[a] X_2 = Total cars per total occupied dwelling unit; X_8 = Jobs per nonresidential acre; X_{19} = Accessibility ratio for W-H trips; X_{24} = Accessibility ratio for NW-H trips; X_{43} = Accessibility ratio for H-W trips; X_{54} = Average transit vehicles per day; X_{55} = Permanent occupied dwelling units per residential acre; X_{56} = Accessibility ratio for H-NW trips; X_{67} = Accessibility ratio for NH-NH trips.

[b] Philadelphia, Camden, and Trenton.

The significance of the accessibility variable was tested statistically in terms of the t-test and the beta-test of the coefficients of the equations. The results have shown that its significance is different for each type of trip. For H-W and H-NW trips, the absolute contribution of transit accessibility is rather small. Clearly the speed of the transit system has a very small association with the number of H-W and H-NW trips made by transit. For W-H trips from the 3 CBD's, the situation is reversed. It appears that people going home from work and from a CBD area place special emphasis on a fast transit system. This is clearly shown by the beta-values and the t-test of the coefficients. For W-H trips from non-CBD origins, however, the significance of the transit accessibility variable is much smaller than either the job density or the frequency of transit service variable. For NW-H trips from the 3 CBD's of the region or for the same trips originating from elsewhere in the region, the transit accessibility variable is also found to have little association with the rate of transit trips. Finally, for NH-NH trips, the transit accessibility (or speed and cost of the transit system) also emerges as a relatively important factor as indicated by both pertinent statistical yardsticks.

Before the accessibility variable was used in the modal-split model, a comparison was made of the 2 sets of accessibility measures (i.e., with policy speeds versus restrained speeds). The results of these comparisons indicate that (a) the largest changes in the accessibility measure occurred for districts within the central part of the region (primarily within Philadelphia, then in Camden, and then in Trenton); (b) the H-W trips register the greatest increases, whereas the NH-NH trips register the smallest increases; and (c) an increase in the transit accessibility has been registered for almost all districts in the region for all 5 trip purposes. No district has experienced a decrease of transit accessibility, and the change has shifted an average line of accessibility to the right of a 45-deg line between restrained and unrestrained accessibility. This shift corresponds, in turn, to approximately 25 percent increase of accessibility for low-accessibility districts to almost 12 percent increase of accessibility for high-accessibility districts.

The application of these changes to the modal-split model of DVRPC produced the new regional projections of transit and highway trips given in Table 3. It becomes apparent that the city of Philadelphia (sectors 1 through 6, Fig. 1) registers the largest shift of trips from highway to transit. Almost 72 percent of the total new diversion to transit occurs in the city. The Philadelphia CBD (sector 1) experiences a greater shift than any other area of the city, accounting for almost 30 percent of the total shift in the region. This appears to be a reasonable result if one considers the fact that the impact of restrained speeds would be felt more strongly on those highway facilities in the CBD than in any other part of the region. At the same time, the CBD is the hub of the region's transit network (rapid transit included), and, as such, the reduction of highway speeds would produce the most striking contrast with the transit speeds.

Also noteworthy is the increase in transit trips in sector 11. This sector contains the modern Lindenwold Rapid Transit Line, which accounts for the fact that this sector absorbs almost 10 percent of the regional total increase in transit trips. The high speeds and quality of service of this line make it clearly an attractive alternative when compared to slowly moving highway facilities resulting from restrained speeds.

The results indicated that the work-trip purpose (H-W and W-H) registers the largest decrease in highway trips—61 percent of the total diversion to transit. If one recalls the changes of accessibility measures presented earlier, these results become both expected and reasonable.

On a regional basis, the total decrease in highway trip origins was less than 2 percent. (Highway trips with either external origins or destinations and through trips were assumed to be unaffected by restrained speeds. This was done because the highway speeds and the transit service within the cordon are expected to have minimal impact on through trips or on trips that only partly use the regional network, i.e., external-internal trips.) The effect of restrained speeds on the regional highway network is, therefore, not a dramatic one. Specific corridors that may register greater changes are explored in the next section of this paper, but it is important to notice that total regional changes of highway trips were very small.

TABLE 3

RESTRAINED AND UNRESTRAINED TRIP PROJECTIONS BY SECTOR FOR 1985

Sector Number	Intermediate Highway[a]				Basic Transit[b]			
	Policy Speeds	Restrained Speeds	Difference		Policy Speeds	Restrained Speeds	Difference	
			Trips	Percent			Trips	Percent
1	352,421	313,467	38,954	-11.1	323,879	376,060	52,181	+16.1
2	466,674	454,130	12,544	-2.7	241,622	257,896	16,274	+6.7
3	278,135	272,202	5,933	-2.1	108,134	116,562	8,428	+7.8
4	563,561	551,795	11,802	-2.1	239,693	256,223	16,530	+6.9
5	589,933	575,232	14,701	-2.5	228,302	247,324	19,022	+8.3
6	607,037	597,547	9,490	-1.6	153,359	165,632	12,273	+8.0
7	600,592	598,461	2,131	-0.4	27,642	30,392	2,750	+9.9
8	842,380	835,258	7,122	-0.8	77,774	87,185	9,411	+12.1
9	1,401,694	1,390,594	11,100	-0.8	169,581	184,509	14,928	+8.8
10[c]	444,232	441,221	3,100	-0.7	47,801	52,003	4,202	+8.8
11[d]	1,190,345	1,177,732	12,613	-1.06	148,977	165,772	16,795	+11.3
12	488,290	485,727	2,563	-0.5	36,007	39,275	3,268	+9.1
Total	7,825,294	7,693,330	131,964	-1.7	1,802,771	1,978,833	176,062	+9.8

[a] Vehicle trips.
[b] Person trips.
[c] Includes Sector 16, Trenton CBD.
[d] Includes Sector 15, Camden CBD.

The percentage increase in transit trips on a regional basis is, of course, more substantial, reaching almost 10 percent of the original projections for this combination of networks. Again, what this regional change implies in specific corridors will be presented in a following section of this paper.

TRIP DISTRIBUTION

Trips from the restrained speeds modal split were distributed by the gravity model as used by DVRPC. Inputs such as friction factors, K-factors, bridge penalties, parking costs, and intradistrict costs were identical to those used in the original 1985 district trip distribution using policy speeds. For transit trips, the only difference was in the number of trips distributed (increase by 176,000 trips).

For highway trips, the difference in distribution was both in the number of trips distributed (decreased by 176,000 person trips or 132,000 vehicle trips) and in the new minimum cost paths that were produced by using the restrained speeds.

Table 4 gives a summary of the results of the 2 trip distributions for 1985 highway and transit trips. The total highway trips, as already mentioned, decrease by 132,000 vehicle trips (equivalent to 176,000 person trips after the application of the car-occupancy factors by trip purpose), but also the number of intradistrict highway trips increase by about 376,000 vehicle trips. Intradistrict trips stay rather constant for transit. In terms of mean trip cost, the highway trips generally increase in travel cost (most noticeably for the work purposes), whereas the transit trips stay rather stable in cost.

The gravity distribution model is, of course, synthetic in nature, determining choices of destinations in a relative manner based on relative travel costs from a given origin point. Thus, by increasing travel cost (using restrained speeds), we increase the friction of space to all destinations outside the district of origin and, therefore, we set in a more favorable position the destinations located within the district of trip origin itself. This situation results in the production of many more intradistrict highway trips (17 percent more), and this, in turn, has significant impacts on all indexes of trip distribution (such as mean trip cost and total travel cost). Because no change in cost paths is introduced in the transit network, no reason exists for changing the proportion of interdistrict transit trips. In fact, the distribution registers only 6.0 percent increase of intradistrict transit trips (versus 10 percent increase of total transit trips), which tends to explain the slight increase of mean trip cost of transit trips registered.

The structure of the gravity model and the nature of the differences introduced in the distribution help to explain the relatively large increase in mean trip cost of highway trips registered, especially for work trips. Trips have to cross congested parts of the networks with unit travel cost being much higher than the cost based on policy speeds. Because work trips have more or less restricted destinations, it should be expected that their trip cost would increase. This is exactly what happened, especially for H-W and W-H trips. For NH-NH trips, this situation did not materialize at all, and the mean trip cost actually decreased slightly.

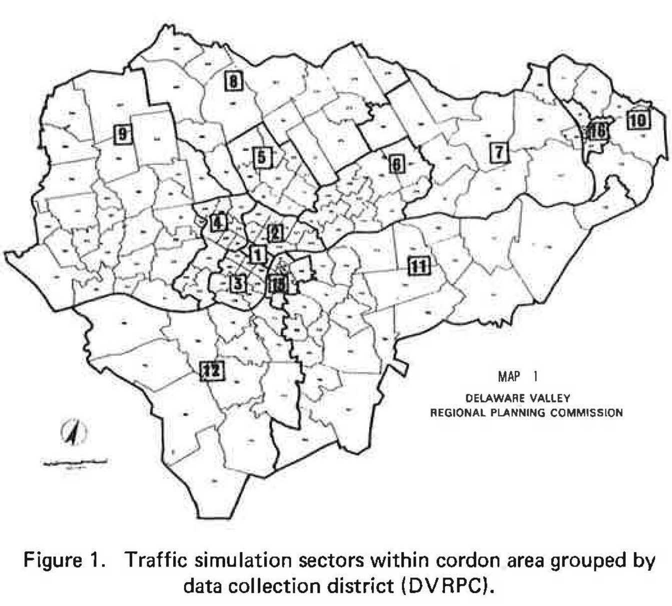

Figure 1. Traffic simulation sectors within cordon area grouped by data collection district (DVRPC).

TABLE 4

SUMMARY OF RESTRAINED AND UNRESTRAINED INTERNAL TRIP DISTRIBUTION

Trip Purpose	Network[a]	Speed	Total Trips Distributed	Intradistrict Trips	Mean Trip Cost (cents)	River Crossings
H-W	Highway	Policy	915,503	118,076	68.48	97,883
		Restrained	875,537	137,946	72.84	87,297
	Transit	Policy	444,318	15,456	91.07	48,106
		Restrained	494,133	16,450	91.40	54,672
H-NW	Highway	Policy	2,026,300	661,063	41.85	59,798
		Restrained	2,012,722	776,145	42.24	56,941
	Transit	Policy	363,112	30,307	80.14	25,904
		Restrained	386,380	31,266	79.59	26,613
W-H	Highway	Policy	914,755	130,477	68.28	96,183
		Restrained	873,197	151,939	73.23	86,172
	Transit	Policy	443,483	15,301	91.37	48,952
		Restrained	494,097	16,306	91.60	55,539
NW-H	Highway	Policy	2,049,611	680,679	41.66	56,870
		Restrained	2,035,523	794,063	41.74	50,519
	Transit	Policy	363,983	30,433	78.99	24,331
		Restrained	387,899	31,353	78.82	25,648
NH-NH	Highway	Policy	1,919,125	588,460	37.94	47,142
		Restrained	1,896,351	694,456	37.28	38,995
	Transit	Policy	187,875	11,941	78.07	18,610
		Restrained	216,324	14,449	78.89	21,318
Total	Highway	Policy	7,825,294	2,178,755		375,876
		Restrained	7,693,330	2,554,549		319,924
	Transit	Policy	1,802,771	103,438		165,903
		Restrained	1,978,833	109,824		183,790

[a]Vehicle trips on highway network, and person trips on transit network.

Table 4 also gives a significant change in the Delaware River crossings. The highway crossings show a decrease of about 38,000 vehicle trips, which is a 10 percent loss resulting from restrained speeds. Converted to person trips, this becomes about 52,000 trips, which is considerably higher than the approximately 18,000 gain in transit river crossings. The increase of the friction of space in crossing the river (using congested highways) has again forced the gravity model to register a reduction of trips selecting this direction and to register a diversion of vehicle trips to destinations on the same side of the Delaware River. These destinations become more attractive substitutes because one does not have to use so many congested highways to reach them.

Mean trip costs for all purposes of transit have remained fairly stable under application of restrained speeds. This result occurs despite the 10 percent increase in total trips. Indications are, therefore, that the 1985 transit network will be more efficiently used when trips are diverted from the highway network and that it will handle the increased volume without any significant increase in average trip cost.

Delaware River crossings by transit have increased about 11 percent (18,000 person trips corresponding to approximately 14,000 automobile trips) as a result of applying restrained speeds to the highway network. Mainly, this is attributable to the

TABLE 5

RESTRAINED AND UNRESTRAINED TRIP PROJECTIONS TO AND FROM THE PHILADELPHIA CBD

Sector	Highway Vehicle Trips			Transit Person Trips		
	Policy Speed	Restrained Speed	Percentage Change	Policy Speed	Restrained Speed	Percentage Change
			From Sector and to CBD			
1	18,199	22,621	+24.3	10,563	11,211	+6.1
2	38,112	35,646	-6.5	33,508	38,833	+15.9
3	47,357	52,132	+10.1	26,475	31,088	+17.4
4	62,599	59,024	-5.7	50,882	59,177	+16.3
5	25,175	19,314	-23.3	51,143	59,703	+16.7
6	21,972	19,442	-11.5	36,339	42,711	+17.5
7	11,365	10,008	-11.9	8,096	9,474	+17.0
8	25,549	19,902	-22.1	21,518	25,350	+17.8
9	71,558	55,057	-23.1	46,099	52,934	+14.8
10[a]	248	306	+23.4	609	625	+2.6
11[b]	24,255	17,872	-26.3	32,211	36,920	+14.6
12	10,028	7,631	-23.9	7,282	8,608	+18.2
Total	356,417	318,955	-10.5	324,725	376,634	+16.0
Difference	-37,300			+52,000		
			From CBD and to Sector			
1	18,199	22,261	+24.3	10,563	11,211	+6.1
2	32,949	30,268	-8.1	37,955	43,894	+15.6
3	42,555	46,315	+8.8	27,382	32,124	+17.3
4	65,143	61,263	-6.0	51,624	60,031	+16.3
5	31,308	24,903	-20.5	50,021	58,510	+17.0
6	22,074	19,440	-11.9	34,167	40,352	+18.1
7	10,324	8,799	-14.8	7,323	8,603	+17.5
8	24,664	19,056	-22.7	19,913	23,597	+18.5
9	70,876	54,002	-23.8	47,811	54,838	+14.7
10[a]	169	208	+23.1	422	467	+10.7
11[b]	23,997	18,757	-21.8	29,652	34,119	+15.1
12	10,157	7,833	-22.9	7,043	8,296	+17.8
Total	352,415	313,465	-11.1	323,876	376,042	+16.1
Difference	-39,000			+52,000		

[a] Includes Sector 16, Trenton CBD.
[b] Includes Sector 15, Camden CBD.

effectiveness of the Lindenwold Line in draining trips from the highways in its corridor and carrying them across the Benjamin Franklin Bridge into Philadelphia. As was pointed out before, a rapid transit facility such as this cannot be anything but favorably affected when restrained speeds are applied to the highway network. Finally, the increase in river crossings is in line with the increase in total transit trips regionally and seems reasonable on all counts.

Another significant aspect of the distribution, worthy of discussion at this juncture, is the nature of travel patterns to and from the Philadelphia CBD. These patterns are given in Table 5. Overall, there is a decrease in highway vehicle trips to and from

TABLE 6

SUMMARY OF RESTRAINED AND UNRESTRAINED TRIP ASSIGNMENT FOR 1985

Item	Policy Speeds	Restrained Speeds	Difference	
			Amount	Percent
Total trips assigned	8,900,000	8,400,000	131,945	-5.6
Vehicle-miles, daily	55,481,349	50,575,920	4,905,429	-8.8
Vehicle-miles, peak hour	6,532,558	5,973,910	558,648	-8.6
Vehicle-hours, daily	2,229,263	1,924,627	304,636	-13.7
Miles of route	2,590	2,590	—	
Average speed, mph	24.9	26.3	1.4	+5.6
Vehicle time cost, $/day	3,343,894	2,886,939	456,955	-13.7
Vehicle operating cost, $/day	1,845,880	1,666,405	179,475	-9.7
Accident cost, $/day	696,741	580,546	116,195	-16.7
Toll cost, $/day	186,366	176,944	9,422	-50.6
Total cost, $/day	6,072,882	5,310,834	762,048	-12.5
Average trip cost, cents	54.7	48.5	6.2	-11.3
Cost per vehicle-mile, cents per mile	10.9	10.5	0.4	-3.7
Average trip length, mile	5.02	4.62	0.4	+8.0

Note: These are regional summaries and do not include approach links.

the CBD of approximately 38,000 trips or about 11 percent. On the other hand, there has been an increase in CBD-oriented transit person trips of approximately 52,000 trips or about 16 percent of the original figures resulting from using policy speeds. In addition, almost 60 percent of the total increase in transit trips to and from the CBD occurs with connection to sectors of the city of Philadelphia (sectors 1 through 6). If one considers that most of the impact of the restrained speeds occurs on the network within the city of Philadelphia, this finding should not be surprising.

TRAFFIC ASSIGNMENT

Highway Trip Assignment

The traffic assignment phase is the final step in the simulation process. Completion of the assignment program provides more detailed data such as link volumes, bridge volumes, travel costs, facility speeds, and other measures of network efficiency that permit a more rational evaluation of the need and role of each facility (5, 6).

Summary results of the district highway traffic assignments are given in Table 6. The restrained assignment indicates a reduction in all summary categories from the ones produced with the policy speed assignment. It should be noted that the total trips assigned represent the actual trips assigned on the network, that is, after the intradistrict trips obtained from the trip-distribution process were deducted from total trips to determine the number of trips actually to be assigned. The total reduction amounted to approximately 500,000 vehicle trips (i.e., 132,000 vehicle trips reduced due to modal-split shifts and 376,000 vehicle trips that became intradistrict trips in addition to the intradistrict trips produced on the basis of policy speeds.)

The regional cost summaries show that the restrained speed assignment experiences a significant (almost 14 percent) reduction in cost from the policy speed levels. This is an obvious result of loading 5 percent fewer trips on the highway network. Also, the average trip length (in dollars and miles) of the assigned highway trips has been reduced. Clearly, the majority of diverted trips are among the longest ones in the region. The combination of these 2 factors produces fewer total vehicle-miles of travel,

TABLE 7

RESTRAINED AND UNRESTRAINED VEHICLE-MILES BY ROUTE FOR 1985

Route Type[a]	Policy Speed Assignment	Restrained Speed Assignment	Change (percent)
Turnpikes	3,885,894	3,717,887	-4.3
Freeways	22,782,662	20,909,344	-8.2
High type of arterials	6,120,630	5,791,718	-5.4
Low type of arterials	22,692,163	20,156,971	-11.2
Total	55,481,349	50,575,920	-8.8

[a]Excludes approach links.

slightly higher average speeds for the entire network, and, in turn, lower costs per vehicle-mile and lower total operating costs to the users.

Restrained speed assignments have varying degrees of impact on different route types. Comparative analysis of this effect is given in Table 7. Turnpikes register the least effect, experiencing only a 4.3 percent decrease in vehicle-miles of travel. A substantial portion of travel on turnpikes is long-distance travel and not very susceptible to any localized diversion to transit; therefore, the foregoing result appears quite reasonable. The opposite end of the spectrum, however, is represented by the low type of arterials. This route type undergoes an 11.2 percent reduction of vehicle-miles in restrained speed assignment. The low type of arterials serves the shorter trips and suffers the most from congestion and speed reduction and, as a consequence, will reflect the greatest diversion to transit.

Another interesting facet of the assignment is the impact of restrained speeds on the projected volumes on the Delaware River bridges. In total, there is a reduction of almost 38,000. The interesting point to note is, On which bridges do the greatest reductions occur? The largest decreases in volume occur on the Benjamin Franklin, Walt Whitman, and Philadelphia-Pennsauken bridges. These facilities are within the area of influence of the Lindenwold Line and are served by relatively congested facilities. As a result, they experience substantial diversion to the high-speed line and to other bridges. Five other bridges actually are projected to have slight increases in volume, which is due to their geographic locations. The locations are such that they have no proximity to a practical transit alternative, are in uncongested areas, and are appropriate for receiving diversions from other congested bridges.

Certain highway facilities in the region are worth examining in a little more detail. The Crosstown Expressway restrained speed assigned volumes consistently show a decrease from policy speed levels on all links. Also, the Vine Street Expressway generally shows a decrease, although some links actually increase in volume. Both of these facilities are affected by the Market Street Subway, which runs in a parallel direction, and by the Locust Street Line and the many bus routes serving the city. The observed volumes on the Schuylkill Expressway show an irregular variation by link. Whenever there is an alternative link, the expressway links decrease in volume because this expressway is exceedingly congested throughout the day. The Delaware Expressway shows a consistent and significant decrease in volume reflecting the decrease of highway trips generated in its vicinity and the congested nature of the facility's operation.

At the conclusion of the highway trip assignment, the final network speeds were averaged and reported. A comparison is included in data given in Table 1 between these final speeds and the ones used as inputs for the modal split, trip distribution, and highway trip assignment (the restrained highway speeds). As one can notice in many cases, the final restrained speed was higher than the input restrained speed. In fact, from the 35 cases presented, 18 cases remain the same, 16 cases increase, and

TABLE 8

1985 TRANSIT TRIP ORIGINS BY SUBMODE BY SECTOR

Sector	Railroad Trips			Subelevated Trips			Surface Bus Trips		
	Policy Speed	Restrained Speed	Percent Increase	Policy Speed	Restrained Speed	Percent Increase	Policy Speed	Restrained Speed	Percent Increase
1	56,300	65,300	15.9	142,200	166,500	16.3	125,400	142,200	14.9
2	3,900	4,200	7.6	85,700	91,700	7.1	152,000	162,000	6.6
3	500	500	0.0	41,200	44,100	7.0	66,400	71,900	8.2
4	7,000	7,500	7.1	85,100	91,400	7.4	147,600	157,300	6.6
5	12,300	14,200	15.4	91,800	100,900	9.8	124,300	132,300	6.5
6	2,500	2,900	16.0	80,500	89,000	10.5	70,300	70,700	4.8
Total Philadelphia	82,400	94,500	14.7	526,500	538,800	11.0	686,000	741,400	8.2
7	6,600	7,600	15.2	7,200	8,000	11.1	13,800	14,800	7.3
8	20,800	24,300	16.8	13,100	14,600	11.3	43,800	48,300	10.0
9	30,100	33,900	12.5	43,500	47,500	9.2	96,000	103,100	7.3
Pennsylvania suburbs	57,600	65,800	14.3	63,800	70,100	9.7	153,600	166,200	8.3
Total Pennsylvania	140,000	160,300	14.5	590,300	653,900	10.8	839,700	907,600	8.2
10	200	200	0.0	900	900	0.0	15,500	16,500	6.4
11	900	1,000	11.1	24,900	28,000	12.5	61,800	68,900	11.4
12	200	200	0.0	6,800	7,300	7.3	29,000	31,800	9.7
15	400	400	0.0	13,200	14,600	10.6	47,800	52,900	10.7
16	400	400	0.0	1,200	1,200	0.0	29,600	32,700	10.4
New Jersey suburbs	2,100	2,200	4.7	46,900	52,000	10.7	183,700	202,900	10.0
Total region	142,200	162,500	14.3	637,200	705,900	10.8	1,023,300	1,110,400	8.4

Note: Figures may not add because of rounding.

only 1 case decreases (for Interstate freeways in the CBD area). Recalling the fact that the input speeds are already quite restrained, because of the inclusion of the volume-capacity ratio delay function in the assignment phase of the initial traffic simulation, one can understand why the final highway speeds increase when the total impact of restrained speeds is incorporated in the modal split, trip distribution, and trip assignment.

Transit Trip Assignment

The task at this part of the project involves essentially the assignment of the new total transit trips, projected for 1985, on the 3 transit subsystems of the region. In reality, the transit trip assignment in the DVRPC package requires that the analyst first go through the submodal-split process. The purpose of this step of the work program is to determine the number of trips to be assigned to the 3 public transportation subsystems, that is, the railroads, the subway-elevated, and all the surface bus lines. [The submodal split is performed in 3 steps. First, the number of railroad trips are computed by applying diversion curves derived from 1960 data on railroad passengers to the total public transportation trips. The second step uses diversion curves derived from 1960 subway-elevated ridership, applies them to transit passengers (total public transportation less railroad), and obtains subway-elevated trips. The remaining trips represent all surface riding (7).]

The results of the transit trip assignment reveal again significant differences from the results obtained with the previous estimate of transit trips. These differences are given in Table 8 on a sector basis for both policy and restrained speed runs. Again, the importance of the differences in the city of Philadelphia is obvious, as are those for sector 11, which includes the city of Camden and the Lindenwold Line. With regard to submodal comparisons, it becomes clear that the railroad system receives proportionally more trips from the newly diverted trips to the transit system. For the region, the railroad system receives 14.3 percent more trips versus 10.8 percent more trips for the subway system and only 8.4 percent more trips for the surface bus lines. Furthermore, sectors with good railroad connections are clearly the ones with the greatest proportion of diverted trips to the railroad system.

Ridership projections for each individual transit facility, produced by both policy and restrained highway speeds, were posted on each line by link and station. Maps were then prepared, and results were tabulated for further economic analysis of each line.

SUMMARY AND CONCLUSIONS

The overall results have shown that for volumes on the highway network the effects of restrained speeds are very small. The change in highway trips was not enough to indicate that the numbers of automobile drivers who would be discouraged by congestion and decide to use transit are sufficient to either reduce a single planned expressway facility or add a new transit line.

Transit projections registered a 10 percent increase in the regional ridership, but the significance of this increase is rather small when one realizes that it is based on a relatively small number of trips and is going to be served by a transit line that can hardly be considered overloaded. The size of such an increase and its areal distribution reduces any chance that it might conclude that a new transit system is needed at a specific location. The corollary statement can also be made; i.e., changes in the transportation system characteristics must be quite substantial before any significant effect (above 10 percent) will be noticed in the number of transit trips. It should be also pointed out that this paper reports only on the effects of a relative downgrading of highway network quality. The transit network, as proposed, was left unchanged. Perhaps stronger insights could be gained from testing the effects of combined changes, e.g., restrained highway speeds and greater frequency of transit service. Because there is currently a renewed interest in transit, and particularly in the newer, more exotic forms, it would be interesting to incorporate system changes of this type into the network and test the effects on modal preference. Present models, however, are not structured to cope with this type of problem. Nevertheless, it is the type of tests that should be the focus of future efforts, if forecasting future transit use is to be a useful tool to the transportation planner in revitalizing transit and alleviating highway congestion.

The new distribution of automobile driver and transit trips reveals important variations. First the intradistrict automobile driver trips register a marked increase (17 percent). This increase of intradistrict trips occurs primarily in NW-H and H-NW trips (61 percent of the increase) and in NH-NH trips (28 percent of the increase). A second important change was registered in the general increase of trip cost found for all automobile driver trips to or from home, and particularly for H-W and W-H automobile driver trips. For all transit trips and for NH-NH automobile trips (the shortest automobile trips), no significant difference in trip length, measured in total travel cost, was found. A third important change was found for trips crossing the Delaware River. In general, a reduction of 38,000 automobile driver trips (corresponding to 52,000 automobile person trips) and an increase of 18,000 transit trips (11 percent of the total diversion to transit) were observed. The reduction of automobile driver trips crossing the Delaware occurs primarily in H-W trips (10,000), W-H (10,000), and NH-NH trips (9,000). The increase in transit trips occurs primarily in the same types of trips (i.e., H-W has an increase of 6,000 trips, W-H has an increase of 6,000 trips, and NH-NH has an increase of 3,000 trips). In total, 34,000 automobile person trips change destination and do not cross the river.

The restrained speeds have also produced an important change in the travel pattern to and from the Philadelphia CBD. In general, a reduction of 52,000 automobile person trips was registered (corresponding to 38,000 vehicle trips), and an equivalent increase of transit trips was reported. The transit trips increase corresponds to 16 percent of previous projections and comes primarily from districts located increasingly distant from the Philadelphia CBD. Also, the sector that includes the new Lindenwold Rapid Transit Line registers the largest percentage decrease of automobile trips to the Philadelphia CBD. The increase of transit trips to the Philadelphia CBD from this sector is among the largest ones, reflecting the fact that the previous projections from this sector already include the impact of the new transit line.

The assignment of vehicle trips on the restrained-speed network reveals that the reduction of 500,000 vehicle trips (132,000 trips diverted to transit plus 376,000 trips becoming intradistrict trips and therefore not assignable) produces a reduction of 4.9 million vehicle-miles and 304,000 vehicle-hours. Most of this reduction occurs on low types of arterials (-11.2 percent), which in turn causes an increase in the average travel speed from 24.9 to 26.3 mph and a reduction of average trip cost from 54.7 to 48.5 cents, average trip length from 5.02 miles to 4.62 miles, and cost per vehicle-mile from 10.9 to 10.5 cents per mile. It is clear that the trips diverted from the highway network are primarily those previously forced to use an indirect path on local arterials. In terms of river crossings, assignment of vehicle trips reveals that the reduction of 38,000 vehicle trips registered in the trip-distribution phase of the comparison is affecting the various bridges differently. Diversions have also been observed from 1 bridge to another with less congested facilities.

In terms of the effect of restrained speeds on the expressway networks, the most uniform impact is observed on the Crosstown Expressway where the assigned traffic load is reduced substantially (30 percent on 1 link). Similar reductions occur on other congested parts of the major networks—Vine Street and Schuylkill Expressways.

This restrained-speed analysis also has implications insofar as regional development patterns are concerned. Congested, slowly moving highways cause diversion to transit and thus induce a somewhat more compact development of the central part of the region. Also, for suburban residents who find that a shift to transit for travel to the Philadelphia CBD is not a desirable or viable alternative, the congested highway speeds constitute a good inducement to avoid long trips and to seek travel destinations close by or in uncongested areas (i.e., mostly suburban areas). To this extent a congested highway system in the central part of the region becomes a strong influence for greater suburbanization and more self-supporting suburbs.

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