Spaghetti Junction

Final Report, Vanderbilt Senior Design 2020

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I. Introduction:

Nashville, like many other cities, is experiencing rapid growth and must address increasing demands on current transportation resources. As a result, it is important for Nashville to use its existing traffic networks in the most efficient and effective manner. East Nashville's intersection of Ellington Parkway, I-24, Main St, Spring St, and Dickerson Pike, nicknamed "Spaghetti Junction," consumes over 85 acres of space with interchanges and unusable land. This is nearly equivalent to Atlanta's Tom Moreland Interchange or L.A.'s Pregerson Interchange, the massive stack interchanges that connect multiple interstates and carry hundreds of thousands of vehicles daily.

Figure 1. Aerial View of Spaghetti Junction

The goal of the project team was to redesign this area to meet current and future traffic demand while repurposing the space to better serve the surrounding community. Working closely with the Nashville Civic Design Center (NCDC), Barge Design Solutions, and the Greater Nashville Regional Council (GNRC), the team analyzed traffic and planning data. The analysis then informed conceptual designs of Spaghetti Junction and allowed the team to forecast

new uses of the space. The results are intended for use in evaluating future projects and for gaining support for the redevelopment of Spaghetti Junction.

II. Significance:

The amount of land lost to interchanges creates the most glaring deficiency for East Nashville's Spaghetti Junction. Some of the nation's largest stack interchanges, such as Atlanta's Spaghetti Junction, require a comparable amount of land to support larger amounts of traffic. The excessive use of land is due in large part to the clover-leaf ramps accommodating each direction of traffic and the unconventional arrangement of Ellington Parkway.

Spaghetti Junction makes up a small part of Nashville's inner loop, the ring of Interstates 24, 40, and 65 that surrounds the city. The inner loop plays an important role in determining movement about the urban core while also defining the possibilities of adjacent neighborhoods. Meanwhile, Spaghetti Junction marks the only cloverleaf design on the inner loop. The 2040 Regional Transportation Plan (RTP) highlighted this by claiming that "downtown interchanges, particularly on the East Bank should be redesigned from the current clover-leaf design to a more appropriate, and less land hungry, urban form" (The Plan, 2016, p. 6-8). Studies are currently being conducted on the inner loop by a partnership including the GNRC, TDOT, and NCDC, providing a pressing opportunity to examine the extent of Spaghetti Junction's overall impact.

In addition to the inner loop, Spaghetti Junction connects to two important transportation corridors. Dickerson Pike runs north several miles from Spring Street to junctions with Briley Parkway and I-65. The corridor's Route 23 is Nashville's fourth-highest ridership bus line (Nashville MTA, 2017). Low-density development characterizes the area around Dickerson Pike, but an estimated 58,000 jobs are within a half mile of the corridor. Evaluations like the Dickerson South Corridor Study envision a pike with considerable change in areas between the corridor and interstates. The area closest to Spaghetti Junction ("The Southern Gateway") was highlighted as an area where change is particularly possible.

The Northeast Transportation Corridor, or Gallatin Pike, also joins Spaghetti Junction by way of James Robertson Parkway and Main Street. Bus Route 56, which runs along the corridor, is MTA's highest ridership route, and over 45,000 people live within a half mile of the corridor

(Nashville MTA, 2017). The 2016 nMotion plan targeted the corridor for a light rail route, and it was considered a major priority in the RTP. Though current traffic is most likely local, transit could support commuters who take the interstate or Ellington Parkway towards downtown. Over 27,000 people commute from Sumner County to Davidson County (GNRC, 2011-2015), and the population of Sumner County is expected to increase by 48% (The Plan, 2016).

Both corridors are vital to economic prosperity and regional transportation connections. Travel numbers, shown below, indicate that people can easily move to the area from surrounding regions and vice versa. Area businesses, such as Topgolf and even the Tennessee Titans, have used this characteristic to expand markets beyond the immediate area. This could be of value to future investors or private businesses. On the public side, the proximity of key transportation corridors and the excess space of Spaghetti Junction provides flexibility in exploring the placement, expansion, and maintenance of transit.

Road	2018 AADT **(TDOT)**
Interstate 24	129,618
Ellington Parkway	53,149
Main Street	27,057
S 5th Street	19,036
Woodland Street	8,927
Dickerson Pike	5,702

Table 1. Annual Average Daily Traffic for Spaghetti Junction Roads

Though access is generally unhindered for cars in the region, this detracts from the connectivity of the surrounding neighborhoods. Walking, biking, and the use of other micromobility options are made difficult by high-traffic roads and a lack of dedicated micromobility infrastructure. Two sections of Spaghetti Junction were given walkability index scores, which describes the likelihood of walking based on built infrastructure, of 6.833 and 7.83 out of 100 (GNRC Walkability Index, 2020). Both are “Below Average Walkable.” The census tracts containing Spaghetti Junction, 11800 and 11900, show that the percentage of workers who walk to their job is 2.5% and 0.8% (Metro Public Health Department, 2020). This is below the 3.1% target for 2020. This takes on additional significance considering that more than 11% of

households in the adjacent census tracts do not own a vehicle (Metro Public Health Department, 2020).

III. Preliminary Research Findings:

Pedestrian Travel

The quality of public space, which includes streets, helps determine urban prosperity (UN-HABITAT, 2013). The UN-HABITAT's global public space toolkit highlights several measures for evaluating the quality of an urban area, two of which show deficiencies present in Spaghetti Junction: Access and Comfort (2016, p. 37).

Inaccessibility and discomfort are evident in two pedestrian pathways. The first is outlined below. I-24, a CSX rail line, and a high-traffic road isolate the neighborhood adjacent to Spaghetti Junction. This makes movement to and from the neighborhood challenging at best. Additionally, important destinations, like grocery stores, remain far away or difficult to access, creating a positive feedback loop of cars, congestion, and heightened discomfort for pedestrians.

Figure 2. Neighborhood Surrounded by Road and Rail

The other instance of poor access and discomfort exists for pedestrians who hope to cross I-24. There are three underpasses in Spaghetti Junction, and they generally appear like the Woodland Street Underpass shown below.

Figure 3. Woodland Street Underpass

Worth noting is the poor lighting and the small sidewalk, already fighting for space with utilities and street signs, next to multiple, wide road lanes. The layout of the underpass does not encourage a perception of comfort and safety for pedestrians. This makes promoting the space as walkable and thriving more difficult, and it restricts movement to East Nashville or East Bank.

Bicycle Travel

Prioritizing bicycle travel was key to the success of the Spaghetti Junction project, and it aligns with the need to improve the level of service concerns highlighted in the RTP (p. 5-14). Walk Bike Nashville developed the map in Figure 4.

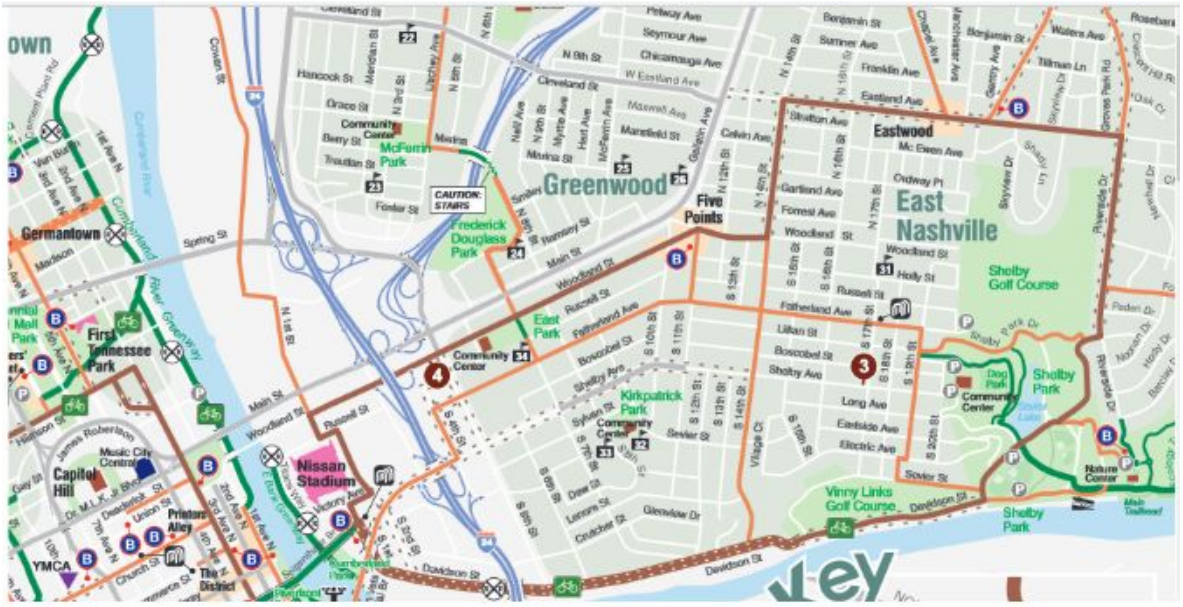

Figure 4. East Nashville Bike Loop

Most important to this effort is Woodland Street, which offers a connection to other paths while avoiding the high-volume James Robertson Parkway and several busy interchanges.

The brown section from Five Points to I-24 in Figure 4 was the primary focus for bicycle travel for this project since it avoids the high-traffic James Robertson Parkway and remains accessible to businesses and neighborhoods. It currently only has a shared lane despite some recent groundwork to expand, as seen in Figure 5. Efforts like the East Nashville Backbones Project aimed to expand bike infrastructure from 1st Avenue North to South 11th Street, but one can see the need for more development in order to make an effective bike lane. The road faces some constraining right-of-ways, yet development can expand these right-of-ways to better suit other modes of travel.

Figure 5. Woodland Street

Automobile Travel

The junction formed at the project area is vital to the flow of vehicles in and out of Downtown Nashville. To design a better road network, it is important to understand where people are traveling and the safety concerns associated with those paths. Figure 6 shows the AADT at key ramps in the junction (TDOT, 2017). Although there are a variety of considerations, the data shows that the highest traffic volumes are for commuters to and from both Ellington Parkway and the Central Business District.

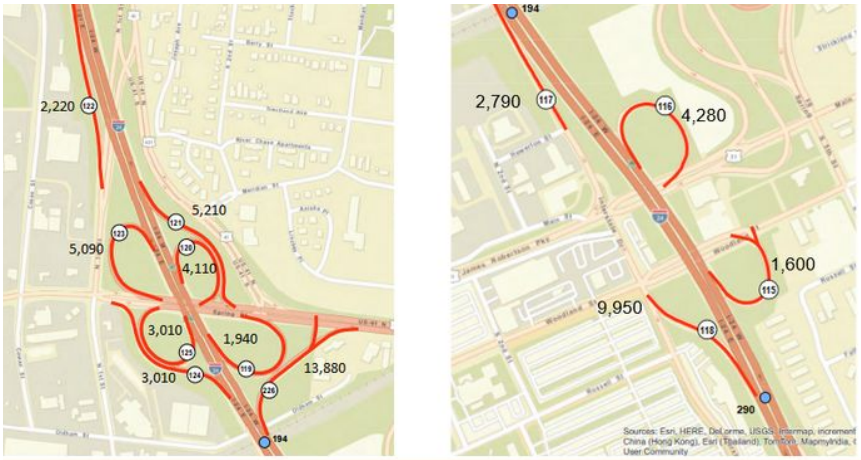

Figure 6. AADT at Spaghetti Junction Ramps

Nashville crash data suggests that merge lanes and varying speeds consistently produce collisions at the cloverleaf section and the Ellington Parkway section. The sections are circled in Figure 6 (Metro Gov. of Nashville). Because crashes occur in similar locations over separate years, it suggests that the design of the roadways and other factors may lead to collisions.

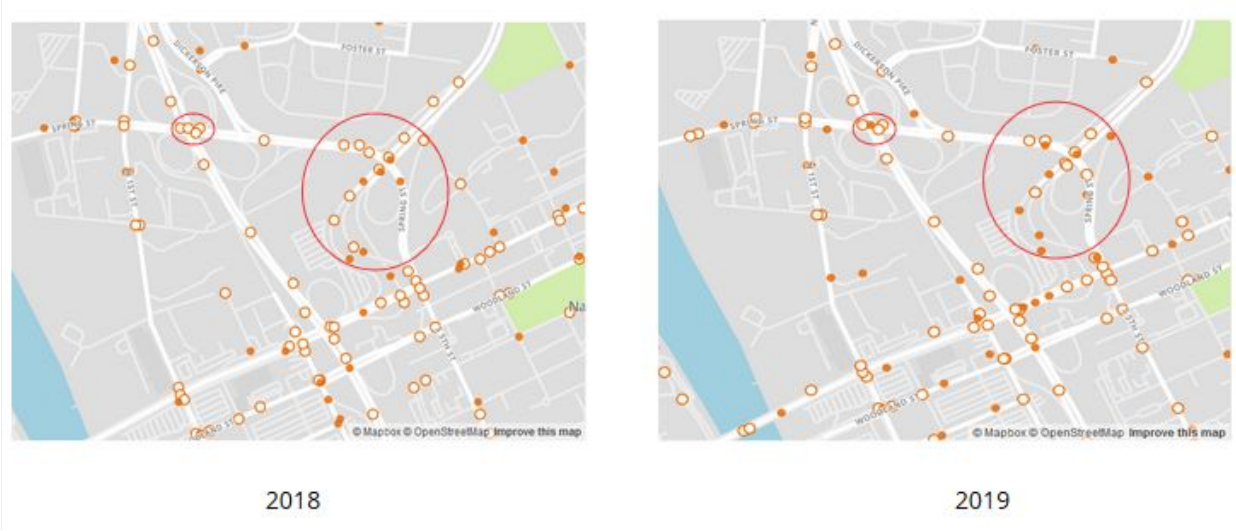

Figure 7. Crash Data; white points represent multiple crashes

Public Transport

Recent public transportation projects have established a framework of bus services connecting Spaghetti Junction to other areas along the corridor. These included a BRT-Lite expansion and a Regional Express Bus Service. The diagram below from the Nashville MTA provides a look at bus services in the region. Several widely used routes, such as Route 56, move through Spaghetti Junction.

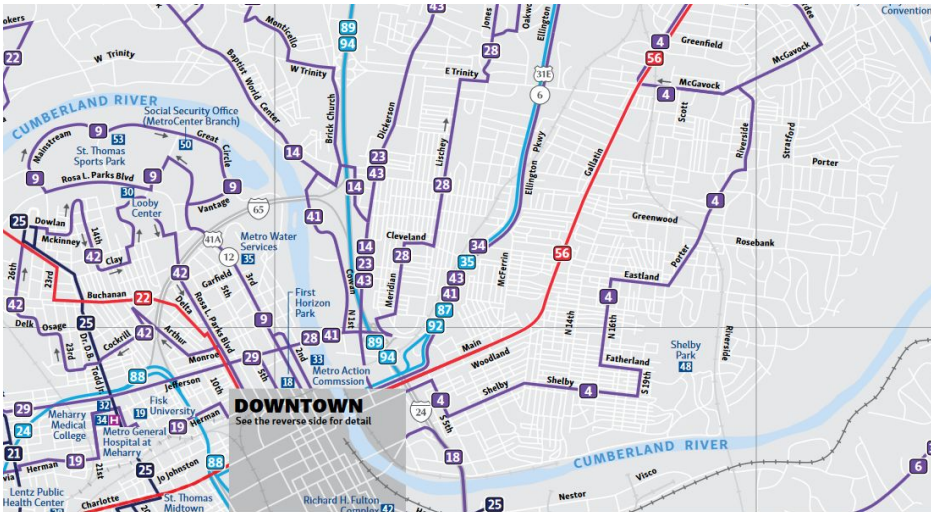

Figure 8. Current Bus Routes

To better understand the need for transit-oriented development around Spaghetti Junction, the team used FHWA guidelines (2018, p. 38) to estimate future AADT (See Appendix A). The projections mirror that of the GNRC (RTP, 2020) in Figure 8. Some road links were congested in 2018 but most will be heavily congested in the 2040, even with the planned bus rapid transit expansion along Ellington Parkway. Nashville already spends an estimated 58 hours per year in delays and $1217 dollars per commuter as a result of congestion (TTI, 2019).

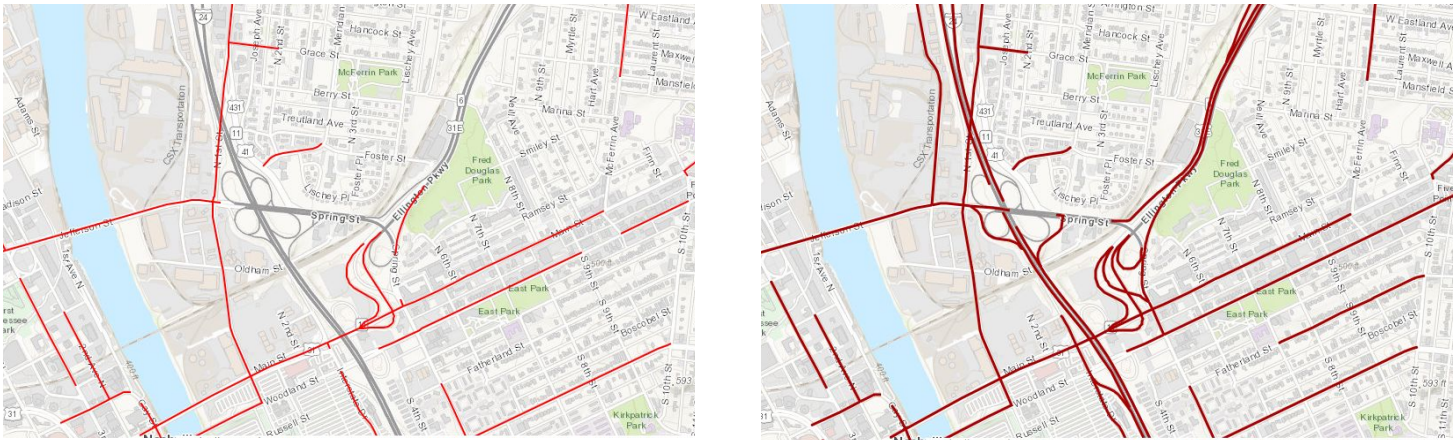

Figure 9. 2018 Congested Links vs. 2040 Congested Links with planned improvements

IV. Design Goals:

The preliminary research informed 3 design goals for the project:

1. Design interchanges that manage traffic with less wasted land.
2. Design an area with multimodal travel options, from pedestrian paths to transit hubs.
3. Design a space that brings value to the local community and to Nashville in general.

V. Design Results and Recommendations:

Challenge 1: Efficient Interchanges

The project team addressed the flow of traffic and the safety concerns with the design shown in Appendix B. All curves were designed in accordance with TDOT-recommended turn radii (Appendix B). The new design includes streamlined movement to and from Ellington Parkway and maintains access to and from the Central Business District. It enables new access to East Nashville via an exit onto Woodland Street from I-24, and it attempts to minimize merge

lanes while simplifying the entanglement of Ellington Parkway with a Y-stack interchange. The next step in evaluating the design would be testing its effectiveness with models and simulations.

Challenge 2: Multimodal Infrastructure

Preliminary research revealed the need for pedestrian connections across Spring Street and S 5th Street. This would ensure access to the additional space freed up by a new design. The design below shows planned connections over the existing infrastructure. It suggests a park in place of the low-traffic portion of Dickerson Pike and connects that park to the existing McFerrin Park and Frederick Douglass Park. This translates well with recent proposals like the Southern Gateway Scenario mentioned in the Dickerson South Corridor Study.

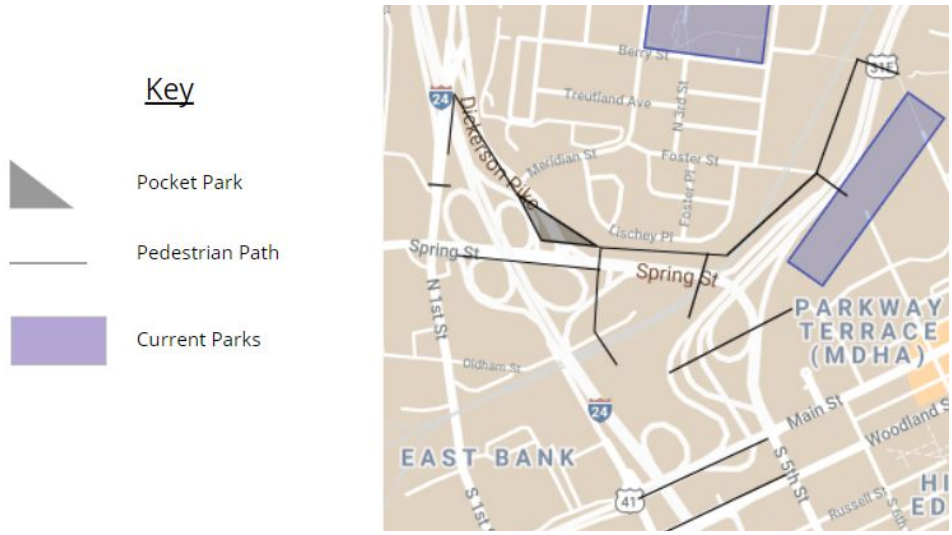

Figure 10. Planned Pedestrian Paths

This plan maintains the need for improved underpasses. Recommendations for each underpass include:

- Beautification and landscaping projects
- Burying utilities
- Improved lighting
- More space for pedestrian movement

Cross sections for Woodland Street and Main Street are adopted from Nashville's Major and Collector Street Plan and are meant to provide a visual for the future of the space. Cross sections are provided in Appendices C and D. Both accommodate NACTO guidelines.

The nMotion High Capacity Transit Briefing Book details the challenges of constructing light rail on Main Street. It is important for future development to contribute to Main Street with right-of-way flexibility and pedestrian walking space. Similarly, Woodland Street can benefit from expanded right-of-way in order to better suit bicycles and pedestrians.

Challenge 3: Valuable Space

The redesigned road network of Spaghetti Junction opens up an estimated 15 acres of usable space. From examining existing data and plans to suggest best uses for the space, a mixed use-development including greenspace, a neighborhood transit hub, housing, and grocery options was found to bring potential benefits to those living nearby. A depiction of the potential space is shown below.

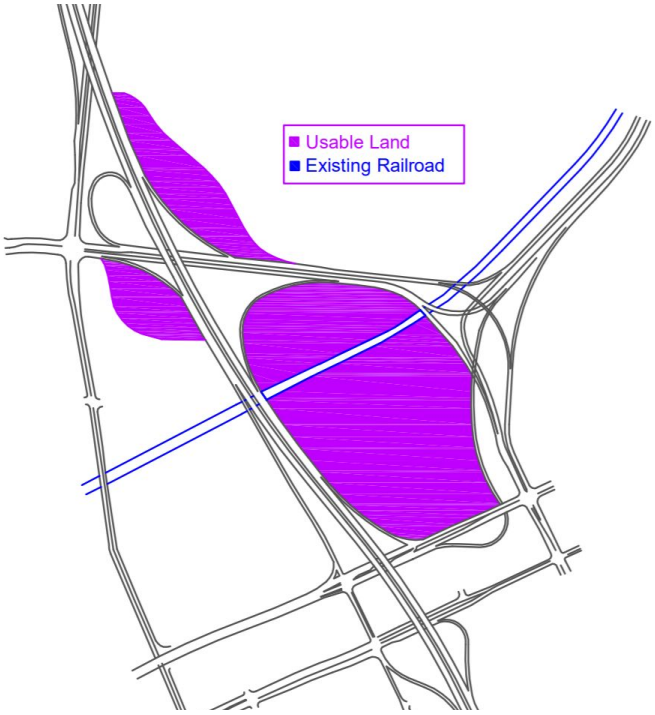

Figure 11. Potential Usable Space

Many elected officials and community leaders have identified the need for affordable housing in Nashville. Other needs include providing access to fresh, nutritious food, which has been a concern for parts of East Nashville (Metro Social Services, 2013). Transportation is a key factor linking food deserts to supermarkets, and the range of bus services moving from food deserts to Spaghetti Junction makes the space an intriguing option for a neighborhood transit hub.

The concept of a neighborhood transit hub stems, first, from the access it would provide to an area that has shown high ridership. One area shows that 7.4% of workers use public transportation to commute to work, which is 5% higher than the Davidson County Average (Metro Public Health, 2018). However, transit hubs, especially those linked to light or commuter rail, often provide the economic benefit of community development and increased property values (TTI, 2009). This potential local economic benefit would not be realized if the 2016 nMotion plan was followed exactly as proposed. The plan puts Dickerson and Gallatin Pike stations just outside of Briley Parkway, which would push economic benefits further away from the Spaghetti Junction communities.

One potential layout for Spaghetti Junction is shown below. Worth noting is the space that is still available even after including a major development and a greenspace. Also worth noting is the idea of capping the lane connecting James Robertson Parkway to Ellington Parkway and using that cap to connect the new development to adjacent neighborhoods.

Figure 12. Proposed Model

VI. Further Research & Final Thoughts

Understanding the complex web of correlations that tie communities to their infrastructure is surely one of the most challenging parts of any project. Most staggering in the research and the conceptual design of Spaghetti Junction was the need for an integrated approach to designing infrastructure. A true community needs assessment would prove valuable in redesigning this space.

This also reiterates the importance of exploring the economic and health impacts tied to the inner loop. The study of these impacts is outside of the scope of this project, yet certain data points related to its research were particularly striking. For example, communities around Spaghetti Junction have median incomes and per capita incomes well below the Davidson County values as a whole (Metro Public Health, 2018). Additionally, health metrics like insufficient sleep are worse near Spaghetti Junction than overall county values (Metro Public Health, 2018). These characteristics are often found on other portions of the inner loop. Prioritizing a holistic evaluation could potentially allow the city to minimize harmful impacts to residents. Resources like "60 Years of Urban Change: Southeast" and "A City Swept Clean" provided a better understanding of some of the complicated history surrounding the inner loop.

Lastly, there is ample room to explore the cost of development for Spaghetti Junction and its fit for smart technology. Because Spaghetti Junction is diverse in development opportunities, it is necessary to specify exactly what projects are planned and where funding is sourced in order to provide an accurate, relevant cost estimate. Another possible Spaghetti Junction project is applying Nashville's Smart City Challenge Vision to the area, as many of the aspirations in the plan align with this project's efforts toward access and inclusivity.

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Appendix A: Traffic Forecasts

The Federal Highway Administration defines future AADT as in Equation 1, where AACR is equal to the Annual Average Change Rate and n is equal to forecasted years. These values were forecasted 20 years ahead, and an AACR equivalent to 0.79% was used. This value represents population growth for Nashville. Data is summarized below.

$$AADT_{Future} = AADT_{Current} \times (1 + AACR)^{n} \quad (1)$$

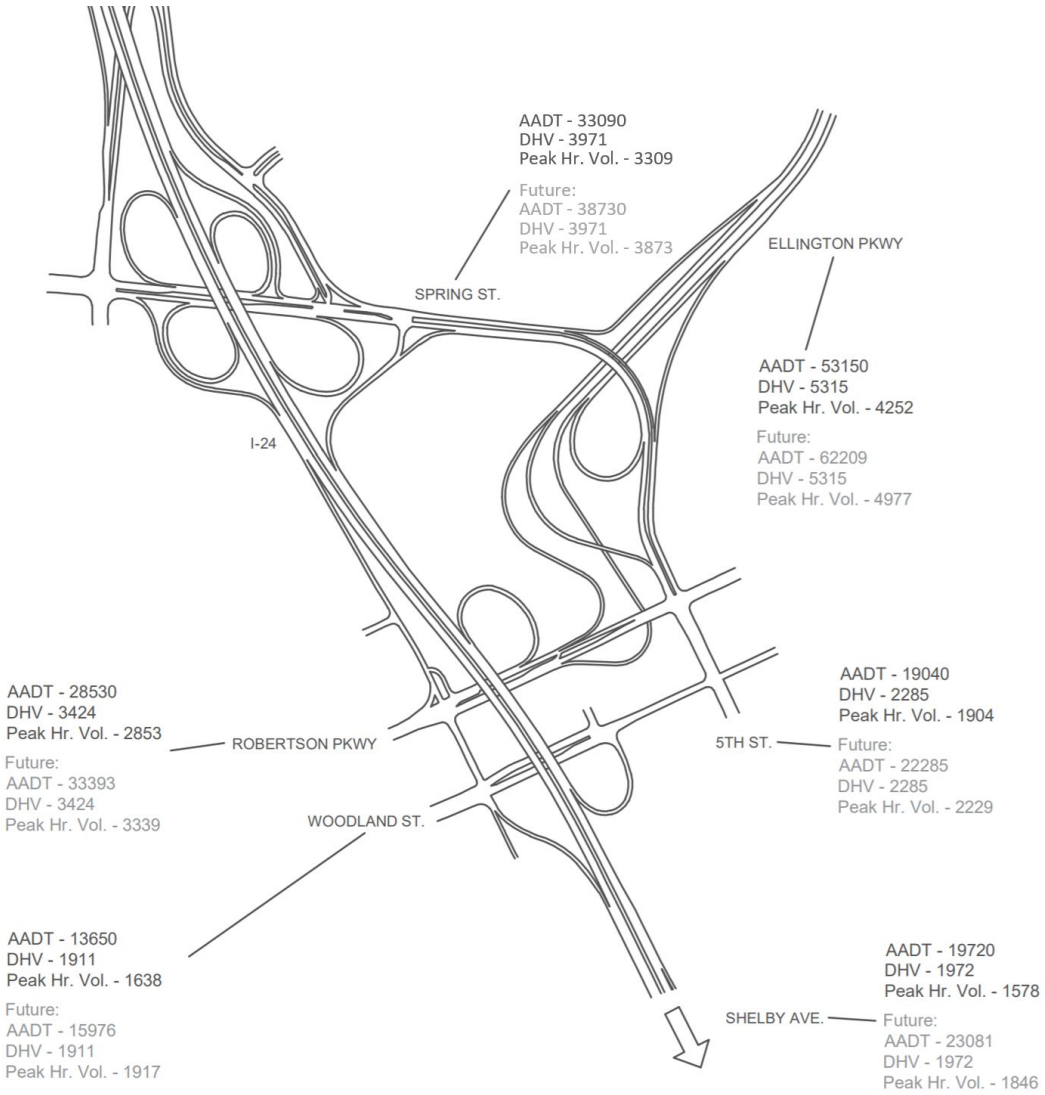

Figure A.1. Projected Spaghetti Junction Traffic

Appendix B: Spaghetti Junction Redesigned

The proposal for the design of Spaghetti Junction includes a Y-stack interchange and the removal of several of the cloverleaf ramps. The goal was to maintain capacity without wasting space.

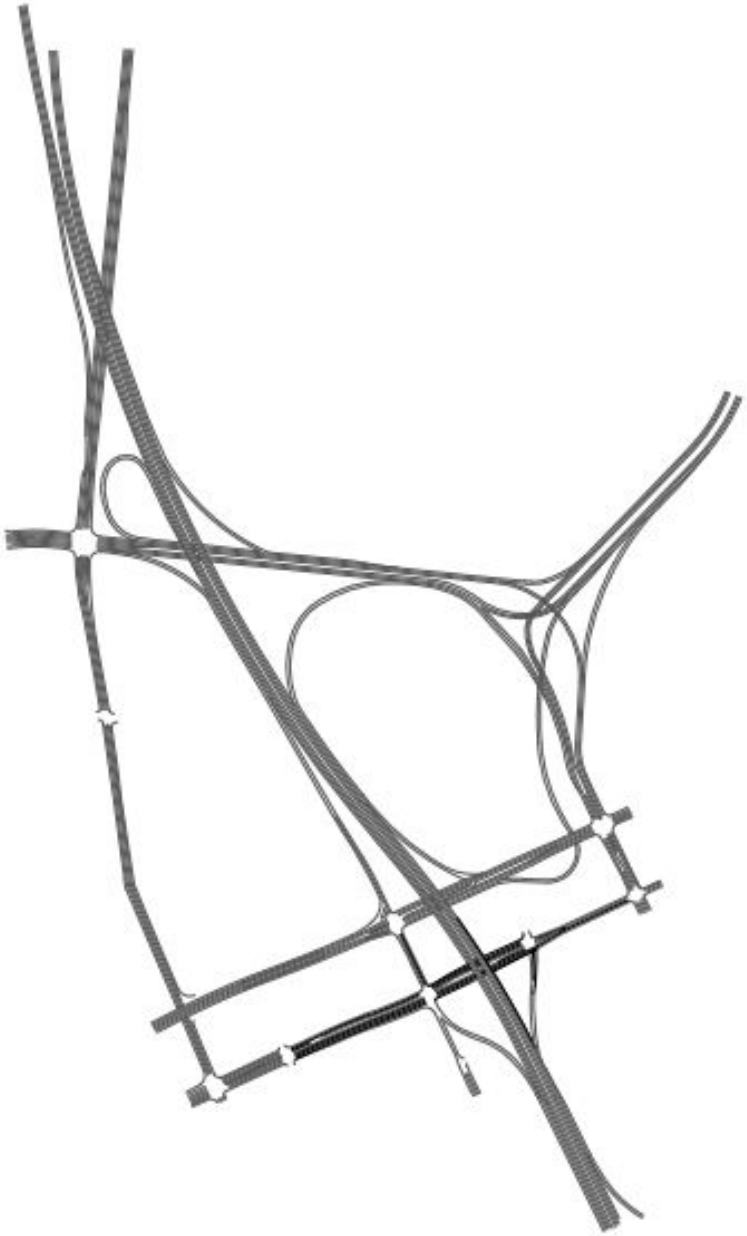

Figure B.1. Proposed Spaghetti Junction Design

E MAX=0.08 DESIRABLE

D	R (FT.)	V=20(MPH)				V=30(MPH)				V=40(MPH)				V=50(MPH)				V=60(MPH)				V=70(MPH)			
		e/F	L(FT.)			e/F	L(FT.)			e/F	L(FT.)			e/F	L(FT.)			e/F	L(FT.)			e/F	L(FT.)		
			2-LN	4-LN	6-LN		2-LN	4-LN	6-LN		2-LN	4-LN	6-LN		2-LN	4-LN	6-LN		2-LN	4-LN	6-LN		2-LN	4-LN	6-LN
0°-15′	22,918	NC	0	0	0	NC	0	0	0	NC	0	0	0	NC	0	0	0	NC	0	0	0	NC	0	0	0
0°-30′	11,459	NC	0	0	0	NC	0	0	0	NC	0	0	0	NC	0	0	0	RC	175	175	215	RC	200	200	240
0°-45′	7,639	NC	0	0	0	NC	0	0	0	NC	0	0	0	RC	150	150	195	.022	175	175	225	.028	200	220	290
1°-00′	5,730	NC	0	0	0	NC	0	0	0	RC	125	130	170	.021	150	150	200	.029	175	200	265	.036	200	255	340
1°-30′	3,820	NC	0	0	0	RC	100	110	145	.021	125	130	175	.030	150	180	240	.041	175	245	325	.051	215	320	430
2°-00′	2,865	NC	0	0	0	RC	100	110	145	.027	125	150	200	.038	150	210	280	.051	190	285	380	.065	255	385	510
2°-30′	2,292	NC	0	0	0	.021	100	115	150	.033	125	170	225	.046	160	240	320	.061	220	325	435	.075	285	430	570
3°-00′	1,910	RC	65	100	130	.025	100	125	165	.038	125	185	245	.053	180	265	355	.068	235	355	470	.080	300	450	600
3°-30′	1,637	RC	65	100	130	.028	100	130	175	.043	135	200	265	.058	190	285	375	.074	255	380	505	D(MAX)=3°-00′			
4°-00′	1,432	RC	65	100	130	.031	100	140	185	.047	145	215	285	.063	200	300	400	.078	265	395	525				
5°-00′	1,146	.021	70	100	135	.038	105	160	210	.055	160	240	315	.071	220	330	440	D(MAX)=4°-45′							
6°-00′	955	.025	75	110	145	.043	115	175	230	.062	175	260	345	.077	235	350	470								
7°-00′	819	.028	80	120	155	.048	125	185	245	.067	185	275	370	.080	240	360	480								
8°-00′	716	.031	85	125	165	.053	135	200	265	.071	195	290	385	D(MAX)=7°-30′											
9°-00′	637	.035	90	135	180	.056	140	210	275	.075	200	300	400												
10°-00′	573	.037	95	140	185	.060	145	220	290	.078	210	310	415												
11°-00′	521	.040	100	145	195	.063	150	225	300	.079	210	315	420												
12°-00′	477	.043	105	155	205	.065	155	230	310	.080	210	315	420												
13°-00′	441	.045	105	160	210	.068	160	240	320	D(MAX)=12°-15′															
14°-00′	409	.047	110	165	215	.070	165	245	325																
16°-00′	358	.051	115	175	230	.074	170	255	340																
18°-00′	318	.054	120	180	240	.077	175	265	350																
20°-00′	286	.057	125	185	250	.079	180	270	360																
22°-00′	260	.060	130	195	260	.080	180	270	360																
24°-00′	239	.062	135	200	265	D(MAX)=22°-45′																			
28°-00′	205	.067	140	210	280																				
32°-00′	179	.070	145	220	290																				
36°-00′	159	.074	155	230	305																				
40°-00′	143	.076	155	235	310																				
44°-00′	130	.078	160	240	315																				
48°-00′	119	.079	160	240	320																				
52°-00′	110	.080	160	240	320																				
		D(MAX)=53°-30′																							

LEGEND	
D	DEGREE OF CURVE
R	RADIUS OF CURVE
V	ASSUMED DESIGN SPEED
e	RATE OF SUPERELEVATION
L	MINIMUM LENGTH OF TRANSITION
NC	NORMAL CROWN
RC	REMOVE ADVERSE CROWN, SUPERELEVATE AT NORMAL CROWN SLOPE

Figure B.2. TDOT Design Table showing the radius of curve for an assumed design speed

Appendix C: Visualising Woodland Street

Figure C.1 shows the current functionality of Woodland Street. Removing the center turn lane, which is mostly used for deliveries, frees up valuable space. Other Nashville areas with similar traffic counts, such as 12th Ave S, have successfully managed traffic without the center turn lane.

The cross section from the Major and Collector Street Plan is shown in Figure C.2. This plan is envisioned in Figure C.3. Standard 8-foot sidewalks are combined with protected bike lanes that exceed the minimum requirement recommended by NACTO.

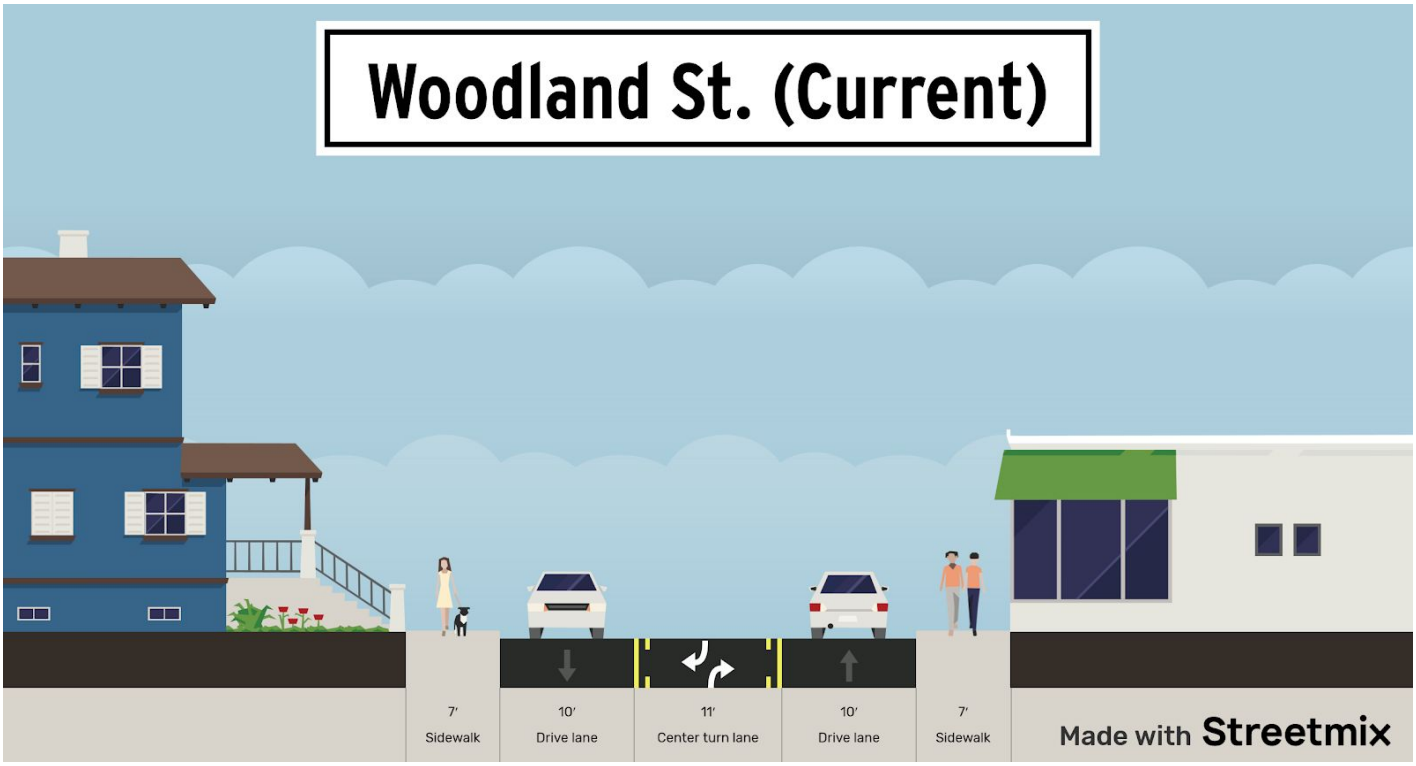

Figure C.1. Current Woodland Street Cross Section

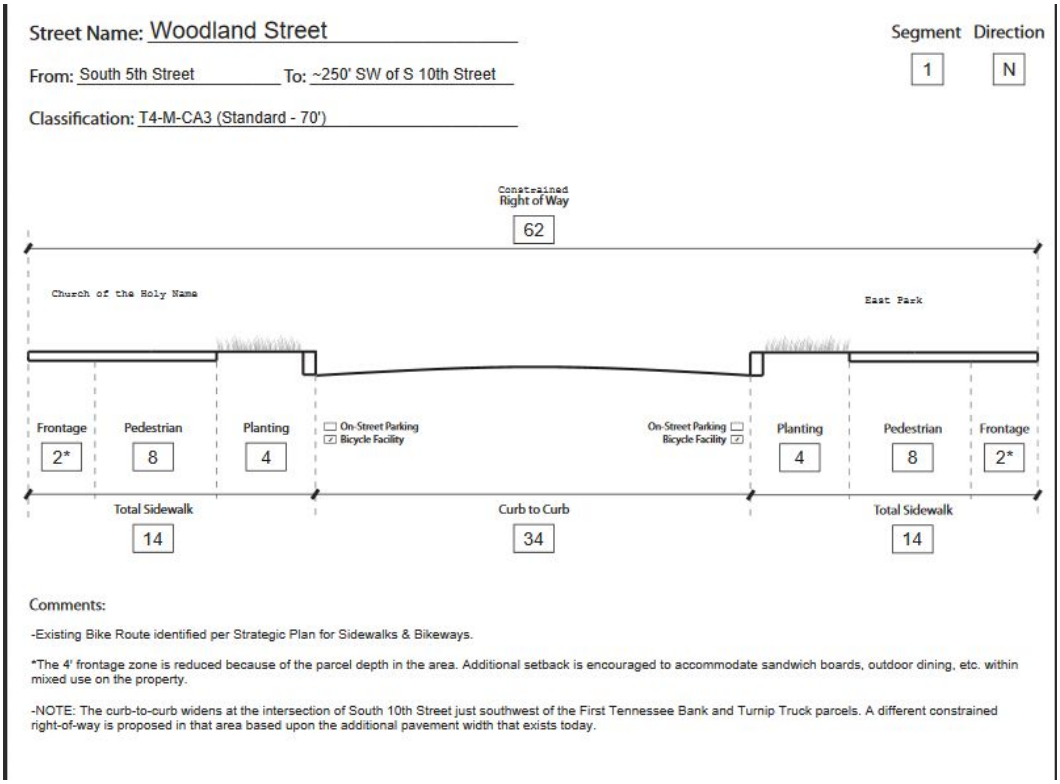

Figure C.2. Plan from MCSP of Nashville

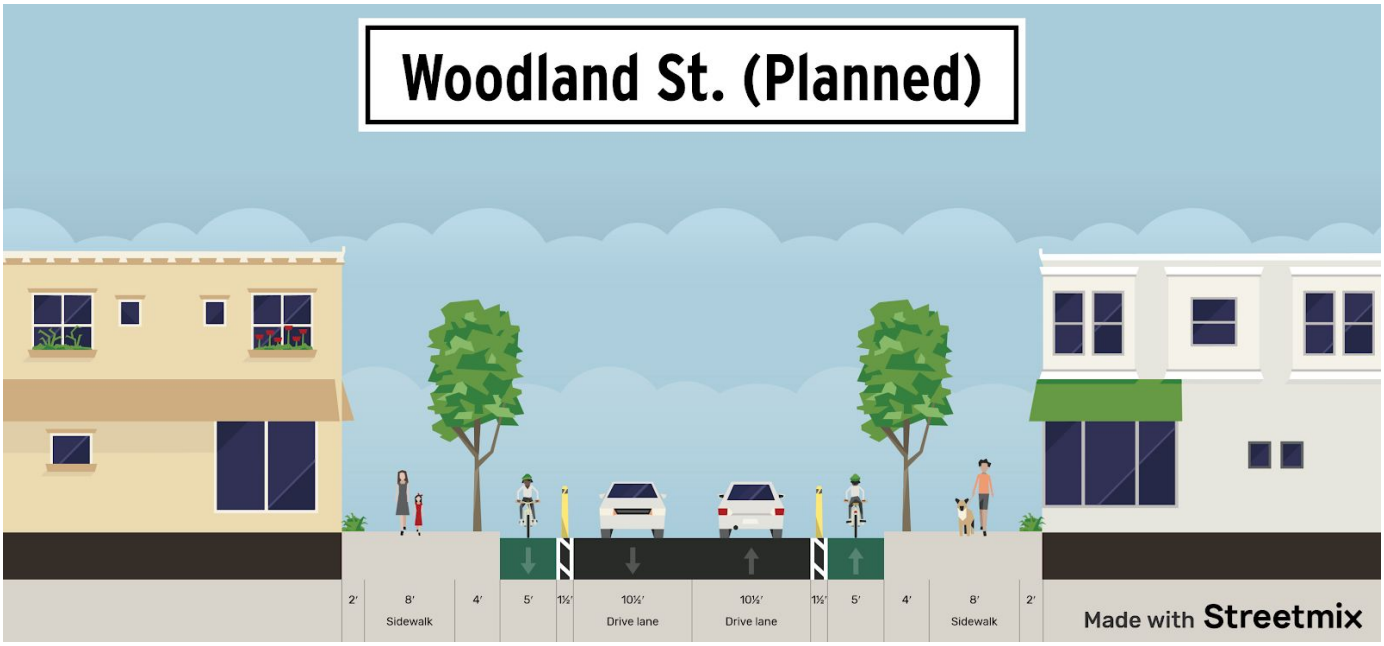

Figure C.3. Proposed Woodland Street Cross Section

Appendix D: Visualizing Main Street

Figure D.1 shows the current layout of a cross section at the intersection of S 5th Street. Figure D.2 depicts the planned layout in the MCSP. They share the same right-of-way at 97 feet.

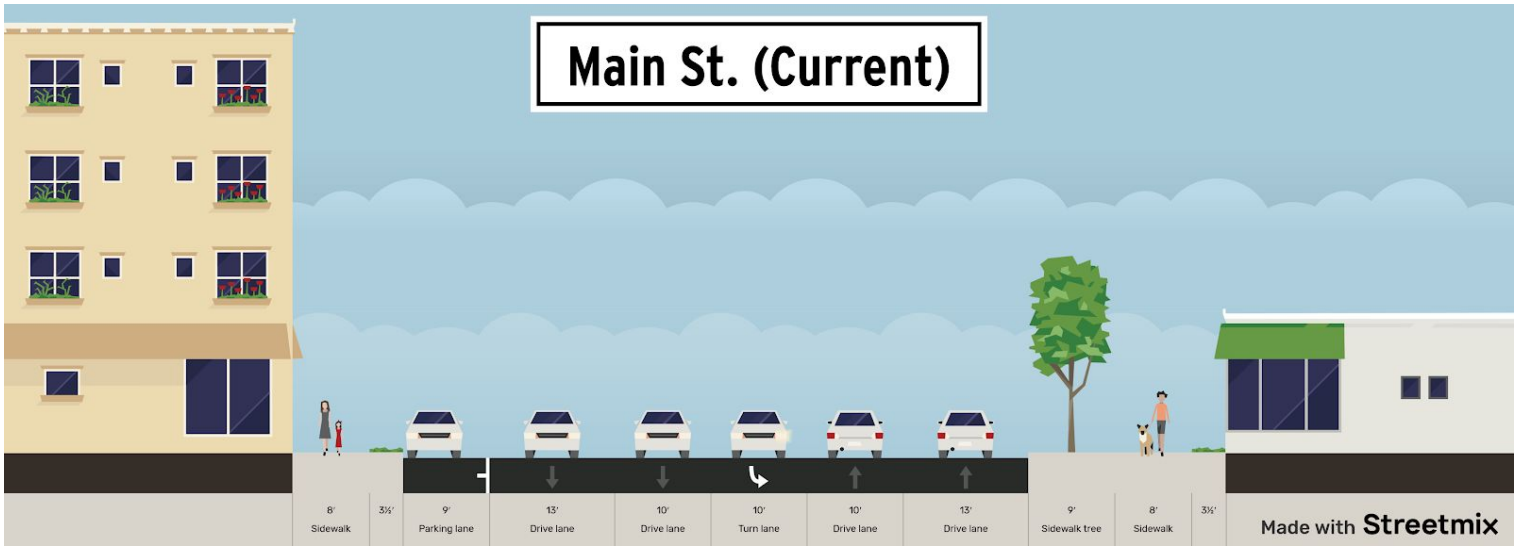

Figure D.1. Current Main Street Cross Section

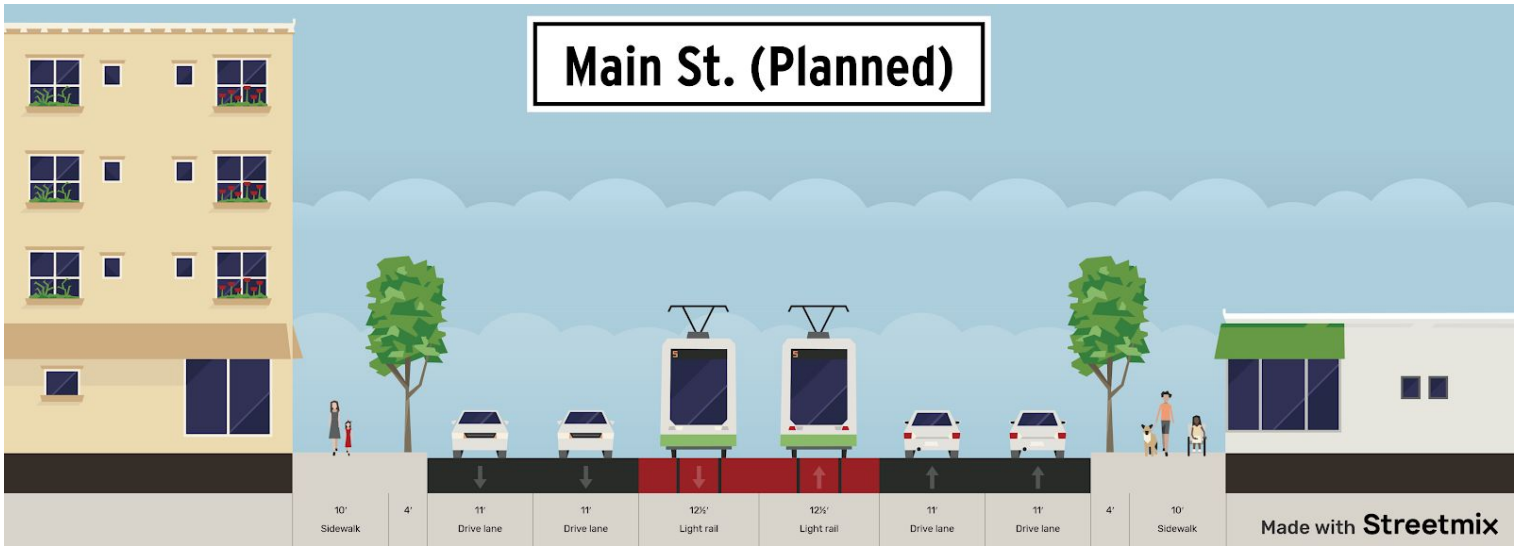

Figure D.2. Proposed Main Street Cross Section

Appendix E: Revised Schedule

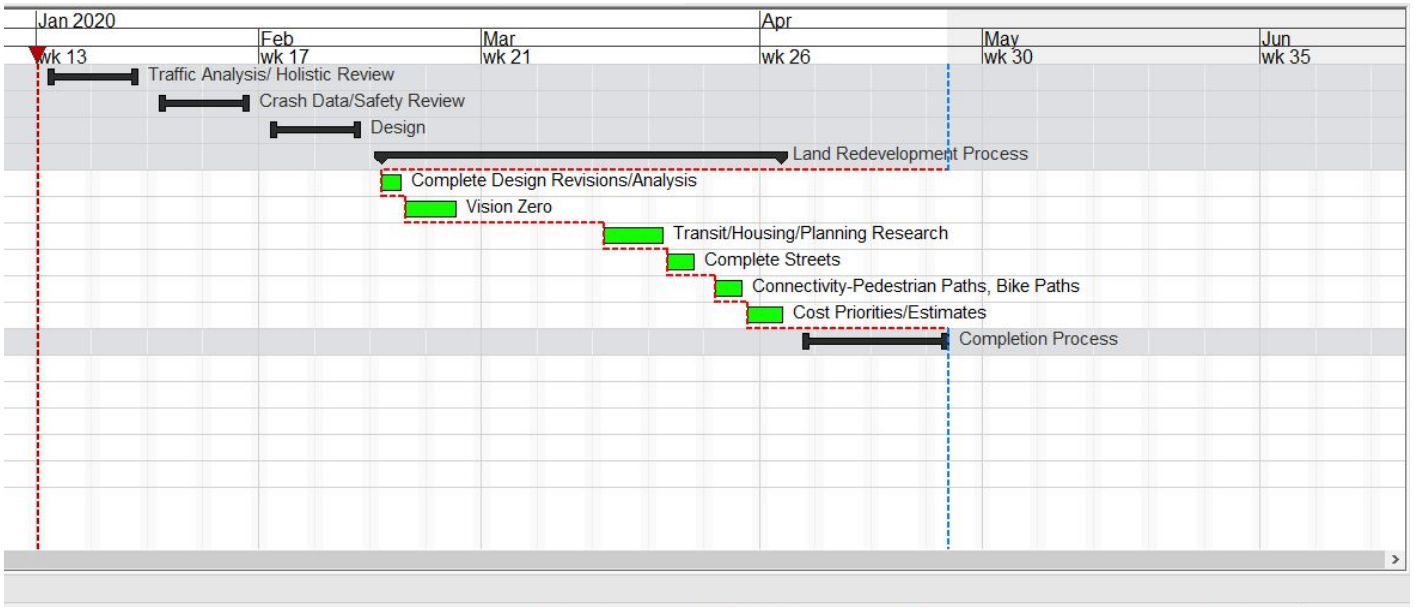

Figure E.1. Revised Schedule