Technical Report: Simpletown Network Analysis

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The transportation network of Simpletown, both in its existing state and under conditions based on a number of proposed transportation/infrastructure changes, has been modeled using the BPR volume-delay function and the Frank-Wolfe algorithm to reach a user-equilibrium state. In this memo, we will analyze the results of the network model, and assess the potential benefits of the various proposals.

Existing Network Conditions

Modeling the existing network conditions produced a total network travel time (T_c) of 42,129 vehicle-minutes per hour (vmph) (the “c” subscript refers to the fact that this value incorporates congestion), with a total of 51,670 vehicle-links traversed per hour.

As one might expect, traffic flow throughout the network is not uniformly distributed. While the median flow is 850 vehicles per hour (vph), the central half of link volumes are broadly distributed across the fourth spread: between 580 to 1200 vph, while the upper fourth (the 15 links with the highest volumes) have volumes greater than 1200 vph. Listed in Table 1, these links account for 39 percent of the traversed vehicle-links and 46 percent of total travel time. Similarly, the top 50 percent account for 71 percent of traversed links and 76 percent of total travel time.

Link	Flow (vph)	V/C
Link 7 - 19	1865	1.04
Link 4 - 7	1524	0.85
Link 2 - 10	1497	0.62
Link 1 - 4	1342	0.75
Link 1 - 2	1311	1.46
Link 7 - 4	1310	0.73
Link 8 - 7	1310	1.46
Link 9 - 8	1303	1.45
Link 18 - 19	1293	1.44
Link 14 - 13	1292	1.08
Link 7 - 8	1268	1.41
Link 8 - 9	1267	1.41
Link 10 - 2	1237	0.52
Link 9 - 17	1218	0.51
Link 17 - 9	1218	0.51

Table 1: Upper fourth of links, ranked by traffic volume (Flow) under baseline conditions..

High traffic volume isn't a problem, per se, but volume that exceeds capacity is a problem. Fifteen (15) network links on

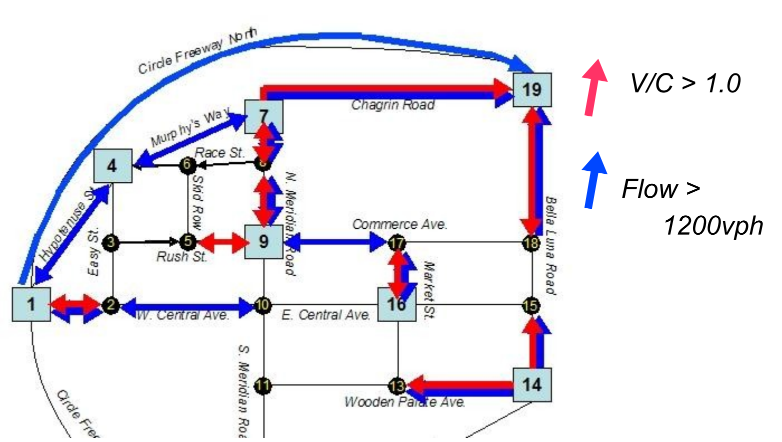

Figure 1: High volume and V/C ratios.

Link	Flow (vph)	V/C
Link 1 - 2	1311	1.46
Link 8 - 7	1310	1.46
Link 9 - 8	1303	1.45
Link 18 - 19	1293	1.44
Link 7 - 8	1268	1.41
Link 8 - 9	1267	1.41
Link 2 - 1	1166	1.30
Link 19 - 18	1080	1.20
Link 14 - 15	1012	1.12
Link 9 - 5	648	1.08
Link 5 - 9	647	1.08
Link 14 - 13	1292	1.08
Link 17 - 16	966	1.07
Link 7 - 19	1865	1.04
Link 16 - 17	1197	1.00

Table 2: Links with V/C > 1.0 under baseline conditions.

nine roadway segments have Volume-to-Capacity (V/C) ratios greater than one, and are listed in Table 1. Not surprisingly, there is significant correlation between volume and V/C ratios, illustrated in Figure 1.

Free-flow Conditions

We further identify heavily congested links by calculating a delay (*D*) associated with each link: $D_{i,j} = V_{i,j}(t_c - t_{ff})$ where *V* = link flow in vph, t_c = link congested travel time, and t_{ff} = link free-flow travel time—with *D* given in vehicle-minutes per hour. This metric result in highly skewed distribution and confirms the identification of several high-priority congestion "hotspots" on Links 1-2, 2-1, 7-8, 8-7, 8-9, 9-8, 18-19, 19-18, 7-19, 14-13 (shown in Figure 2), and perhaps others, depending on how we define "hot."

Free-flow conditions also act as a point of comparison at the network level. In a "free-flow" scenario, the total travel time (T_{ff}) is 32,273 vehicle-minutes per hour. This yields a "congestion index" for the transportation system of $CI_N = 1.31$. This means that on average, traveling in Simpletown takes 1.31 times longer than it would in uncongested traffic—a ten-minute trip is likely to take 13 minutes.

Critical Links

Some links in the transportation network are more important than others. For each origin-destination pair, our model favors the shortest path from the origin to the destination. Some links are used by several shortest paths. In particular, 16 links are included in five or more shortest paths, and are listed in Table 3. These links make up eight roadway segments that form a diagonal "spine" of Simpletown,

Methodology: Network Free-flow Conditions

Link free-flow travel times are based on infrastructure characteristics, but total network free-flow travel time must be calculated using the model algorithm. The model uses the standard BPR volume-delay formula to determine congested travel time (t_c) for each link as function of free-flow travel time (t_{ff}), traffic volume (*V*), roadway capacity (*C*), and two parameters, typically *α* and *β*:

$$t_c = t_{ff}\left[1 + \alpha\left(\frac{V}{C}\right)^{\beta}\right]$$

These values are then used to calulate T_c. By setting α = 0, we ensure that $t_c = t_{ff}$, effectively eliminating congestion throughout the system, and modeling total "free-flow" network travel time (T_{ff}). A network level "congestion index" can then be defined by:

$$CI_N = \frac{T_c}{T_{ff}}.$$

In addition, we use the total system delay D_N to assess the function of the network overall, defined by:

$$D_N = \sum_{\forall(i,j)} D_{i,j}.$$

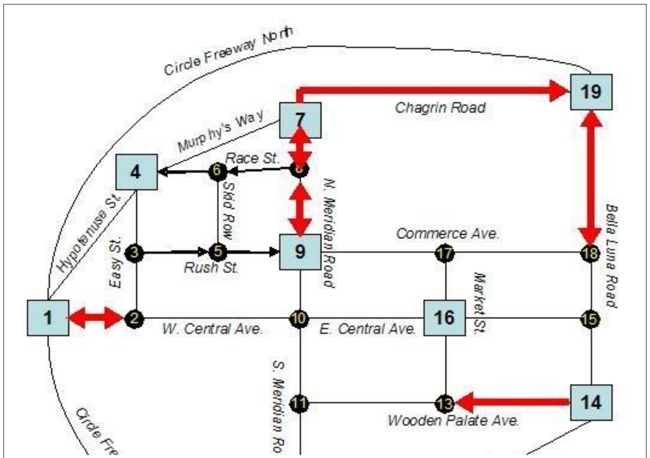

Figure 2: High-Priority congestion "hotspots."

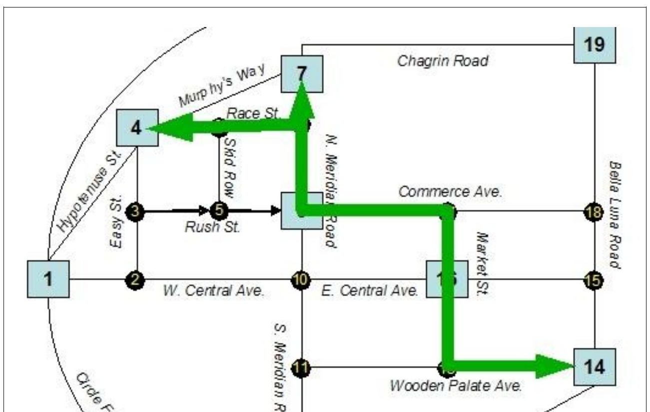

Figure 3: The "spine" of Simpletown.

from Node 14 in the southeast to Nodes 4 and 7 in the northwest, illustrated in Figure 3. These links can be considered critical to regional connectivity, and include several previously identified as congestion "hotspots": 7-8, 8-7, 8-9, 9-8, and 14-13. However, in this analysis several links with large total delays are not identified as "critical." For example, Node 19 is accessible via three links, all three of which carry more than 1200 vph. Of these three, Links 18-19 and 7-19 have the first and forth highest total delays, and V/C ratios greater than 1. This reminds us that the shortest-path method identifies links critical for overall connectivity, but does not take into account demand or node-specific accessibility.

	Number of shortest paths
Link 7 - 8	9
Link 8 - 9	8
Link 9 - 8	8
Link 6 - 4	7
Link 8 - 6	7
Link 8 - 7	7
Link 16 - 17	7
Link 17 - 16	7
Link 9 - 17	6
Link 17 - 9	6
Link 4 - 6	5
Link 6 - 8	5
Link 13 - 14	5
Link 13 - 16	5
Link 14 - 13	5
Link 16 - 13	5

Table 3: Critical Links

Skid Row Pedestrian Boulevard

Modeling a recent proposal to create a pedestrian boulevard on Skid Row, that is, to close Links 5-6 and 6-5 to motor vehicle traffic, suggests that this proposal is likely to have minimal benefits and a few drawbacks, in terms of vehicular traffic.

> ***Methodology: Finding Critical Links***
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> To find the number of shortest paths that traverse each link in the network, we set the the demand for each O-D pair to one (except for intra-zonal demands, which remain set to zero). Executing the model algorithm under these conditions ensures that each shortest path is traversed exactly once. The resulting flow volume on any particular link is exactly the number of shortest paths that traverse that link.

Model results indicate that beyond removing traffic from Skid Row, the proposal would eliminate virtually all traffic on Race St., and would reduce flow volume on Rush St. between Skid Row and N. Meridian Rd. by less than 10 percent in each direction.

Under baseline conditions, Skid Row and Race St. carry volumes of approximately 265 vph, with V/C ratios less than 0.25, so reducing or eliminating these flows would amount to fixing non-existent problems. The reduced flow volumes on Rush St. would lower V/C ratios from 1.08 to 1.0, westbound, and 1.08 to 1.00 eastbound.

On the other hand, the proposal is likely to increase flow volumes by 15 to 20 percent in both directions on Rush St. between Easy St. and Skid Row (Links 3-5 an 5-3) and on Easy St. between Rush St. and Race St. (Links 3-4 and 4-3). The average V/C ratios on these segments of Rush and Easy Streets. would rise from 0.85 to 1.01, and from 0.71 to 0.85, respectively. Though Rush St. would be just over full capacity, no links appear likely to be pushed grossly beyond capacity. En masse, total network travel time would increase by 78 vmph, or 0.2 percent (for a total network travel time of 42,207 vmph), and total delay would increase by one percent.

Rush-Race Couplet

The second proposal under consideration includes the Skid Row closure, but also the creation of a one-way couplet with Race St. one-way westbound and Rush one-way eastbound. Model results suggest that these changes would have broad impacts on the surrounding network. Nine links' flows would *increase* by more than 10 percent over baseline rates, another eight by more than five percent, and seven links' flows would *decrease* by more than 10 percent. In particular, improvement would be seen in reduced flows and V/C ratios on several currently congested links: eastbound Chagrin Rd. (Link 7-19), southbound Bella Luna Rd. (Link 19-18), and part of N. Meridian Rd. (Links 8-7). Furthermore, most of the increased flow is predicted to occur on links previously below capacity—and with sufficient capacity to accommodate the increased volume. On the other hand, increased traffic flow is likely to cause problems in some areas: V/C ratios for Links 4-3 and 4-7 would rise above 0.90; Link 9-10 would become congested (its V/C rising from 0.86 to 1.25); and Link 9-8, previously a congestion "hotspot," would incur an additional five percent in volume, attaining a network-high V/C of 1.51.

Reverse Direction Couplet?

What would happen if the one-way couplet was constructed with Rush St. westbound and Race St. eastbound: could we improve the result? No: the model indicates that the initially proposed couplet is the better choice. The reverse-couplet produces a total network travel time of 42,678 vehicle-minutes per hour, about 400 vm greater than the proposed couplet, and 550 vm greater than the baseline conditions. Furthermore, the reverse-couplet results in small flow and V/C increases to several links with V/C ratios greater than one, where the proposed couplet shows the reverse.

Overall, the model predicts that network travel time would increase by 155 vmph, to a total of 42,284 vehicle minutes per hour, but that *total delay* under the Rush-Race couplet would *decrease* from the baseline conditions by two percent.

Corridor Enhancements

In an effort to increase ridership on the Simpletown Streetcar, a proposal has been put forward to rededicate one lane of Commerce Ave. in each direction to reduce the attractiveness of driving. Modeling this proposal yields a total network travel time of 42,495 vmph, an increase over baseline conditions of 366 vmph (0.9 percent), with an increase in total delay 380 vmph (4.4 percent).

Zone	Inter-zone Travel Time (minutes)			*Drive* Mode Share	
O - D	Baseline Scenario	Commerce Ave. Proposal	Δt_{drive}	Baseline Scenario	Commerce Ave. Proposal
9 - 16	1.067	1.140	+ 0.073	90 %	90 %
16 - 9	1.027	1.081	+ 0.054	90 %	90 %

Table 4: Impacts of proposed corridor enhancements on mode share.

In terms of the specific effects on travel times and mode shares on Commerce Ave, average travel time from Zone 9 to Zone 16 is likely to increase by 0.073 minutes (and by 0.054 in the opposite direction). Change in the utility (*V*) for the *drive* mode is given by $\Delta V_{drive} = -0.035(\Delta t_{drive})$, where Δt_{drive} is the change in inter-zone travel time, and the *drive* mode share in the new scenario is given by

$$p_{drive} = \frac{p^0_{drive} \exp(\Delta V_k)}{\sum_{\forall modes\ j} p^0_j \exp(\Delta V_j)} = \frac{p^0_{drive} \exp(\Delta V_{drive})}{p^0_{walk} + p^0_{bike} + p^0_{streetcar} + p^0_{drive} \exp(\Delta V_{drive})} .$$

The results of these calculations are shown in Table 4, and suggest that the proposed changes to Commerce Avenue would have no affect on the existing mode splits. Driving would retain 90 percent mode share and the streetcar would not increase from its current five percent. The model results also indicate that the V/C ratios of all links on Commerce Ave would increase substatially, but that none are likely to rise above 0.91. This is one reason why the mode split was not significantly affected.

The broader link-specific affects of the Commerce Ave. proposal would be neither outstanding nor controversial. 13 links would see volumes and V/C ratios increase by five to 20 percent, but none of these links would have V/C ratios greater than one. In addition, seven links are predicted to see *decreases* in volume and V/C ratio between five and 15 percent. Notably, congestion is likely to be reduced by approximately 10 percent on Link 16-17, a high volume link that is part of the "spine of Simpletown." Under baseline conditions this link has V/C = 1.00, whereas under the corridor enhancement scenario V/C = 0.91.

Neumall Shopping Mall Proposal

The Oldboy Corporation has proposed construction of Neumall regional shopping center, located in Simpletown Zone 7. The city has expressed support for the project, but would prefer the mall to be located in Zone 12. The mall is likely generate 600 new peak-hour auto trips to and from the surrounding Zones. These trips have been allocated these trips to the various origins and destinations based on household proportions in each zone (P_i) and travel time between zones ($t_{i,j}$) using an attraction-constrained gravity model, with new trips attracted to the new mall location (zone *j*) from the other zones (*i*) given by:

$$T_{i,j} = 600 \frac{P_i \exp(-0.40 t_{i,j})}{\sum_{\forall Zones\, i \neq j} P_i \exp(-0.40 t_{i,j})} .$$

Origination (Destination) Zones	New Mall Location: Zone 7	Zone 12
1	86 (57)	90 (60)
4	107 (71)	63 (42)
7	-	35 (24)
9	43 (28)	51 (34)
12	24 (16)	-
14	12 (8)	35 (23)
16	35 (23)	60 (40)
19	53 (35)	25 (17)

Table 5: New trips to (from) mall zone, based on location proposals by the City (Zone 7) Oldboy Corp.(Zone 12).

Assuming 60 percent of these trips end in the mall zone (and 40 percent originate there), the allocations of new trips under the two location proposals are shown in Table 5, and the complete trip tables are provided in Tables 6 and 7.

Adding these new trips to our model indicates that total network travel times will increase: by 4.3 percent under the Zone 7 proposal (to 43,757 vmph), and 3.4 percent under the Zone 12 proposal (to 43,548 vmph). These moderate figures do not tell the whole story. Total delay under the Zone 7 proposal would increase by 706 vmph, 8.1 percent, while under the Zone 12 proposal delay would increase by only 113 vmph, 1.3 percent.

O-D Table with Neumall at Zone 7								
	1	4	7	9	12	14	16	19
1	0	346	556	458	442	326	527	917
4	161	0	409	293	281	205	334	583
7	439	433	0	386	362	261	433	751
9	563	225	224	0	281	205	334	583
12	322	362	386	221	0	133	269	322
14	281	201	253	241	269	0	482	804
16	322	281	260	322	213	181	0	322
19	322	241	234	322	221	241	201	0

Table 7: Trip Table for Zone 7 Neumall proposal. Origination zones are in the left column, destination zones are listed across the top.

O-D Table with Neumall at Zone 12								
	1	4	7	9	12	14	16	19
1	0	346	470	458	532	326	527	917
4	161	0	302	293	344	205	334	583
7	382	362	0	358	381	253	410	716
9	563	225	181	0	332	205	334	583
12	382	404	386	255	0	156	309	339
14	281	201	241	241	304	0	482	804
16	322	281	225	322	273	181	0	322
19	322	241	181	322	246	241	201	0

Table 6: Trip Table for Zone 12 Neumall proposal. Origination zones are in the left column, destination zones are listed across the top.

Both mall location proposals would have significant affects on traffic volumes on many links throughout the system. All links with increased volumes are listed in Tables 8 and 9. In particular, each proposal is likely creates one new congestion "hotspot." Under the Zone 7 proposal, the V/C ratio for Link 4 – 7 rises 13 percent, from 0.85 to 0.96, while under the Zone 12 proposal, the V/C ratio for Link 11 – 12 rises nine percent to 1.01. Furthermore, the Zone 7 proposal is likely to increase congestion to a lesser degree on a number of already congested links with V/C ratios already greater than 1.0 (8-7, 19-18, 8-9, et al.), whereas the Zone 12 proposal is likely to increase traffic on a number of links with V/C ratios in the 0.75 to 0.90 range (12-11, 1-4, 7-4, et al.).

Based on these affects, and the relative increases in total network travel time and delay, it is our recommendation that you continue to promote the Zone 12 location for the Neumall development.

Link	Baseline V/C ratio	Zone 7 V/C ratio	Zone 7 ΔV/C
4 - 7	0.85	0.96	0.11
7 - 4	0.73	0.82	0.09
6 - 8	0.01	0.08	0.07
1 - 4	0.75	0.8	0.05
4 - 1	0.64	0.69	0.05
8 - 7	1.46	1.51	0.05
19 - 7	0.41	0.44	0.03
3 - 4	0.66	0.69	0.03
9 - 17	0.51	0.54	0.03
19 - 18	1.20	1.23	0.03
5 - 6	0.20	0.23	0.02
18 - 15	0.75	0.77	0.02
17 - 9	0.51	0.53	0.02
12 - 1	0.37	0.39	0.02
7 - 8	1.41	1.43	0.02
17 - 18	0.31	0.33	0.02
8 - 9	1.41	1.42	0.02
1 - 19	0.40	0.41	0.02
12 - 11	0.76	0.78	0.02
9 - 5	1.08	1.10	0.02
18 - 19	1.44	1.45	0.01
10 - 2	0.52	0.53	0.01
1 - 12	0.24	0.25	0.01
18 - 17	0.21	0.22	0.01
9 - 10	0.86	0.87	0.01
10 - 9	0.73	0.73	0.01
11 - 10	0.77	0.77	0.01
15 - 14	0.72	0.72	0.01
17 - 16	1.07	1.08	0.01
9 - 8	1.45	1.45	0.01

Link	Baseline V/C ratio	Zone 12 V/C ratio	Zone 12 ΔV/C
11 - 12	0.93	1.01	0.08
4 - 1	0.64	0.72	0.08
1 - 12	0.24	0.32	0.08
16 - 13	0.50	0.57	0.07
12 - 11	0.76	0.83	0.07
12 - 1	0.37	0.42	0.05
13 - 11	0.69	0.73	0.05
1 - 4	0.75	0.79	0.05
7 - 4	0.73	0.77	0.04
13 - 16	0.79	0.83	0.04
11 - 13	0.67	0.7	0.03
14 - 12	0.20	0.23	0.03
4 - 7	0.85	0.87	0.02
15 - 14	0.72	0.74	0.02
18 - 15	0.75	0.77	0.02
10 - 9	0.73	0.74	0.01
12 - 14	0.08	0.09	0.01
14 - 15	1.12	1.14	0.01
11 - 10	0.77	0.78	0.01
9 - 10	0.86	0.87	0.01
16 - 17	1.00	1.01	0.01
10 - 11	0.86	0.86	0.01
15 - 18	0.98	0.98	0.01
9 - 17	0.51	0.51	0.01
17 - 18	0.31	0.31	0.01

(dark orange)	**V/C > 1.00**
(medium orange)	**1.00 > V/C > 0.90**
(light orange)	**0.75 > V/C**

Tables 8 and 9: Links with high V/C ratios, under Neumall proposals.