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# Memorandum

To: Town of Wellesley
Traffic Safety Committee

Date: May 30, 2015

Project #: 12309.06

From: Michael Regan, PE, PTOE

Re: Brook Street at Benvenue Street/Radcliffe Road
FINAL Safety and Traffic Operations Evaluation

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This memorandum has been prepared by VHB at the request of the Town of Wellesley to assess safety and operations at the intersection of Brook Street and Benvenue Street/Radcliffe Road. Specifically, the Town has expressed concerns regarding pedestrian safety at the Brook Street crosswalk approximately 50 feet east of the intersection. Existing (2014) and future (2019) conditions evaluations are summarized herein. Three potential options to improve pedestrian safety at this intersection were developed and are discussed.

## Study Location

Radcliffe Road and Benvenue Street intersect Brook Street from the north and south, respectively, to form a four-way, two-way stop controlled intersection. All approaches consist of one general purpose lane, however, there is unusual geometry on the Benvenue Street northbound approach. At the intersection, Benvenue Street is divided by a triangular island creating two, bidirectional legs. Generally, most vehicles turning right do so from the right side of the island and the through and left-turn movements are made to the left of the island. There are STOP signs on Radcliffe Road and to the right of the island on Benvenue Street. There is no STOP sign or STOP bar controlling through and left-turn movements on Benvenue Street. A sidewalk is present along the northern side of Brook Street on both approaches and along the southern side on the westbound approach to the intersection. Sidewalk at the northeast corner of the intersection is not provided due to right-of-way restrictions, creating a break in pedestrian connectivity and a potential safety concern of pedestrians having to enter the roadway particularly during inclement weather conditions. There is a crosswalk located across Brook Street, east of the intersection. There are no sidewalks or crosswalks on Benvenue Street or Radcliffe Road.

## Existing Conditions

This section summarizes the existing conditions at the study intersection, including an assessment of traffic volumes, crash data, and vehicular speeds. Two additional data collection efforts were completed and are summarized: a stop compliancy study and a conflict and event study. Finally signal and all-way stop control warrant analysis and a sight distance evaluation were completed at the study intersection.

### Existing Traffic Volumes

Turning Movement Counts (TMCs) were collected on a weekday for a 12-hour period from 6:30 AM to 6:30 PM, during the month of November 2014; this time period provides the necessary data to evaluate signal warrants. A review of the data collected indicates that the weekday morning peak hour is from 7:45 to 8:45 AM and the weekday evening

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peak hour is from 4:45 to 5:45 PM. The 2014 existing condition volume networks are presented in Figure 1 for the both peak hours. Traffic count data is included as an attachment to this memorandum.

**Crash Data**

Crash data for the study intersection was obtained from the MassDOT records for the most recent five-year period: January 2008 through December 2012. There were a total of five crashes at the intersection during this time period and three were rear-end type accidents. The current MassDOT average crash rates for unsignalized intersections in District 6 (the MassDOT district designation for Wellesley) is 0.58. The study area intersection crash rate is 0.48 – indicating that the intersection operates safer than an average unsignalized intersection in District 6. The intersection crash rate is also below the statewide average (0.60 for unsignalized intersections). While the crash data did not show any accidents involving pedestrians at this location within the last five years, the Town indicated a recent "near miss" at the Brook Street crosswalk and has prioritized safety improvements. A summary of the crash data and all raw crash data are included as attachments to this memorandum.

**Vehicular Speeds**

Vehicular speed data along Brook Street was provided by the Town of Wellesley. It should be noted that the speed data was collected approximately 215 feet east of the study location, at the intersection of Brook Street and Juniper Street. Table 1 summarizes the observed 85th percentile speeds – the speed at or below which 85 percent of vehicles travel. The 85th percentile is used extensively in the field of traffic engineering and is a dominant factor in establishing posted speed limits. As shown, the highest 85th percentile speed is the eastbound approach at 37 mph. Based on the location (residential area) a speed limit of 30 mph was assumed to be the speed limit for the study location. Vehicular speed data are included in the attachments.

**Table 1 Vehicular Speeds**

| | Weekday 85th Percentile Speed (mph) | | |
|---|---|---|---|
| **Location** | **EB** | **WB** | **Average** |
| Brook Street at Benvenue Street/Radcliffe Road | 37 | 33 | 35 |

Source: Town of Wellesley, November 2014

**Stop Compliancy Study/Conflict and Event Study**

Based on conversations with the Town and field observations of the study intersection, two additional data collection efforts were conducted: a stop compliance study and a conflict and event study. These studies supplement the traditional traffic data collection efforts discussed above to gain insight related to compliance with the study area intersection's traffic control device (i.e. stop sign) on the Benvenue Street and Radcliffe Road approaches and to supplement crash data discussed above.



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## Stop Compliancy Study

Based on the FHWA publication "Motorist Compliance with Standard Traffic Control Devices," a compliance study determines if there is a compliance problem with a given intersection's traffic control devices, defines the magnitude of the problem, and assesses potential countermeasures.[1]

To collect the necessary data, vehicles arriving to the stop signs controlling Benvenue Street and Radcliffe Road were observed from 7:30 AM to 9:00 AM. During observations, it was noted if a vehicle arrived alone or with a queue of vehicles. Next, it was determined if the lead vehicle made a voluntary full stop, was stopped by a vehicle or pedestrian cross traffic, or did not stop at all before entering the intersection. Finally, an assessment on whether the previous action caused a conflict with another vehicle or pedestrian was made. A table summary of the peak hour data and all raw data is provided in the attachments.

From the observations, 278 vehicles out of 439 vehicles from Benvenue Street northbound did not comply with the stop sign – a noncompliance rate of approximately 63 percent. At Radcliffe Road, zero out of 18 vehicles complied with the stop sign – a noncompliance rate of 100 percent. Based on the results, noncompliance could be due to low vehicular volume on Brook Street, 240 vehicles in the morning peak hour. As a result, drivers get impatient and do not feel the need to stop every time, especially if the vehicle was part of a queue of vehicles where the previous vehicle did not stop. Of the non-compliant vehicles, approximately two percent caused a conflict. Also, 77 percent stopped in crossing traffic, indicating sightlines could be an issue.

## Conflict and Event Study

Many times crash data is insufficient because not all incidents result in an accident or accident reports are incomplete. Based on the FHWA publication "Traffic Conflict Techniques for Safety and Operations," a conflict study collects avoided conflict data to supplement accident data and helps engineers make decisions and recommendations for intersection improvements. Avoided conflicts are defined as an occurrence of evasive vehicular actions and are recognizable by braking and/or weaving maneuvers. This is used in conjunction with traffic accident data, stop and/or signal warrants, capacity analysis, speed data, and any additional data needed to identify the problems and recommend improvements.[2]

To collect the necessary data, the intersection approaches without control devices are observed and avoided accidents or conflicts are counted. Brook Street eastbound and westbound were observed from 7:45 AM to 9:15 AM on a typical weekday. In addition, other necessary data needed to make a complete study of the location, such as approaching cars crossing the centerline in the roadway, was collected to help determine if speed is a factor through the curve. The conflict types per vehicle maneuver were recorded during this data collection process. A table summary of the peak hour data and all raw data is provided in the attachments.

[1] Pietrucha, M. T. et al. (1989). *Motorist Compliance With Standard Traffic Control Devices*. FHWA Publication No. FHWA-PD-89-103.
[2] Parker, Jr. H.R. et al. (1988). *Traffic Conflict Techniques for Safety and Operations--Observers Manual*. FHWA Publication No. FHWA-IP-88-027.



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Based on the conflict study results, Brook Street experienced 18 conflicts westbound and 15 conflicts eastbound during the peak hour. The left-turn from Brook Street westbound had the highest number of conflicts with 11 - approximately 23 percent of total through volume from Brook Street westbound. The conflicts demonstrate that speed is an issue and sightlines around the Brook Street westbound curve are limited. The right-turn from Benvenue Street northbound and opposing through on Brook Street eastbound had eight conflicts in the peak hour – approximately 16 percent of the total through volume from Brook Street eastbound. This conflict demonstrates non-compliance with the Benvenue Street stop sign, and also that sightlines from Benvenue Street northbound looking left could be insufficient or obstructed. In addition, vehicles are traveling at higher than posted speeds on Brook Street eastbound.

Both studies indicate vehicles are not compliant with the Benvenue Street northbound stop sign. Since Benvenue Street northbound volumes are high when compared to Brook Street, reversing the right-of-way at the intersection could be considered, though this will affect driver expectations. The installation of an all-way-stop control or a roundabout could also be considered. A roundabout is recognized as a traffic calming device along with improving driver compliance and intersection operations.

**Warrant Analyses**

VHB performed a traffic signal warrant analysis at the unsignalized intersection. The Manual on Uniform Traffic Control Devices (MUTCD)[3] lists specific criteria, or warrants, for the consideration of installation of a traffic signal at an intersection. The MUTCD also notes that, "the satisfaction of a traffic signal warrant or warrants shall not, in itself, require the installation of a traffic control signal." The traffic signal warrant analysis provides guidance as to locations where signals would not be appropriate and locations where they could be considered further.

Traffic signal warrant analyses were performed for three volume-based warrants (Warrant 1: Eight-Hour Vehicular Volume; Warrant 2: Four-Hour Vehicular Volume; and Warrant 3: Peak Hour Volume). The results of all the signal warrant analyses are displayed in Table 2 and are included in an attachment to this memorandum. As shown, none of the warrants are met at the intersection. Additionally, the intersection did not meet the traffic signal warrants based on pedestrian volumes or history of vehicle crashes.

[3] MUTCD, Part 4 – Highway Traffic Signals, USDOT, FHWA, December 2009.



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**Table 2** **Signal Warrants Analysis Summary**

| Intersection | Warrant Met? Warrant 1: Eight-Hour | Warrant 2: Four-Hour Volume | Warrant 3: Peak Hour Volume |
|---|---|---|---|
| Brook Street at Benvenue Street/Radcliffe Road | No | No | No |

Source: VHB
Note: Minor street volumes were analyzed both with and without the right-turn movement. The warrants were not met for either case.

In addition to traffic signal warrants, the All-Way Stop and Pedestrian Hybrid Beacon Warrants were also analyzed for this intersection. The All-Way Stop Warrant considers crash data, vehicular volume, right-of-way operations, left-turn conflicts, and conflicts related to high pedestrian volumes. Based on these criteria, it was determined that all-way stop control was not warranted at this location.

A Pedestrian Hybrid Beacon may be considered at a location that does not meet traffic signal warrants or that meets traffic signal warrants but a decision is made to not install a traffic control signal. At this location, the traffic control signal warrants were not met, therefore, a hybrid beacon was considered based on major street volumes, speeds, widths and gaps in traffic in conjunction with pedestrian volumes, walking speeds, and delay. Based on these criteria, a pedestrian hybrid beacon was not warranted at this location. Warrant analyses worksheets are included in the attachments.

**Sight Distance Analyses**

Sight distance analysis, in conformance with guidelines of American Association of State Highway and Transportation Officials (AASHTO)[4] was performed for the unsignalized intersection. Speed data (Table 1) were used to calculate the required stopping sight distance (SSD) and intersection sight distance (ISD). SSD is the distance required for a vehicle approaching an intersection from either direction to perceive, react, and come to a complete stop before colliding with the exiting vehicle from a driveway or minor street. ISD is the distance that is based on the time required for perception, reaction and completion of the desired critical exiting maneuver (typically, a left turn) once the driver on a minor street approach or driveway decides to execute the maneuver. Calculation for the critical ISD includes the time to (1) turn left, and to clear the near half of the intersection without conflicting with the vehicles approaching from the left; and (2) upon turning left, to accelerate to the operating speed on the roadway without causing approaching vehicles on the main road to unduly reduce their speed. According to AASHTO:

[4] A Policy on the Geometric Design of Highways and Streets, American Association of State Highway and Transportation Officials, 2011



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*"If the available sight distance for an entering or crossing vehicle is at least equal to the appropriate stopping sight distance for the major road, then drivers have sufficient sight distance to anticipate and avoid collisions. However, in some cases, a major-road vehicle may need to stop or slow to accommodate the maneuver by a minor-road vehicle. To enhance traffic operations, intersection sight distances that exceed stopping sight distances are desirable along the major road."*

Table 3 summarizes the available and required SSD and ISD for the unsignalized intersection and the sight distance worksheets are included in the attachments.

**Table 3 Sight Distance Analysis Summary**

| Intersection | Stopping Sight Distance | | | Intersection Sight Distance | | |
|---|---|---|---|---|---|---|
| | Traveling | Required [a] | Measured [b] | Looking | Desirable | Measured |
| Brook Street at Benvenue Street | eastbound | 270 | 135 | Left | 410 | 135 |
| | westbound | 230 | 80 | Right | 355 | 25 |
| Brook Street at Radcliffe Road | eastbound | 270 | 90 | Left | 410 | 25 |
| | westbound | 230 | 80 | right | 320 | 30 |

Source: based on guidelines established in A Policy on the Geometric Design of Highways and Streets, American Association of State Highway and Transportation Officials [AASHTO], 2011

Note: Shaded cells denote locations where sight distance does not meet the requirements

a required sight distance in feet, based on an 85th percentile speed of 37 mph for the eastbound lanes and 33 mph for westbound lane

b in feet

The sight distance measurements summarized in Table 3 indicate that required SSD is not met for the Brook Street approaches to the intersection. Field measurements indicate that the desirable ISD is not available from Benvenue Street or Radcliffe Road. Limiting factors include the horizontal and vertical alignment of Brook Street and shrubbery on the northeast, northwest, and southeast corner properties. Although the intersection crash rate is low, advanced intersection warning signs are recommended for the Brook Street approaches to the intersection due to the limited sight distances.

## 2019 Future Condition

In order to assess future operations at this intersection, the existing volumes were grown at a rate of a quarter (0.25) percent per year over a five year period. This growth rate was based on engineering judgment to reflect anticipated limited growth in traffic volumes over time. The intersection is in a residential area where it is unlikely there will be any site development or other factors which would result in a large increases in traffic. A volume growth worksheet is included in the attachments.



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## Potential Alternatives

In order to improve pedestrian safety, geometric and traffic control improvements were considered and analyzed for the study intersection. The alternatives include two-way stop control with geometric improvements, all-way stop control and a roundabout option. In addition, installation of a fully operational traffic signal and a pedestrian hybrid beacon were also considered and subsequently dismissed based on the warrant analyses results presented above.

### Option 1: Two-Way Stop Control

Under this Option 1, the intersection would maintain the current two-way stop control, but would undergo geometric improvements, including eliminating the island on the Benvenue Street northbound approach and realigning Benvenue Street and Radcliffe Road to create a more perpendicular intersection. In order to achieve this, all four corners of the intersection would be reconstructed to reduce turning radii. The crosswalk on Brook Street would be relocated to intersect the Brook Street westbound approach at the newly reconstructed corners of Benvenue Street and Radcliffe Road. The revised alignment enables construction of the missing section of sidewalk at the northeast corner of the intersection and installation of a new crosswalk would be installed across the Radcliffe Road approach. The concept plan for Option 1 is included in the attachments (Figure 1).

### Option 2: All-Way Stop Control

Under this Option 2, all four approaches would operate under stop control, and would undergo the same geometric improvements detailed under Option 1. However, as outlined in the warrant analysis above, this intersection does not meet the warrant for all-way stop control.

### Option 3: Roundabout

Under this Option 3, the intersection would be completely reconstructed as a roundabout. The concept plan for Option 3 is included in the attachments (Figure 2). As shown in Figure 2, the roundabout is undersized to avoid property impacts. The resulting roundabout would include a mountable center island, as well as flared approaches to accommodate heavy vehicles. Due to the small size, the recommended splitter islands on each approach to increase the deflection angle of approaching vehicles and provide pedestrians a safe refuge while crossing the approaches are not possible. Consequently, the crosswalk on Brook Street would be close to the existing location offset from the roundabout. The roundabout as shown in Figure 2 does not meet the minimum inscribed diameter dimensions, deflection angles or splitter island recommended by current engineering standards or provide an enhanced pedestrian crossing configuration. Redesign of the roundabout to meet these requirements would lead to property impacts to all four corners of the intersection. Based on these facts, a roundabout option is not recommended.

## Traffic Operations Analysis

Understanding the relationship between the supply and demand on a roadway is a fundamental consideration in evaluating how well a transportation facility safely and efficiently accommodates the traveling public. Methods from



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the 2010 Highway Capacity Manual (HCM)[5] were used to evaluate how the unsignalized intersection of Brook Street at Benvenue Street/Radcliffe Road accommodates the traffic demands, consistent with current MassDOT standards.

Level of service (LOS) is the term used to denote the different operating conditions which occur under various traffic volume loads. It is a qualitative measure of a number of factors including traffic volumes, roadway geometrics, speed, travel delay and freedom to maneuver. Similar to a report card, level-of-service designations range from A to F, with LOS A representing the least congested operating conditions and LOS F representing the most congested conditions. The computer software program, SYNCHRO 8.0, was used for the LOS evaluation of the study area intersection. This modeling software is widely used by traffic engineers and is consistent with procedures in the HCM. Levels-of-service analyses were conducted for the 2014 Existing and 2019 Future with improvements conditions under weekday morning and weekday evening peak hours. The results are summarized in Table 4 and are included in the attachments to this memorandum.

As shown, the intersection operates at an overall LOS of C or better during the weekday morning and weekday evening peak hours under 2014 Existing conditions. It should be noted that the Benvenue Street northbound right-turn was analyzed under yield control in the 2014 Existing condition due to observed non-compliance. As previously outlined, three alternatives were developed to improve safety at the study location. As shown in Table 4, Option 1 would result in minor increases in delay when compared to the 2014 Existing condition. Option 2 would result in increases in delay on all approaches except the Radcliffe Road approach, which would experience a decrease in delay and an improvement in LOS. Option 3 would reduce delays for all approaches during both peak periods, except for the Brook Street eastbound approach.

[5] 2010 Highway Capacity Manual; Transportation Research Board Washington, D.C.



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## Table 4 Unsignalized Intersection Capacity Analysis Summary

| | | 2014 Existing* | | | | | Option 1: Two-Way Stop with Geometric Improvements | | | | | Option 2: All-Way Stop with Geometric Improvements | | | | | Option 3: Roundabout | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Critical Movement(s) | Dem[1] | v/c[2] | Del[3] | LOS[4] | 95th Q[5] | Dem | v/c | Del | LOS | 95th Q | Dem | v/c | Del | LOS | 95th Q | Dem | v/c | Del | LOS | 95th Q |
| ***Weekday Morning*** | | | | | | | | | | | | | | | | | | | | | |
| Brook St | EB L | 65 | 0.00 | 0 | A | 0 | 65 | 0.00 | 0 | A | 0 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| | EB L/T/R | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 65 | 0.13 | 10 | A | 0 | 65 | 0.08 | 5 | A | 0 |
| Brook St | WB L | 175 | 0.10 | 8 | A | 0 | 175 | 0.10 | 8 | A | 0 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| | WB L/T/R | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 175 | 0.35 | 12 | B | 2 | 175 | 0.21 | 5 | A | 1 |
| Benvenue St | NB L/T/R | 550 | 0.62 | 14 | B | 5 | 560 | 0.70 | 18 | C | 6 | 560 | 0.79 | 22 | C | 8 | 560 | 0.62 | 12 | B | 5 |
| Radcliffe Rd | SB L/T/R | 15 | 0.06 | 17 | C | 0 | 15 | 0.08 | 22 | C | 0 | 15 | 0.03 | 9 | A | 0 | 15 | 0.02 | 4 | A | 0 |
| ***Weekday Evening*** | | | | | | | | | | | | | | | | | | | | | |
| Brook St | EB L | 50 | 0.00 | 0 | A | 0 | 50 | 0.00 | 0 | A | 0 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| | EB L/T/R | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 50 | 0.08 | 8 | A | 0 | 50 | 0.08 | 6 | A | 0 |
| Brook St | WB L | 315 | 0.22 | 8 | A | 1 | 320 | 0.23 | 8 | A | 1 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| | WB L/T/R | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 320 | 0.47 | 12 | B | 3 | 320 | 0.33 | 7 | A | 1 |
| Benvenue St | NB L/T/R | 130 | 0.14 | 9 | A | 1 | 130 | 0.18 | 10 | B | 1 | 130 | 0.19 | 8 | A | 1 | 130 | 0.14 | 5 | A | 0 |
| Radcliffe Rd | SB L/T/R | 15 | 0.08 | 21 | C | 0 | 15 | 0.08 | 22 | C | 0 | 15 | 0.03 | 8 | A | 0 | 15 | 0.02 | 5 | A | 0 |

1 Demand in vehicles per hour
2 volume to capacity ratio
3 average intersection delay, measured in seconds
4 level-of-service
5 95th Percentile queue measured in vehicle
*Benvenue Street northbound right-turn analyzed under yield control due to observed non-compliance.



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## Recommendations

Based on the data and analyses outlined above, it is recommended that Option 1: Two-way stop control be advanced at this location. While the operations analyses showed that the intersection would operate best under Option 3: Roundabout, concept plan development indicates the current alignment of Benvenue Street does not provide sufficient deflection to slow entering vehicles and a properly sized roundabout would have property impacts to each corner of the intersection. As a result, Option 3: Roundabout is not recommended for this location. As previously mentioned, Option 2: All-way stop was not warranted at this location.

The two-way stop control alternative includes geometric improvements which will encourage motorists to operate with increased traffic control compliance over existing conditions by better defining movements and slowing travel speed through the intersection. The revised alignment will allow for improved sidewalk conditions and pedestrian connectivity and visibility. With these proposed improvements and advanced intersection warning signs for the intersection and pedestrian crossing, safety at this intersection is anticipated to improve for both pedestrians and vehicles.



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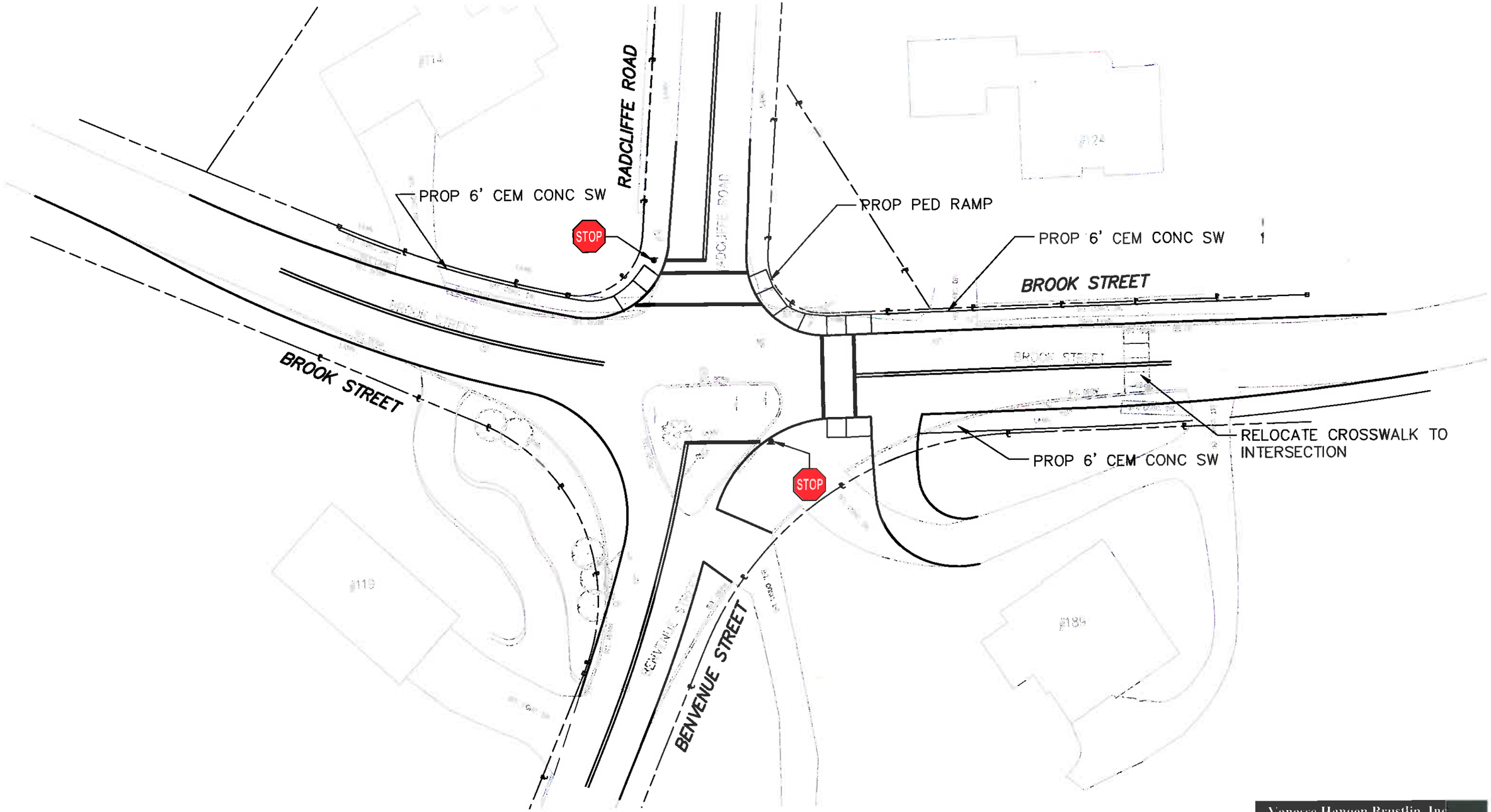


Vanasse Hangen Brustlin, Inc.

Figure 1 March 16, 2015

Conceptual Intersection Realignment
Benvenue Street at Brook Street
Wellsley, Massachusetts

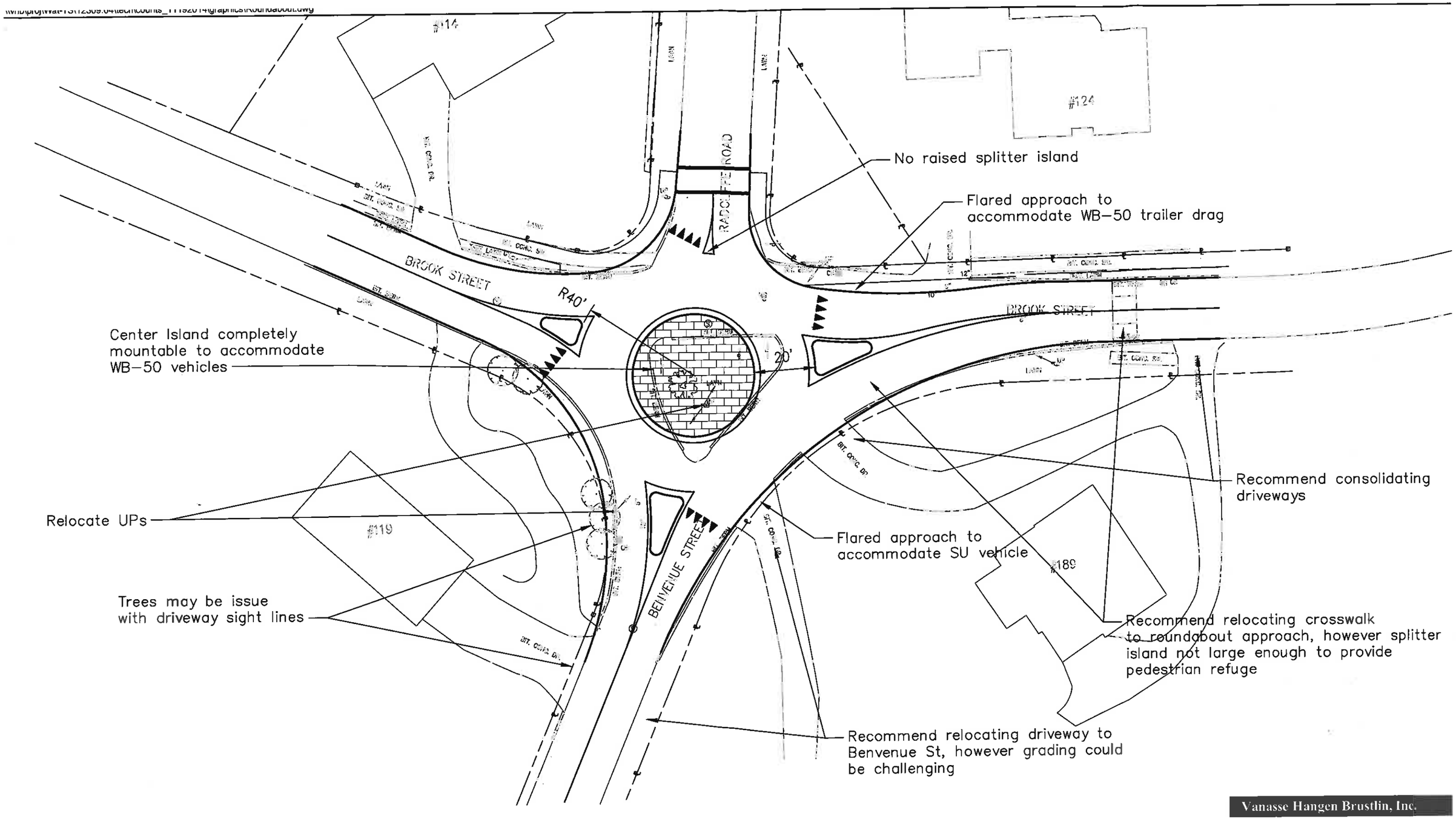


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Figure 2 March 16, 2015

Conceptual Roundabout
Benvenue Street at Brook Street
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