Maryland Transportation Authority

Evaluation of Additional Safety Measures at the William Preston Lane Jr. Memorial Bridge

FINAL REPORT

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Executive Summary

The William Preston Lane Jr. Memorial (Bay) Bridge is composed of two spans which cross the Chesapeake Bay along US 50/301. The bridge carries five (5) travel lanes, with three (3) on the westbound span and two (2) on the eastbound span. During periods of peak congestion one of the westbound lanes is reversed so that three lanes can be provided in the eastbound direction. Safety concerns about reversible operations on the westbound bridge have prompted the Maryland Transportation Authority (MDTA) to evaluate the need for additional safety measures to reduce crashes that cause injuries and/or fatalities.

MDTA assembled a cross-functional workgroup to answer the following question: "Can additional actions be taken to reduce head-on crashes on the westbound span during two-way operations?" The group reviewed the nature and magnitude of crashes and potential solutions. Its review also included the evaluation of movable barriers, which was a solution recommended by an interested third party.

The work-group reviewed nine possible solutions involving moveable barriers, permanent barriers, various buffers, and the elimination of two-way operations. Moveable and permanent barriers provide positive separation; however, safety and operational downfalls significantly outweighed the benefits. Certain buffer options would result in fewer downfalls, but only provide minimal separation value, current traffic volumes during the AM and PM peaks as well as weekend travel times made the elimination of two-way operations impractical. Ultimately, the workgroup recommends the painted buffer with rumble strips alternative as the primary course of action. The workgroup's recommendations are further outlined in the following report.

Background

The William Preston Lane Jr. Memorial (Bay) Bridge crosses the Chesapeake Bay along US 50/301. Its dual spans provide a direct connection between recreational and ocean regions on Maryland's Eastern Shore and the metropolitan areas of Baltimore, Annapolis and Washington, D.C. At four miles, the spans are among the world's longest and most scenic over-water structures. The original span opened in July 1952 and provides a two-lane roadway for eastbound traffic. The parallel structure opened in June 1973 and has three lanes for westbound travelers. During periods of heavy eastbound traffic, one lane of the westbound bridge is reversed to carry eastbound travelers ("two-way" traffic operations).

Westbound Bay Bridge in 2-way
Photo Courtesy of
Misty Garrick Miller

The westbound bridge includes a reversible lane, which permits traffic to travel either westbound or eastbound, depending on the heavy directional traffic flows during the morning and evening peak hours, especially during summer weekends, holidays and events.

The reversible lane is the left lane of the westbound bridge (lane 3) and is denoted by reversible pavement markings (a set of two, dashed yellow lines used as lane lines), and by overhead lane use control signs which display either a green “down arrow” to inform motorists they can enter the lane and are traveling in the correct direction, or a red “X” to inform motorists not to enter the lane. The reversible lane is regulated by a crossover or transition area at each end of the bridge. The crossover is used exclusively for the reversible lane at each end of the bridge and permits one side of the lane to be “coned off” to discourage motorists in one direction from entering the lane while permitting easy access for motorists in the other direction to enter the lane. The cones can be repositioned to permit flow into and out of the reversible lane.

The westbound bridge carries two (2) 13 feet wide curb lanes and a single 12 feet wide center lane. There are no shoulders on the bridge. There is no positive separation, or physical barrier between traffic, between vehicles traveling opposite directions on the span. Due to growth in traffic, the reversible lane has been used with increasing frequency. Reversible operation has increased over the past ten (10) years in order to serve peak traffic demands and perform construction on the Bridge.

A relatively small number of high profile crashes on the bridge have caused internal and external stakeholeders to question if there are additional safety measures that can be enacted on the westbound span of the bridge. MDTA reviewed and implemented several improvements in response to those crashes, and has researched several additional measures. Improvements which were previously implemented in response to the crashes include the installation of rumble strips between traffic lanes, installation of strobe lights on the lane use control signals, installation of static signing along the bridge, as well as other traffic control device and procedural changes. In addition, trucks over 5 Tons GVW are restricted to using the right lane of the bridge in each direction in order to minimize their impact on the reversible lane.

Problem Statement

A work-group was convened to evaluate potential additional safety measures. The workgroup met to attempt to answer the following question: “Can additional actions be taken to reduce head on crashes on the westbound span during two-way operations?”

Data Analysis

In fiscal year 2012 approximately 26.5 million vehicles crossed the eastbound and westbound Bay Bridge spans, with approximately 7% of those vehicles being trucks and tractor trailers. During weekdays roughly 14 % of vehicles cross during the AM and PM peak hours. Traffic volumes are 18.7% higher during the summer months of June through August. Overall traffic on the spans has increased by roughly 3 million vehicles per year since fiscal year 2000.

Fiscal Year	Average Daily Traffic	Change from 2000 (#)	Change from 2000 (%)
2000	32,048	–	–
2001	32,954	906	2.8%
2002	34,253	2,205	6.9%
2003	34,430	2,382	7.4%
2004	35,654	3,606	11.3%
2005	35,707	3,659	11.4%
2006	36,778	4,730	14.8%
2007	37,179	5,131	16.0%
2008	35,165	3,117	9.7%
2009	35,884	3,836	12.0%
2010	36,232	4,184	13.1%
2011	36,089	4,041	12.6%

* AADTs shown in the table represent eastbound traffic only and are based on vehicle count from toll plaza receipts and are in vehicles per day (vpd).

MDTA first received public concerns about the two-way operations on the Bay Bridge following a fatal crash in November 1996. The westbound span was in two-way operations when a passenger vehicle traveling westbound stalled after running out of fuel. A commercial vehicle, also traveling westbound, failed to see the stalled vehicle in time and rear-ended the passenger vehicle. Two-way operations of the bridge were not determined to be a contributing factor to the crash.

Since January 2000, there have been five crashes resulting in fatalities on the Bay Bridge facility (including approach roadways). Four of the crashes occurred during two-way operations, alcohol contributed to one of the crashes and one of the crashes occurred on the eastbound span. A brief discussion of the four crashes follows:

> In November 2000, the westbound span was in two-way operations, with the center lane closed. A two-vehicle crash occurred when a westbound vehicle ran into the back of a slow moving/stopped vehicle resulting in one (1) fatality.

In October 2001, the westbound span was in two-way operations. A two-vehicle crash occurred when a vehicle crossed into opposing traffic resulting in one (1) fatality.

In May 2007, the westbound span was in two-way operations. A seven-vehicle crash occurred when a small trailer being towed by a SUV became un-hitched. Six of the seven vehicles, including the vehicle towing the trailer, were traveling eastbound on the westbound span when the crash occurred. This crash resulted in three (3) fatalities.

In August 2008, the eastbound span (2-lane span) was in two-way operations. A two-vehicle crash occurred when the driver of a passenger vehicle traveling eastbound crossed the double painted lines into the path of a commercial truck traveling westbound. The commercial vehicle struck the right side jersey wall ultimately going over the barrier into the Bay resulting in one (1) fatality.

Personal injury crashes occurring on the bridge have been limited. In 2010, there were five (5) personal injury crashes on the westbound span, only one of which occurred during two-way operations. In 2011 there were seven (7) personal injury crashes on the westbound span, of which four (4) occurred during two-way operations.

Following the fatal crashes in May 2007 and August 2008 improvements were made to the bridge in an attempt to improve safety and motorist awareness. These include the installation of rumble strips between lanes, stay in lane signing, and updates to the procedure for closing or reversing lanes on the bridge. There have been no fatal crashes attributable to reversible operations since these changes have been implemented.

Analysis

The workgroup discussed the potential for a moveable barrier system as well as permanent barrier, temporary barrier, W-Beam traffic barrier, delineator posts and pavement marking treatments to reduce the potential for fatal crashes on the westbound span during two-way operations. Two moveable barrier options were explored during the discussion. Option 1 consisted of routinely leaving the system in place between lanes 2 and 3 of the westbound span (i.e. between the left and center lanes westbound). Option 2 consisted of storing the system against the shoulder of lane 3 (the westbound left lane) and moving it into place between lanes 2 and 3 during two-way operations.

Moveable Barrier System Option 1

Leaving the moveable barrier system in place between lanes two (2) and three (3) would create positive separation of opposing traffic during two-way operations. This would provide barrier separation between opposing directions of travel while mitigating the likelihood of head-on collisions into other vehicles during two-way operations. The barriers would also lessen weather’s impact on the ability to operate in two-way. Due to safety concerns, when the weather limits visibility or traction the bridge is not operated in two-way regardless of the impact on congestion.

The fact that the system is movable created some distinct advantages over other options. The system could be moved if necessary, a factor that no other option could provide while also creating positive separation. The barrier could also be moved to maintain positive separation between one westbound lane and two eastbound lanes if the need to reverse the center westbound lane arose.

Moveable Barrier System Photo Courtesy of FHWA

Moveable barrier has had limited use in applications with constraints similar to those found on the Bay Bridge. A number of challenges offset the benefits of utilizing a moveable barrier system. These challenges apply to both normal and reversible operations on the bridge and include:

Reduced Lane Widths - The westbound bridge carries a single 12 feet center lane with two 13 foot outside lanes and no shoulders. Most of the moveable barrier systems that MDTA has found range from 1.5 to 2 feet in width. If a barrier is placed on the bridge between the left and center lanes on the westbound span, the lane width for each of these lanes will be reduced by 1 foot providing 12 feet in lane 3 and 11 feet in lane 2. Based on American Association of State Highway and Transportation Officials (AASHTO) Green Book standards, the National standards for geometric design, rural arterials which have an annual average traffic volume of 2,000 vehicles or more per day are required to have 12 foot lanes. Since US 50 and US 301 are both arterials, national standards require 12 foot lanes.

The AASHTO Highway Safety Manual, which was published and released in July 2010 provides a methodology for predicting future crashes based on a change to the roadway. Crash Modification Factors are the primary tool used to evaluate a change to an element of the roadway. Decreasing the lane width from 12 feet to 11 feet is projected to cause a 4% increase in the total number of crashes (property damage, injury and fatal combined). The 4% increase in crashes from narrowing the 12 foot lane to 11 feet does not consider the number of additional nuisance hits that will happen when motorists inadvertently hit the barrier.

Inadequate Shy Distance - The AASHTO Roadside Design Guide provides information on roadway elements beginning at the edge of the traveled way (edge line of the roadway). Based on the Guide, drivers do not like to drive with their tires immediately against a fixed object. Typically, drivers require a 1 to 2 foot offset between the vehicle and a fixed object of 6 inches or less in height. As a result, curbs are typically placed 1 to 2 feet from the traveled way. However, when the fixed object exceeds 6 inches in height, drivers require substantially more distance between their vehicle and the fixed object. The distance between the fixed object (over 6 inches in height) and the vehicle is referred to as the “shy distance”, and it is based on the speed of the vehicle. For example, at 30 mph the shy distance is 3.6 feet, but at 55 mph the shy distance is at 7.2 feet. If the shy distance cannot be provided, drivers will either slow down or reposition the vehicle from the center of the lane away from the fixed object, or both. This can lead to an increase in crashes and a reduction in capacity due to slower vehicles driving with greater spacing between vehicles, negating the primary reason for the reversible lane.

Sight Distance - The height of concrete barrier is 32 inches for existing installations and 42 inches for new installations. The 42 inch high barrier is preferred on new installations because it provides improved crash test performance and is rated to Test Level 5 (TL-5) while the 32 inch high barrier is only rated to Test Level 4 (TL-4) according to the AASHTO Roadside Design Guide. Stopping sight distance, the distance required to see a vehicle, react and stop prior to hitting the vehicle, is based on seeing the tail lights of the vehicle you are approaching. The generally accepted height of tail lights based on the AASHTO Green Book is 20 inches. A barrier when combined with the existing horizontal and vertical curves on the bridge will obstruct driver visibility of vehicles ahead thereby reducing sight distance. This will make it more difficult for a motorist to see a stopped vehicle in time to stop or slow down.

National Cooperative Highway Research Program (NCHRP) 350 Test Level – All longitudinal traffic barriers must be crash tested following the procedures outlined in either NCHRP 350 or the more recently updated Manual for Assessing Safety Hardware (MASH). These guidelines outline a series of Test Levels from 1 through 6 which define the vehicle size, vehicle weight, vehicle speed and angle of impact for standard crash tests. MASH Test Level 1 (or TL-1) requires crash testing with a 5,000 lb pickup truck at 31 MPH and an impact angle of 25 degrees while MASH TL-6 requires crash testing an 80,000 lb tanker truck at 50 MPH and 15 degree impact angle. For both NCHRP 350 and MASH, tractor trailers are tested at TL-5 and above.

Many of the serious crashes on the bridge have involved large trucks which comprise approximately 7% of the traffic stream. This includes the crashes in November 1996, and August 2008. None of the moveable barrier systems MDTA has identified are crash tested and rated to TL-5 or above. The highest rated system identified is the Quickchange® Concrete Reactive Tension Barrier System, a type of moveable concrete longitudinal barrier. It has been rated to NCHRP 350 Test Levels (TL) 3 and 4. At TL 3 the barrier is tested to withstand a 4,400-lb pickup truck at 25 degrees and 60 MPH. At TL 4 the barrier is tested to withstand a 17,600 lb Single Unit truck at 15 degrees and 50 MPH. Tractor trailers and tanker trucks (80,000 lb) are not tested below NCHRP 350 TL 5. MDTA has no performance information to determine how the system would react if struck by the type of commercial vehicles that represent 7% of the traffic on the bridge.

Barrier Deflection – Federal standards require that all traffic barriers (including moveable barriers) must be crash tested in accordance with either NCHRP 350 or the Manual for Assessing Safety Hardware (MASH). The dynamic deflection is the measure of the distance a barrier moves when hit. The dynamic deflection of the moveable barriers shown in the

AASHTO Roadside Design guide is 4 feet. This means if the lane width was reduced to eleven (11) feet, from twelve (12) feet, due to the addition of moveable barrier, if struck the barrier could move an additional four (4) feet into the eleven (11) foot lane. The Quickchange® Concrete Reactive Tension Barrier System is rated for a maximum dynamic deflection of twenty-seven (27) inches under TL 3 test conditions (which involves a maximum vehicle weight of 4,400 lbs). This deflection would reduce the adjacent lane width to less than nine (9) feet when struck by an typical vehicle and the deflection would likely be greater if the crash involved an interstate tractor trailer or other large truck. Therefore the moveable barrier might reduce head-on crashes between vehicles; however, the deflection of the moveable barrier into the reversible lane (or into another lane) will cause secondary incidents which could have an equivalent severity (e.g., head-on crashes into the barrier, rear-end crashes from sudden traffic stops).

<u>Secondary Impacts with Barrier</u> - It is anticipated that there would be a substantial number of crashes from vehicles hitting the barrier. Motorists that crash into a barrier are frequently deflected back in the opposite direction, causing secondary crashes with objects on the opposite side of the roadway (e.g., other vehicles, barriers, etc.). Crashes in the 12 foot wide reversible lane will provide vehicles closely following the crash no means of escape and they will also become involved in the crash. These types of crashes will require the motorists involved to remain in their vehicles until emergency services can arrive and remove the vehicles from the roadway. Since there are no shoulders on the bridge, the vehicles involved in the crash will have to remain in their lanes reducing capacity and increasing congestion for an even longer duration while waiting for emergency services personnel to create a break in the moveable barrier. While the damaged vehicles are in the reversible lane, it will shut down traffic flow. Additionally, vehicles in Lane 2 which hit the barrier will frequently be redirected back into Lane 1 and cause secondary crashes involving vehicles from Lane 1.

<u>Weight of the Barrier System</u> – The weight of any barrier system will place additional stress on the bridge structure, which it was not originally designed to handle. Additionally, the Bay Bridge's existing suspension span is not capable of supporting the additional weight of any type of concrete barrier and the span would require strengthening before a barrier could be installed on that section of the bridge. If the barrier is only installed on the approaches to the suspension span, a break of over ½ mile in the positive separation will be created. This would be counter to the purpose of a barrier system, and would create the additional hazard that a motorist could use the gap in the barrier with flexible delineator posts to change lanes.

<u>Crash Attenuation</u> - Regardless which direction of travel is using the reversible lane, each direction of travel would face the blunt end of the barrier at each end of the bridge and at the suspension span. The potential crash severity of striking the blunt end of concrete barrier can be similar to a head-on crash. The crash attenuation for a moveable barrier system would be limited to a small number of Maryland Approved attenuators which can fit into the two (2) feet of available width. The moveable barriers and crash attenuators that could be used on the bridge are not crash tested for the interstate tractor trailers which frequent the Bay Bridge and make up approximately 7% of vehicular traffic.

Incident Management – Incidents on the bridge are cleared from the adjacent lanes, which are used to clear backed up traffic and also stage recovery and response equipment. While the movable barrier systems can be separated to allow access to incidents, this would require additional time to mobilize equipment and create breaks in the barrier. This additional delay would add to traffic congestion, reduce response flexibility and increase response time for police, fire and emergency medical services (EMS). The presence of the barrier would also make it difficult to clear a queue of vehicles trapped behind the incident. The queue of vehicles would also create difficulties for EMS responders to transport crash victims to local hospitals.

Past experience has shown that larger and longer duration incidents on the bridge can have a significant impact on Kent Island traffic. If incidents on the Westbound span of the Bay Bridge are more difficult to clear, traffic backups will impact traffic operations on local roadways on Kent Island and potentially reduce the emergency services response time to any incidents which occur on the bridge as well as emergency response to non-bridge incidents.

Snow Removal – The presence of the movable barrier on the bridge will create a challenge to snow removal. The system would either have to be moved prior to the snow fall, or the confined lane will be difficult for snow plows to maneuver and make it more challenging to remove snow from the deck.

Increased rear-end crashes – As traffic congestion on US 50 is increased by the moveable barrier concerns above, the likelihood of rear-end collisions increases. Between 2008 and 2010 the predominant crash type on the bridge was rear end collisions. Texas Transportation Institute states "A major safety concern associated with freeway bottlenecks is increased rear-end crash potential. Rear-end type collisions comprise over half of all urban freeway crashes and about one-third of work zone crashes. Depending on the speed differentials between queued and approaching traffic, rear-end collisions can be quite severe." Rear-end collisions are an estimated 3.6 times more likely at the back of the queue than in free flowing conditions (Yeo, 2008).

Moveable Barrier System Option 2

Option 2 consisted of storing the system against the shoulder of lane 3 and moving it into place between lanes 2 & 3 during two-way operations. The advantages of using this option are identical to those of Option 1. In addition to the challenges listed for Option 1, there were two additional challenges of using this option:

Time Required to Move the Barrier – It currently takes MDTA approximately 25 minutes to convert the westbound span from one-way to two-way operations. Based on the information available about moveable barrier systems, it would take 45 to 60 minutes just to move the barrier into place. While there are routine times that two-way operations can be anticipated such as weekday peak periods, there are occasions when two-way operations are used to relieve unexpected traffic volumes at varying times during the summer months. The additional time required would likely add to congestion at the bridge and along US 50.

MDTA's experience on the Bay Bridge with an older version of a similar moveable barrier system was met with only limited success due to issues associated with the reliability of the placement equipment and with longer than anticipated deployment times.

Width of Lane 3 – Since there are no shoulders on the bridge, the moveable barrier would be stored against the parapet wall in lane 3, and the lane width would be reduced to approximately ten feet. As discussed earlier under Option 1, decreasing lane width from twelve (12) feet to eleven (11) feet is projected to cause a 4% increase in the total number of crashes. The 4% increase in crashes from narrowing the twelve (12) foot lanes to 11 feet does not consider the number of additional nuisance hits that will happen when motorists inadvertently hit the barrier. If the width of Lane 3 is reduced to ten (10) feet, the AASHTO Highway Safety Manual projects crashes will increase by 23%.

Feasibility of Implementing Moveable Barrier

Based on the analysis of the advantages and challenges associated with both options, the workgroup determined that while installing a moveable barrier may be feasible, it is not advisable. Significant negatives to a moveable barrier approach include the deflection of the moveable barrier by up to four (4) feet into an adjacent lane of traffic, reduced stopping sight distances, reduced lane widths, as well as risk of increased congestion, increased rear-end collisions, potential head-on collisions with the crash attenuator, and negative impacts to operations such as snow removal. The addition of moveable barriers on the bridge would also make incident response more difficult and time consuming. The workgroup determined that other options should be considered. The workgroup conducted a brainstorming session to identify other possible alternatives to reduce the potential for head-on collisions during two-way operations. Seven (7) alternatives to the moveable barrier system were considered.

Alternative 1: Never Operate the Bridge in Two-way Traffic

As discussed earlier, MDTA operates the Bay Bridge in two-way traffic to manage vehicle throughput and reduce associated congestion. There are three (3) lanes available westbound and only two (2) lanes available eastbound. As eastbound traffic increases beyond available capacity (For example on Fridays and Saturdays when travelers head to the Eastern Shore) one of the westbound lanes is used to increase throughput and decrease eastbound congestion. Summer peak traffic may easily back up beyond the Severn River Bridge when reversible operations cannot be implemented. Never operating two-way traffic would increase eastbound congestion significantly during these peak congestion times as well as increase the likelihood of secondary collisions within the queued vehicles. This alternative was not found to be feasible by the workgroup.

Alternative 2: Platooning Traffic

Platooning traffic refers to the operation of the bridge in a manner similar to a flagging operation routinely seen at a work zone. For example, all of the eastbound traffic is stopped completely and held so that all of the available lanes on both bridges can be used to move in the westbound

direction. After a period of time, the westbound traffic is stopped and the all of the lanes are then used to move traffic in the eastbound direction. This alternative takes significant time to set-up, has negative impacts on overall throughput, and would create significant congestion in both directions. While this option has utility for specific instances and/or emergencies, the workgroup determined that it is not useful for routine management of congestion at the Bay Bridge.

Alternative 3: W-Beam Traffic Barrier (Guide Rail)

W-Beam Traffic Barrier would allow for positive separation of traffic traveling in opposite directions, while avoiding some of the challenges associated with the moveable barriers such as total weight on the bridge. W-Beam Traffic barrier is designed to deflect up to four (4) feet when struck by a vehicle, and therefore presents many of the same challenges as the moveable barriers evaluated. The workgroup determined that the difficulty in mounting them to the bridge deck combined with same other challenges as the moveable barriers make this alternative not feasible.

Alternative 4: Permanent Barriers

The workgroup considered installing permanent barriers between lane 2 and 3 on the westbound span. Permanent barriers offer many of the advantages of the movable barrier system. The one major difference between the permanent barriers and the moveable ones is that the permanent ones would not deflect into an adjacent lane if struck by an average vehicle. Interstate tractor trailers and/or tanker trucks might still be able to break through or tip over the permanent barrier. They would also create positive separation of opposing traffic during two-way operations, they are likely to reduce head-on collisions, would address the public's concerns about reducing head-on collisions, and lessen weather's impacts on the ability to operate two-way.

The challenges presented by permanent barriers are also very similar to the moveable barrier system. They would reduce lane widths to less than twelve (12) feet, reduce sight distance, would place additional weight stress on the bridge structure, there would be a need for crash attenuators on both ends, snow removal would be difficult and take longer, traffic capacity would be decreased due to shy distance, and rear-end collisions are likely to increase due to decreased traffic capacity and queuing. As with moveable barriers, the suspension span of the bridge would require strengthening in order to support the additional weight of the permanent concrete barrier. Permanent barriers also create additional challenges which would be difficult to overcome.

<u>Lack of Flexibility</u> - Unlike the moveable barrier system, permanent barrier would be attached to the bridge deck. That would limit MDTA's ability to operate two eastbound lanes on the westbound span or platoon vehicles in an emergency. In general, the installation of permanent barriers would remove the facility administrators' and first responders' flexibility in addressing routine operational management of the Bay Bridge.

Incident Management – As the barriers would be permanently attached to the bridge deck, first responders would not be able to separate them to access incidents on the bridge. Vehicles in the left lane in the westbound direction will be "boxed in" between the bridge's outer railing on the extreme left side and the permanent barrier on the right side. If a vehicle has a crash, or has mechanical trouble and stops within the reversible lane, it will be very time consuming to remove the vehicle from the bridge and will cause major tie-ups and congestion. For example, if a vehicle "broke down" in the middle of the bridge during the peak hour, a wrecker would either have to travel backwards for 2.15 miles to reach the vehicle with the wrecker's back end, or a queue of vehicles 2.15 miles would have to back off the bridge in the other direction to allow a wrecker to back up for 2.15 miles in that direction to reach the vehicle with the wrecker's back end.

Photo Courtesy of
Qwick Kurb®, INC

Mounting – Mounting permanent barrier to the bridge structure would be difficult, costly, and time consuming.

The only advantages permanent barriers offer over the moveable barrier system (option 1) are the barrier will not deflect into the adjacent travel lane during a crash, and they can be designed and constructed to withstand the highest NCHRP 350 TL 6 crash rating. The challenges of reduced stopping sight distances, reduced lane widths in Lanes 2 and 3, lack of flexibility and incident management concerns, as well as the risk of increased congestion, increased rear-end collisions, and potential head-on collisions with the attenuators led the workgroup to rule that permanent barriers are infeasible.

Alternative 5: Temporary Concrete Barrier

The workgroup also discussed the installation of temporary concrete barrier between lanes two (2) and three (3) of the westbound span. Temporary concrete barrier would introduce the same concerns as moveable barriers, however, it would also require significant time to relocate the barrier and therefore would be left permanently between lanes two (2) and three (3). In the event of an incident in the reversible lane, several sections of the temporary concrete barrier could be removed in order to provide an exit for trapped vehicles. Because temporary concrete barrier provides no additional benefit over moveable barriers they were not considered a viable option.

Alternative 6: "Qwick Kurb®" Type Channelization Device

Several options could be considered to create a buffer space between the reversible lane and the westbound center lane (lanes 2 and 3). One such system is designed by Qwick Kurb® Inc. which features flexible markers or bollards mounted to a base. The system features continuous linked bases that can be anchored to the bridge deck, left in place without being bolted to the deck and are capable of being moved by a machine. While originally designed for work zones, Qwick

Kurb® Inc. states "use of the system has evolved so that it is deployed much more often in permanent configurations than in construction zones".

The workgroup identified several advantages that a "Qwick Kurb®" type device offers over the moveable barrier system. Each advantage is discussed below.

<u>Limited Space Requirements</u> – The system has a width of 11.5 inches which would fit within the space taken by the current lane markers on the Bay Bridge. If the system was stored on the shoulder of lane three, the lane width would still exceed 11 feet.

<u>No Weight Issues</u> – The system is light compared to the other options considered. The Qwick Kurb® Inc. system weight is ten pounds per foot (10 lbs/ft), which would minimize the additional stress placed on the bridge structure. The system is also light enough that it could be continued across the suspension span of the Bay Bridge without the need for additional strengthening.

<u>Experience with the System</u> – MDTA currently uses a buffer designed by Qwick Kurb® Inc. at the Baltimore Harbor Tunnel Facility (BHT). Crews have experience with its maintenance and operation; however, the BHT system is not moved on a daily basis. MDTA may realize some economy of scale benefits from quantity discounts associated with ordering replacement parts in larger quantities.

Photo Courtesy of
Qwick Kurb®, INC

<u>Fewer Impacts on Incident Management</u> – The "Qwick Kurb®" type systems are simple to walk back and forth between. At ten pounds per foot, the system could easily be moved by maintenance crews or first responders if necessary to gain access to an incident scene. The system also allows vehicles to easily drive over the delineator posts and linear curbing without causing damage to vehicle or delineator posts if required during incidents.

<u>Perceived Proactive Measure</u> – This is a very visible solution and the public is likely to have a positive response to efforts taken to enhance safety at the bridge.

The system would also create some of the same challenges created by the movable barrier. Challenges such as the sight distance, and negative impacts on snow removal were considered to be very similar by the workgroup. The group felt that speeds would be reduced due to shy distance, but it would have less of an impact than it would with either of the barrier options. Several distinct challenges were presented by the "Qwick Kurb®" type system:

<u>No Positive Separation</u> - While the buffer would serve as a strong indicator of where to travel, it does not create positive separation. Vehicles at highway speeds could simply drive over the flexible markers or bollards into the adjacent lane.

<u>Creates a False Sense of Security</u> – Motorists may make the assumption that the buffer would be able to withstand the impact of a vehicle and prevent it from exiting its travel lane. This false sense of security may lead motorists to engage in risky behavior.

Drainage - The design of the buffer system may restrict the movement of water away from the travel lanes. This may increase the stopping distance of vehicles when the roadway surface is wet.

High Maintenance – While the system is designed for the markers or bollards to flex when they are struck at highway speeds, there will be instances when they are separated from their bases. This is especially likely to occur during snow removal operations. This creates the possibility of loose or flying objects after one of the markers has become separated from the base.

Potential for Loose Markers/Bollards on Bridge – The Qwick Kurb® system has been designed and crash tested to withstand vehicles traveling at 65 MPH; however, it's NCHRP 350 crash test approval is for use as a work zone longitudinal separator. If left in place on a permanent basis, markers or bollards are more likely to separate from the base and be loose on the bridge. These loose markers or bollards present a safety concern to all vehicles on the bridge.

The Qwick Kurb® option was determined to be feasible by the workgroup; however, it was considered less desirable than the painted buffer option (Alternative 7) due to the concerns listed above.

Alternative 7: Painted Buffer with Rumble Strips

The workgroup discussed enhancements to the current lane markings. A painted buffer would consist of two solid lines with diagonal hash and would also contain a continuous rumble strip. This option presented numerous advantages when compared to the barrier and other buffer options.

Photo Courtesy of www.bikesd.org

No Impact on Lane Widths - The painted buffer would replace the existing lane markings and would not reduce the lane widths at all.

No Impact on Incident Management – The buffer would have no impact on incident management as emergency responders could simply drive over it.

No Impact on Sight Distance – The buffer is painted on the surface and has no vertical component to interfere with sight distance.

Minimal Impact on Throughput – The buffer would eliminate lane changes which in-turn may have a minimal negative impact on throughput. This option eliminates the shy distance concerns of all of the barrier options. Any impacts on throughput are estimated to be negligible.

Enhancement to What is Currently in Place – While the painted buffer will not create positive separation of opposing traffic, it is a visible enhancement over what is currently in place. Physical enhancements will include continuous rumble strips; however, the group determined that it is highly unlikely any vehicle can change lanes today without hitting the existing rumble strips. The buffer would be a clear indication to traffic in both directions that lane changes are not authorized, and this message could be reinforced through motorist education and additional roadway signs. The continuous rumble strips will serve as an audible and physiological warning to motorists that they are dangerously close to exiting their lane.

The painted buffer presented very few challenges to the workgroup. The challenges included the following:

Lack of Positive Separation – The painted buffer would not create the positive separation that any of the buffer systems creates.

Eliminates Lane Changes – As mentioned above, the painted buffer would make lane changes illegal regardless of the direction of travel within the reversible lane. While restricting lane changing between lanes 2 and 3 will tend to improve overall safety, it could reduce capacity during times that slow moving vehicles enter the reversible lane and vehicles behind them are not allowed to pass.

The workgroup found that the painted buffer with continuous rumble strips was the most feasible option due to the simplicity, the numerous advantages, lack of challenges to implementation, and the immediacy with which it could be implemented.

Recommendations

As a result of its analysis of each of the alternatives, the workgroup recommended the painted buffer with rumble strips alternative as the primary course of action. The “Qwick Kurb” type system could be considered in the future if additional measures are required. The workgroup recommended that none of the other options be considered for further evaluation due to the overwhelming challenges identified.

Following implementation of the painted buffer and continuous rumble strips on the westbound bridge, the performance of the system will be monitored and a determination made as to its applicability on the eastbound bridge.

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