Improving Pedestrian and Bicyclist Safety and Comfort Along the Water Street Corridor

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Mark Schenkel
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Technical Project Team Members
Emily Chen
Ricky Dobson
Nicholas Kim
Cem Kutay
Tiffany Nguyen
Brendan Vachris

On my honor as a University Student, I have neither given nor received
unauthorized aid on this assignment as defined by the Honor Guidelines
for Thesis-Related Assignments

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Mark Schenkel
Engineering Systems and Environment
University of Virginia
Charlottesville, United States
mfs8db@virginia.edu

Tiffany Nguyen
Engineering Systems and Environment
University of Virginia
Charlottesville, United States
ttn2ba@virginia.edu

Cem Kutay
Engineering Systems and Environment
University of Virginia
Charlottesville, United States
ck7cn@virginia.edu

Emily Chen
Civil Engineering
University of Virginia
Charlottesville, United States
ecc7qd@virginia.edu

Brendan Vachris
Civil Engineering
University of Virginia
Charlottesville, United States
bcv8ek@virginia.edu

Nicholas Kim
Civil Engineering
University of Virginia
Charlottesville, United States
ngk2wh@virginia.edu

Ricky Dobson
Civil Engineering
University of Virginia
Charlottesville, United States
rdd5cn@virginia.edu

***Abstract*—The Virginia Department of Transportation (VDOT) has identified the West Water Street corridor in downtown Charlottesville as an area of focus for bicyclist safety due to a high rate of pedestrian crashes between 2012 and 2016. Water Street hosts one of the main bicycle routes in the city; however, there is a high level of traffic stress for bicyclists. Therefore, it is critical to determine pedestrian and bicyclist safety countermeasures. Ideally, Water Street would be able to accommodate vehicles, pedestrians, and bicyclists in a safe and efficient manner.**

The focus of this project is to research, create, and test alternative roadway designs to improve bicyclist and pedestrian safety in the Water Street corridor. The design team analyzes best practices from other bicycle- and pedestrian-friendly cities to inspire design ideas for the specific Water Street corridor. Multi-criteria decision analysis is used to choose the best design concept. This one concept is then extrapolated to other similar designs in which one aspect of the main design alternative is changed. The team tests those designs using a virtual reality (VR) environment and biometric data collection. The team is currently (February 2020) starting to conduct experiments in the VR environment. A user testing plan is being created and reviewed that will then be executed in March 2020 to conduct experiments. User comfort and safety will be evaluated across four different design alternatives. From this evaluation, a recommendation will be proposed to the City of Charlottesville as to what design should be implemented.

Keywords—safety improvements, roadway design, virtual reality

I. Introduction

In Charlottesville, there is strong, existing community support and enthusiasm for walking and bicycling. The Charlottesville Bicycle & Pedestrian Master Plan Update of 2015 aims to build upon that existing culture [1]. The plan was developed over a 12-month period in 2014-2015 and was overseen by City staff as well as the Bicycle and Pedestrian Master Plan Update Steering Committee. The City and the Bicycle and Pedestrian Steering Committee used a multi-faceted approach to gather the baseline data and input needed to develop their recommendations [1]. That approach included four key steps: inventory of existing bicycle and pedestrian facilities, public and stakeholder input, bicycle and pedestrian demand analysis, and bicyclist level of traffic stress analysis [1].

To help identify where bicycle and pedestrian facilities are most needed, the City measured demand for walking and biking. This analysis helped locate the roads where the greatest number of people are expected to walk and bike, which influences where active transportation infrastructure will be most needed. From this analysis, Water Street was identified as having a “high” generalized bicyclist and pedestrian demand [1]. Based on the above research, the City of Charlottesville recommended bicycle and pedestrian infrastructure projects for the city to build as part of their active transportation vision. The plan is divided into a few parts, including bicycle recommendations and pedestrian recommendations.

The focus of this paper is to test those recommendations in a VR environment to assess user comfort and safety. In that process, other conceptual designs were created and assessed. At the end of the project, full recommendations regarding bicyclist and pedestrian safety improvements will be put-forth. However, due to the novel Coronavirus COVID-19, the University of Virginia had to modify its class scheduling and research programs. Therefore, user testing was not able to be completed in Spring 2020 and the team instead will write a white paper regarding how user data would have been evaluated.

As an overview, the process used to implement this project is as follows.

- Conduct background research to gather information
- Create design requirements based on the background research
- Identify possible design concepts
- Perform multi-criteria analysis to finalize one main design concept

- Establish the extrapolated finalized design alternatives
- Carry-out user testing in VR
- Propose a roadway design recommendation to the City of Charlottesville

II. Background Information

This section highlights evidence to support design decisions. Many of the decisions the team made stemmed from “Safe Systems” best practices. However, other evidence to support design decisions will be introduced as necessary in the rest of the paper.

According to the Institute of Transportation Engineers (ITE), the Safe Systems approach differs from conventional safety practice by being human-centered – i.e. seeking safety through a more aggressive use of vehicle or roadway design and operational changes rather than relying primarily on behavioral changes – and by fully integrating the needs of all users (pedestrians, bicyclists, older, younger, disabled, etc.) of the transportation system [2]. The design concepts implement some of the ITE’s best practices for Safe Systems, such as

- Separating users in space
- Increasing attentiveness
- Reducing vehicle speeds

Separating users in space is important because it segregates the physical space to provide travelers with a dedicated part of the right-of-way [2]. Typically, travelers moving at different speeds – pedestrians, bicyclists, etc. (e.g. sidewalks, cycle tracks) – or different directions (e.g. turning vehicles in separate turn lanes) are separated in space to minimize conflicts with other users [2]. The design concepts have a separated bicycle lane to provide bicyclists with a buffer between the bicycle and travel lanes. From the Charlottesville Bicycle & Pedestrian Master Plan Update of 2015, separated bicycle lanes also increase the perceived sense of safety and can make bicycle routes less stressful [3].

In addition, increasing attentiveness and awareness is critical. This approach seeks to alert users to potential hazards and/or the presence of other users. These techniques can be vehicle, user, or infrastructure-based [2]. One way to increase attentiveness is through rectangular rapid flashing beacons (RRFB) that warn drivers of the presence of crossing pedestrians [4]. Therefore, the design concepts implement four different RRFBs at two major intersections along the Water Street Corridor.

Lastly, the laws of physics dictate that greater harm will occur at higher speeds and that, typically, the greater the mass of a vehicle, the more harm it will inflict on others [2]. Reducing speed in the presence of vulnerable users is a key Safe Systems strategy. One approach to tackle this issue is in physical roadway designs (i.e. width and horizontal alignment) to limit free flow speeds [2]. Some of the initial designs had wider roadway widths (12 and 13 feet), but the team decided to reduce those widths to 10 feet to allocate more space for sidewalk expansion and bicycle buffers.

III. Design Requirements

To create the design requirements, the team researched basic information concerning bicycle and travel lane widths. Below is information gathered regarding these two entities.

According to VDOT’s Bicycle and Pedestrian Facility Guidelines, the width of a bicycle lane is five feet minimum from the face of a curb to the bicycle lane stripe on roadways without a gutter pan [5]. Greater bicycle lane widths (five feet minimum) are required where substantial truck traffic is present, transit buses are present, or where posted speeds exceed 40 mph [5]. Therefore, the design concepts have a minimum width of five feet for bicycle lanes.

From VDOT’s Subdivision Street Design Guide, residential and mixed-use local streets should have lane widths that vary between 10 and 12 feet [6]. From these guidelines, the design concepts have a minimum of 10-foot travel lanes.

In addition, the 2018 measurements conducted by Toole Design Group of the Water Street corridor were used to create the design requirements [7].

Therefore, the following design requirements were created based on city infrastructure standards (as described above), the current infrastructure in Water Street, along with feedback given from industry mentors.

- Accommodate vehicular and bicyclist traffic in a minimum road width of 35 feet, 8 inches to a maximum of 65 feet, 5 inches
- Maintain speed limit at 25 mph
- Have car lanes be at least 10 feet wide
    - 11 feet+ is ideal (to account for buses)
- Have any included bicycle lanes be at least 5 feet wide
- Design for at least 50% of users tested in the environment to report at least an “intermediate” comfort level
- Meet the Americans with Disabilities Act (ADA) requirements
    - Keep at least the current level of walkability for pedestrians
- Implement better signage and lighting

IV. Conceptual Designs

Three preliminary design concepts were determined after observing the design requirements, scope of the project, and current best practices. The first design concept is based off of existing Charlottesville city plan improvements that consist of two-way travel lanes and a five-foot westbound bicycle lane. After conducting research, the second concept is a one-way street because it eliminates risk and fear of collisions with vehicular traffic [8]. Historically, many two-way downtown streets were converted to one-way streets in the mid-20th century to streamline traffic operations and reduce conflicts [8]. Therefore, the one-way concept consists of a one-way travel lane, an expanded parking lane for ease of loading (for delivery vehicles, especially those that need to access the pedestrian-only downtown mall), a five-foot bi-directional cycle track, and a two-foot sidewalk expansion. The third concept is to remove parking in order to allow for wider travel and bicycle lanes. This design has two-way travel lanes, five-foot bi-directional bicycle lanes, and a two-foot sidewalk expansion.

After these three preliminary designs were drafted and designed in AutoCAD, the team discussed the designs with industry mentors. The feedback received was that additional lane width can encourage higher speeds. The designs originally had 12-foot travel lanes, so this was then reduced to 10-foot travel lanes. Slightly narrower travel lanes also allocate more space for sidewalk expansion and bicycle buffers. In addition, in the one-way concept, a two-way separated bicycle lane needed a buffer. This was addressed by taking one foot from the travel lane and two feet from the parking lane to create a buffer. Lastly, in the no parking concept, the industry mentors did not think it was worthwhile to expand a sidewalk's width by only one foot given the construction work involved. It was recommended to expand one side of the sidewalk by two feet and leave the other side alone. Ultimately, accommodations were made following feedback from the industry mentors.

The three design concepts are shown in Fig. 1, 2, and 3.

V. Multi-Criteria Analysis

In order to choose one conceptual design out of the three described above, multi-criteria analysis (MCA) was performed. Evaluative factors were created, weights for those factors were calculated, and a final score for each design concept was determined.

First, the team created different factors to evaluate the concepts against. These factors were generated and finalized with the help of recommendations from faculty supervisors and industry mentors. The factors are shown in the left column of Fig. 4.

The team then evaluated each of these factors against each design concept, as shown on the right-hand side of Fig. 4. The factors were evaluated on a scale of one to five – one meant that the design concept met the factor the least, and five meant that the design concept met the factor the most.

To calculate the weights for each factor, the team released a survey to users of Water Street who have bicycled, drove, or walked through the corridor, as well as to the faculty supervisors and industry mentors. The survey asked participants to rank the importance (one being least important, and five being most important) of each factor in the context of a roadway improvement project. From the 29 responses received, the weight for each factor was calculated following (1).

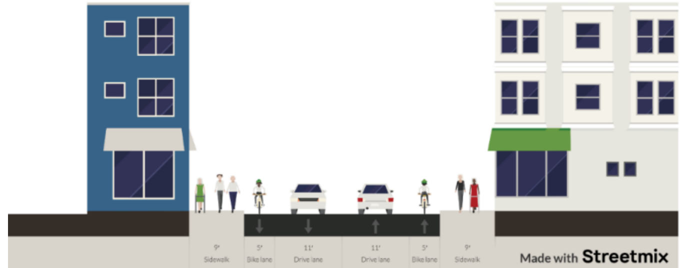

Fig 1. The modified city plan concept

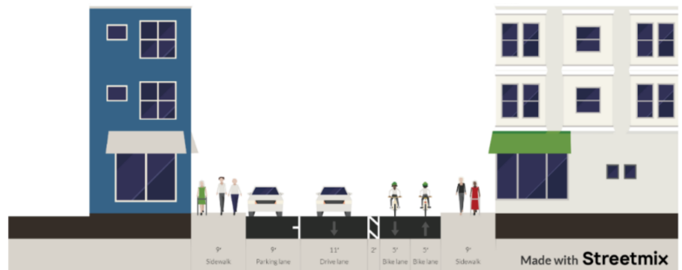

Fig 2. The one-way design concept

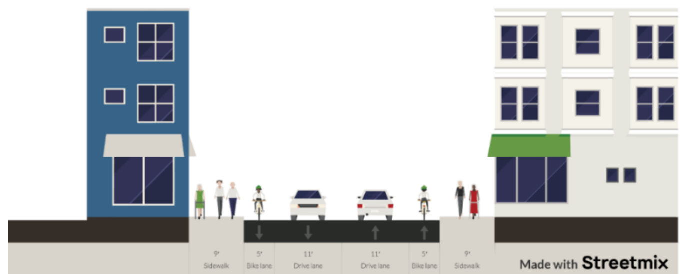

Fig 3. The no parking design concept

$$w_i = \frac{average\ of\ the\ responses\ from\ factor\ i}{sum\ of\ the\ average\ responses\ of\ all\ factors} = \frac{\bar{x}_i}{\sum_1^8 \bar{x}_i} \quad (1)$$

where

- x = factor
- i = 1, 2, …, 8 (represents each of the 8 factors)
- w_i = weight for factor i

In Fig. 5, each weight is shown. Each weight has also been multiplied with its preliminary score from Fig. 4 to create a new score. The last row in Fig. 5 shows the total score for each design concept. From this analysis, the modified city plan was chosen as the best concept.

VI. Finalized Designs

From the analysis in Fig. 5, the modified city plan design concept was chosen. However, this single design was then extrapolated out to two new designs to test different changes to

Factors		No-Build	City Plan	One-Way	No Parking
		Design Concepts			
		No-Build	**City Plan**	**One-Way**	**No Parking**
Safety	**Bicyclist**	1	3	4	4
	Pedestrian	2	4	5	4
	Driver	3	3	5	4
Comfort	**Bicyclist**	1	3	4	3
	Pedestrian	2	3	5	4
	Driver	3	3	5	4
Cost		5	4	1	2
Time of Construction		5	4	1	1
Maintenance of Traffic During Construction		5	3	1	3
Maintenance of On-Street Parking		5	4	5	1
Environmental Impact		5	4	3	3
Constructability/Feasibility		5	4	2	3

Fig. 4 Preliminary scores for MCA

Factors		**Weights**	**Design Concepts**			
			No-Build	**City Plan**	**One-Way**	**No Parking**
Safety	**Bicyclist**	0.15	0.15	0.45	0.60	0.60
	Pedestrian		0.30	0.60	0.75	0.60
	Driver		0.45	0.45	0.75	0.60
Comfort	**Bicyclist**	0.12	0.12	0.36	0.48	0.36
	Pedestrian		0.24	0.36	0.60	0.48
	Driver		0.36	0.36	0.60	0.48
Cost		0.11	0.55	0.44	0.11	0.22
Time of Construction		0.12	0.60	0.48	0.12	0.12
Maintenance of Traffic During Construction		0.13	0.65	0.39	0.13	0.39
Maintenance of On-Street Parking		0.09	0.45	0.36	0.39	0.09
Environmental Impact		0.13	0.65	0.52	0.39	0.39
Constructability/Feasibility		0.15	0.75	0.60	0.30	0.45
SUM		1.00	5.27	5.37	5.22	4.78

Fig. 5 Final scores for MCA

the roadway in VR. Experimental design processes call for a change to only one element of the design for the best comparison [9]. In this experiment, the one element that changed across all designs was the level of the bicycle lane buffer. There was either 1) no buffer, 2) a striped buffer, or 3) barrier posts. These design alternatives are shown in Fig. 6, 7, and 8.

To recap, three majorly different design concepts (modified city plan, one-way, and no parking) were narrowed-down to one concept (modified city plan) based on MCA. This one concept was then expanded out to two new alternatives (three total) to determine which level of bicycle lane buffer is best.

All of the finalized designs include the additional following recommendations that cover the other general design requirements. These include

- Adding additional signage and lighting to alert vehicular traffic of bicyclist and pedestrian right-of-way
- Installing ADA-compliant ramps at all intersections that do not already have ADA-compliant ramps
- Implementing RRFBs at the two major intersections of Water Street: the 1st Street S and 4th Street SE intersections

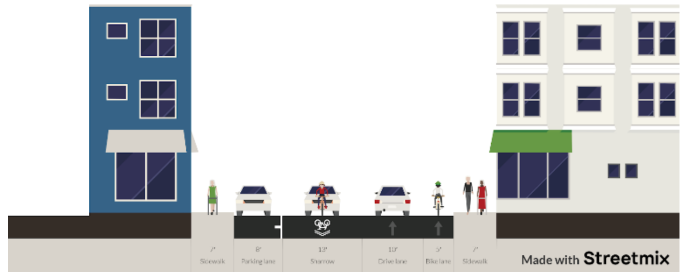

Fig. 6 The modified city plan alternative with no bicycle barrier

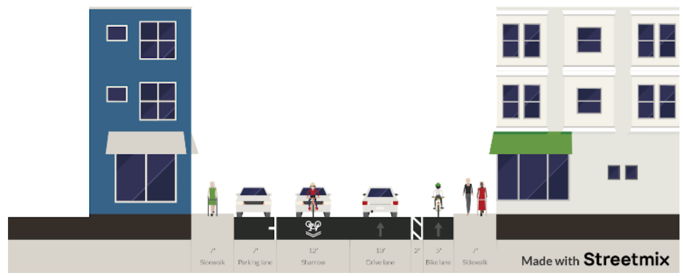

Fig. 7 The modified city plan alternative with a striped bicycle barrier

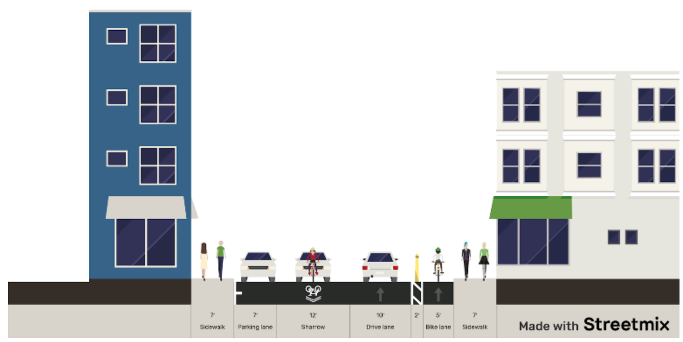

Fig. 8 The modified city plan alternative with a bicycle barrier post

Virtual Reality Testing

Consistent with guidance from the Centers for Disease Control and Prevention (CDC), the United States Department of State, and the Virginia Department of Health, UVA moved all classes online beginning March 19, 2020 due to the COVID-19 Coronavirus outbreak. Because students were also asked to leave UVA Grounds, the team was in a situation to continue the work of this project on an online basis. Consequently, the user testing in the VR environment was not carried-out. However, the original testing plan is explained below and the team instead will write a white paper regarding how user data would have been evaluated.

User testing was originally planned to take place in mid- to late-March 2020 in the Omni-Reality and Cognition Lab (ORCL). Users would wear a VR headset and ride a stationary bicycle that is connected to the VR environment in order to assess the alternative bike infrastructure designs. Users would begin the testing with a baseline VR environment to get their heart rate up to a steady pace using a smart watch that collects physiological data. Users would then ride through the no-build condition and the three finalized designs (i.e. city plans with no buffer, striped buffer, and barrier posts). After each test, users would answer feedback questions that analyze the users' safety and comfort on a one to five scale (one being the least safe/comfortable, and five being the most safe/comfortable). This likert-scale data would be combined with the physiological data to determine a final score for each alternative design. The alternative with the best score would then be recommended to the City of Charlottesville. The white paper that addresses how the final score would be calculated has not yet been written (as of the end of March 2020) but will be completed by May 2020.

The white paper will examine how user experience data has been analyzed in other transportation-related use cases that evaluated preferred alternatives, instead of analyzing actual data from the experiment.

VII. Conclusion

In this capstone project, the focus of the team was around researching, creating, and testing conceptual designs to improve bicyclist and pedestrian safety in the Water Street corridor. In achieving this goal, the team analyzed Safe Systems best practices from other bike- and pedestrian-friendly cities to inspire design ideas focusing on the descriptive and normative scenarios. This study includes the presentation of various evidence sources to support design decisions as necessary, in-line with the ITE's Safe Systems approach. The best practices utilized for Safe Systems include separating users in space, increasing attentiveness, and reducing vehicle speeds. In order to choose the most suitable option out of the three design concepts, an MCA methodology was implemented, and the 'modified city plan with no barriers' was chosen as the best design concept. This was based on a variety of criteria, including safety, comfort, cost, time of construction, maintenance of traffic during construction, maintenance of on-street parking, environmental impact, and constructability/feasibility. Furthermore, to ensure that safety and comfort were incorporated as important behavioral factors of the potential users, the one city plan concept was expanded out to two new alternatives. These two new alternatives differed in their levels of bicycle lane buffer. Lastly, future studies could be carried-out by expanding the testing model. Projects could be completed using novel methods that are applicable to a larger user sample size, or a larger number of design alternatives that have different variations of the previously mentioned design factors.

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