Appendix L

Bridge Analysis

TECHNICAL MEMORANDUM

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Topic: Existing Bridge Structures and Streetcar Alternatives

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1.0 Introduction

This technical memorandum discusses the structural feasibility of installation of streetcar tracks across the bridges identified along the proposed Nicollet Central alignment. The proposed Nicollet Central streetcar alignment is planned to cross several existing bridge structures. The bridges include 1st Street (or alternatively, Blaisdell Avenue) bridge over the Midtown Greenway, Nicollet Avenue over I-94, Hennepin Avenue Suspension Bridge over Mississippi River, eastbound Hennepin Avenue over the Mississippi, westbound 1st Avenue over the Mississippi or, alternatively, the Central Avenue (3rd Avenue S) concrete arch bridge over the Mississippi River.

Adding streetcar tracks to existing bridges requires the evaluation of a number of options. The most feasible option will be dependent upon the existing bridge load rating, adjacent roadway geometry, the potential for dedicated streetcar tracks vs. mixed-operations and capital costs. Stray current can also be a concern which will be addressed with the selected track design. This technical memorandum reviews the following elements:

- Existing features of each structure
- Alternative track design options
- Any issues concerning track installation and associated streetcar loads
- An order of magnitude cost estimate for the necessary improvements anticipated for each structure.

Streetcar track design options across roadway structures typically include either direct fixation or embedded track. Each track design has different requirements to prepare the structural deck to accept the tracks. The track design options are discussed below along with typical sections.

The cost estimates presented in this technical memorandum represent order of magnitude costs associated with structural modifications to the bridges to accommodate streetcar tracks. These costs are based upon construction cost estimates developed for the specified scope of work.

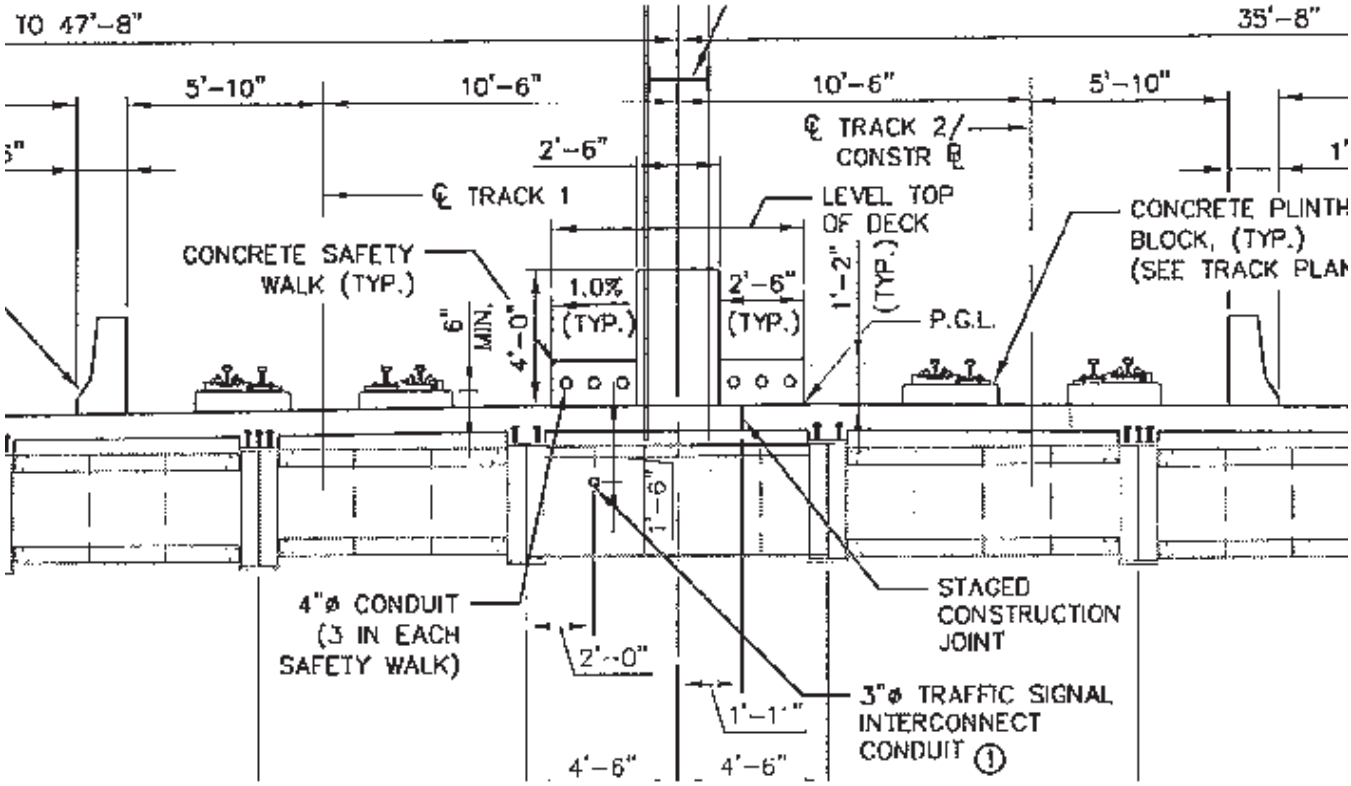
2.0 Track Structures

2.1 Direct Fixation (DF) Track

Direct Fixation (DF) track is an open track structure in which the rail is mounted on direct fixation fasteners that are in turn anchored to an underlying concrete slab. The slab could be a slab on grade, an aerial structure deck surface, or a concrete tunnel invert. DF track can be constructed upon reinforced concrete plinths, cementitous grout pads, booted tie blocks or a “plinthless” installation where the track is mounted directly to the underlying

slab. Typically DF track requires a dedicated guideway as the top of rail elevation is not flush with the roadway surface.

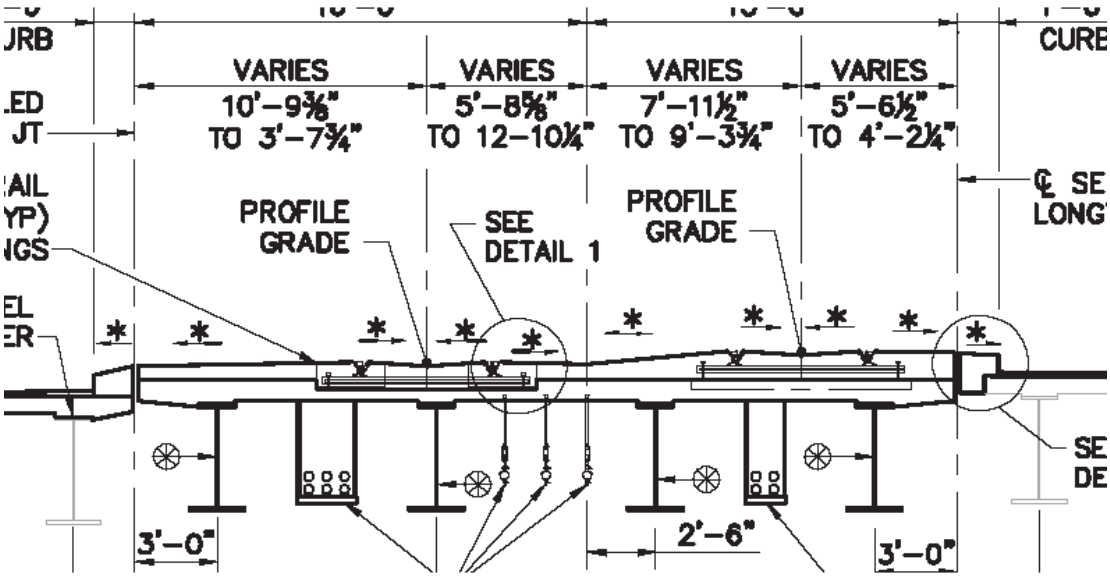
Figure 1 – Direct Fixation Track on Aerial Structure



2.2 Embedded Track

Embedded track can be described as a track structure that is completely encased—except for the tops and gauge sides of the rails—within pavement. Portland Cement Concrete is generally preferred as the pavement material; however, asphalt concrete has also been used in these applications. Flangeways can be provided either by using Girder rail or by forming a flangeway in the embedment material when Tee rail is used.

Embedded track provides for mixed roadway and streetcar operations and generally is required when the track is located in a street within a shared traffic lane which must accommodate rubber-tired vehicle traffic or for reasons of aesthetics or maintenance.



3.0 Bridge Structures

3.1 First Avenue S over Midtown Greenway

Existing Features

The existing structure was constructed in 1914 and consists of a reinforced concrete T-beam superstructure supporting a three span reinforced concrete deck. The length of the bridge is 94.4' and the deck width is 55'. Traffic is configured for three lanes northbound (one-way) with an 8.3' sidewalk on each side of the bridge. The First Avenue structure is in poor condition, classified as structurally deficient with a sufficiency rating of 36.0. The bridge inventory rating on the structure is currently nearly 50% less than the HS 20 design load. A 2007 study of the Midtown Greenway bridges identifies a remaining useful life of four years for this structure. The preferred streetcar route would run along a temporary, single-track alignment on First Avenue until the Nicollet Avenue right-of-way is restored across the Kmart development site. At that time, the streetcar alignment would continue along Nicollet Ave to a new terminus at Lake Street or further south with a Phase 2 streetcar extension.

Track Installation Alternatives

The proposed streetcar alignment will include a shared single track for both northbound and southbound streetcar operations in the westernmost lane of the First Avenue structure. This requires the streetcar tracks to be in a dedicated right-of-way on DF track separated from travel lanes by a traffic barrier. Due to the current sufficiency rating, it is anticipated that the First Avenue Bridge structure will need to be replaced or reconstructed. Given the structure's condition, its design and reconstruction are likely to be separate from implementation activities of streetcar; however, both efforts need to be coordinated should the preferred streetcar alignment between Nicollet Avenue/28th Street S and Lake Street utilize First Avenue S.

Construction Costs

The estimated construction cost of First Avenue Bridge is $170,000 in year 2013 dollars. The cost includes structure deck preparations to accommodate the DF anchor systems, installation of a barrier curb and modest pavement overlay modifications to accommodate streetcar tracks. Track and streetcar system components are

not included in these costs. The construction cost to replace the First Avenue Bridge is not carried in the capital costs for the Nicollet Central Streetcar alternative.

3.2 Blaisdell Avenue S over Midtown Greenway

Existing Features

An alternative alignment for the proposed streetcar places a shared single track for both northbound and southbound streetcar operations in the eastern most lane of the Blaisdell Avenue structure. The existing structure was constructed in 1982 and consists of a three span reinforced concrete slab superstructure. The length of the bridge is 91' and the width of the bridge is 68'. Traffic is configured for three lanes southbound (one-way) with and 6.5' sidewalk on each side of the bridge. The Blaisdell Avenue structure is in good condition, classified as structurally adequate with a sufficiency rating of 96.4. The bridge inventory rating on the structure is 40% over the HS 20 design load; therefore the existing structure should be able to accommodate additional loading from streetcars and track structure.

Track Installation Alternatives

Due to the shared single track for both northbound and southbound streetcar operations the streetcars will operate in a dedicated right-of-way separated from travel lanes by a traffic barrier. Therefore, the tracks will likely be installed with a DF design on top of the bridge deck. Based on the bridge inventory and load ratings, the Blaisdell Avenue Bridge can likely accept the loads of the streetcar and associated infrastructure.

Construction Costs

The estimated construction cost of Blaisdell Avenue Bridge is $195,000 in year 2013 dollars. The cost includes structure deck preparations to accommodate the DF anchor systems, installation of a barrier curb and modest pavement overlay modifications to accommodate streetcar tracks. Track and streetcar system components are not included in these costs.

3.3 Nicollet Avenue over I-94

Existing Features

The proposed streetcar alignment will introduce tracks for a northbound and southbound streetcar line in the associated travel lanes along Nicollet Avenue across the I-94 structure. The existing structure was constructed in 1966 and consists of a four-span reinforced concrete prestressed beam with concrete deck superstructure. The length of the bridge is 230' and the width of the bridge is 70'. Traffic is configured for one lane northbound and one lane southbound with parking lanes and 8' sidewalk on each side of the bridge. The deck has a 2" low slump overlay that was installed in 1980. The Nicollet Avenue structure is in good condition, classified as structurally adequate with a sufficiency rating of 69.0. The bridge inventory rating on the structure is HS-35, 40 percent over the HS 20 design load; therefore, the existing structure should be able to accommodate additional loading from streetcars and track structures. Based on discussions with MnDOT, there is work planned for 2017 that involves pier struts and sealing the railing. Re-decking is proposed for the 2023-2033 timeframe, currently estimated at $1.3 million. Based on the superstructure rating of 5, it might be necessary to consider the cost of replacing the structure. Any planned improvements should be coordinated with the proposed streetcar project.

Track Installation Alternatives

An embedded track design will be needed in order to share operations with general traffic along Nicollet Ave across the bridge structure. Based on the bridge inventory and sufficiency ratings, the Nicollet Avenue Bridge can accept an embedded track design . To avoid extensive reconstruction of the structural deck, it is feasible to plane

the existing wear course, install the tracks on top of the bridge deck and overlay the entire deck to create a new driving surface that matches the top of rail. This approach raises the grade at both bridge approaches and will require additional street reconstruction to accommodate the rail profile. The neighboring driveway access points will be reviewed to ensure proper access will be provided from the street right-of-way. Additionally, the overlay will add additional dead load and reduce the load capacity and inventory rating of the structure.

Installation of the rails on top of the existing concrete deck is the recommended approach. This would involve planing the deck by 1½ – 2 inches in the areas of the new rail, installing 5-inch rail embedded in concrete and the addition of approximately 3 - 5 inches of concrete wearing surface to raise the roadway surface to the top of the rails. The additional concrete overlay should be sloped away from the rails in order to limit added weight on the bridge; however, no strengthening of the structure is anticipated. The rails will also need to accommodate the transverse expansion joints on the bridge which will need to continue to provide for movement. The additional concrete on the Nicollet Avenue structure deck will result in a very short (2 in.) curb height. This can be mitigated by adding a curb section on top of the existing sidewalk.

Construction Costs

The estimated construction cost of Nicollet Avenue Bridge is $205,000 in year 2013 dollars. The cost includes structure and overlay modifications to accommodate streetcar. Track and streetcar system components are not included in these costs.

3.4 Hennepin Avenue Suspension Bridge over Mississippi

Existing Features

The proposed streetcar alignment places a single track for the eastbound and westbound streetcar line in the inside lane across the Hennepin Avenue suspension bridge. The existing structure was constructed in 1988 and consists of dual steel suspension superstructure with one main and four approach spans. The approach spans have a steel girder superstructure. The total length of the bridge is 1037’ (including approach spans) and the deck width is 134’. The bridge is configured for two-way traffic with eastbound traffic on one structure and westbound traffic on the other with a 14’ sidewalk on each side. There are three travel lanes for both eastbound and westbound traffic. The Hennepin Avenue structure is in good condition, classified as structurally adequate with a sufficiency rating of 86.1. The bridge inventory rating on the structure is over the HS 20 design load; therefore, the existing structure may be able to accommodate additional loading from streetcars and track structures. The controlling section for the Inventory Rating is not indicated in the MnDOT Structure Inventory Report; however, it is likely that little modification would be necessary to accommodate 5” of new concrete overlay on the existing structure. The suspension bridge was designed for HS-25 loading using service design for the cables and load factor design for the other components. Streetcar loads are not specifically identified in the design data on the bridge plans, but could be accommodated under the original HS-25 load design.

Experience has shown that conversion of modern bridges from roadway to combined roadway/streetcar use is generally feasible for bridges without load restrictions. This is largely due to the fact that modern streetcar vehicles when fully loaded do not exceed the gross vehicle weight of standard legal trucks and the streetcar vehicle suspensions distributes the loads to allow for use on standard highways. The Hennepin Avenue Bridge is a modern structure, opened in 1990, without posted load restrictions and therefore can reasonably be assumed capable of carrying modern streetcar service. Depending upon whether service will be on dedicated or shared right-of-way, the weight of track structure and any needed protective barriers could prove significant. Any conversion to modern streetcar service is likely to be limited in the magnitude of dead load increase accommodated without bridge strengthening. Modern streetcar service also imposes dynamic loads and fatigue loads different from standard highway trucks. Any conversion of the Hennepin Avenue bridge to modern

streetcar use must include, in addition to a detailed evaluation of load capacity, a detailed evaluation of dynamic vibrations and deflections and an evaluation of structural fatigue under the modern streetcar and combined modern streetcar/truck loads, with the structure modified accordingly. It should also be noted that sidewalks on this bridge are broad and the pedestrian loads significant. Rational combination of highway, modern streetcar and pedestrian loads will warrant the development of project specific design criteria for efficient application of design standards. A detailed structural analysis is necessary to affirm this recommendation and to evaluate structural feasibility, likely during environmental review/advanced concept design assuming modern streetcar is selected as the preferred alternative.

Track Installation Alternatives

Based on the bridge inventory and sufficiency ratings, the Hennepin Avenue suspension bridge can likely accept either embedded track or direct fixation track structures. If a shared guideway with general traffic vehicles is desired, an embedded track design will be utilized. To avoid extensive reconstruction of the structural deck and framing, direct fixation track will be affixed to the existing deck and the entire deck overlayed to create a new driving surface that matches the top of rail. This approach raises the grade at both bridge approaches and may require additional street reconstruction to accommodate the rail profile. The additional weight of the deck overlay must be evaluated for structural feasibility.

If a dedicated guideway can be accommodated across the Hennepin Avenue bridge (removing one lane of travel in each direction), it is recommended that direct fixation track on plinths be installed across the bridge. The profile of the rail will need to be adjusted as the alignment nears the approach spans for the bridge. It will be necessary to either dedicate guideway with a traffic barrier as the streetcar approaches the bridge on the east side or remove and reconstruct a portion of the deck and structural steel on the approach spans to a lower elevation to accommodate the rail profile. The rails will also need to accommodate the transverse expansion joints on the bridge which provide for significant movement of the structure.

Construction Costs

To be conservative, the cost estimate currently assumes a shared guideway with general traffic. Direct fixation track will be affixed to the existing deck and the entire deck overlayed to create a new driving surface that matches the top of rail. This approach will be confirmed in the next phase of design development. The estimated construction cost of Hennepin Avenue Bridge is $830,000 in year 2013 dollars. The cost includes structural modifications to accommodate streetcar tracks. Track and streetcar system components are not included in these costs.

3.5 Hennepin (Eastbound) and First Avenue (Westbound) over Mississippi

Existing Features

The proposed streetcar alignment places a single track for the eastbound alignment in the left lane on Hennepin Avenue over Mississippi and a single track for the westbound alignment in the left lane on First Avenue over Mississippi. The existing structures were constructed in 1973 (Hennepin Avenue) and 1971 (First Avenue). Each structure consists of a four-span steel girder bridge with a reinforced concrete deck. The total length of the Hennepin Avenue bridge is 383’ and the First Avenue bridge is 414’. The deck width for these structures is approximately 65’. The bridges are configured for one-way traffic, with eastbound traffic on one structure and westbound traffic on the other and a 14’ sidewalk on one side. There are three lanes for both eastbound and westbound traffic. The decks appeared to have received a 2” overlay in the early 1990’s. The Hennepin Avenue and First Avenue structures are in good condition, classified as structurally adequate with a sufficiency rating of 78.9. The bridge inventory rating on the structure is over the HS 20 design load; therefore, the existing structure

should be able to accommodate additional loading from streetcars and track structures. It is likely that little modification would be necessary to accommodate 5" of new concrete overlay on the existing structure. A detailed structural analysis is necessary to affirm this recommendation and to evaluate structural feasibility, likely during environmental review/advanced concept design assuming modern streetcar is selected as the preferred alternative.

Track Installation Alternatives

Based on the bridge inventory and load ratings, the First Street and Hennepin Avenue bridges can accept either an embedded track or direct fixation track structure. If a shared guideway with general traffic vehicles is desired, an embedded track design will be utilized. To avoid extensive reconstruction of the structural deck and framing, it is structurally feasible to install direct fixation track to the existing deck and then overlaying the entire deck to create a new driving surface that matches the top of rail. However, due to the proximity of the bridge abutments to cross streets at Main Street, it will be necessary to install embedded track on these bridges in the eastern span with a rail profile at the existing deck elevation. In order to complete this, deck reconstruction will be required. This work will consist of deck removal and replacement and replacement of the existing structural steel members which are in alignment with the streetcar tracks. The remaining three spans are assumed as DF track with concrete overlay.

The rails will also need to accommodate the transverse expansion joints on the bridge which provide for movement of the structure. The cost estimate assumes the removal and reconstruction of the deck and structural steel members in the span closest to the Main Street intersection to accommodate a lower rail profile on both bridges. The remaining three spans are assumed as DF track with concrete overlay to provide for a share streetcar/vehicle lane.

Construction Costs

The estimated construction costs of First Avenue and Hennepin Avenue Bridge are $850,000 and $915,000 in year 2013 dollars, respectively, if the bridge deck were to be reconstructed with embedded track. The cost includes structural modifications to accommodate streetcar tracks. Track and streetcar system components and utility modification allowances are not included in these costs.

3.6 Central Avenue (Third Avenue S) Bridge over the Mississippi River

Existing Features

An alternative alignment for the proposed streetcar places the alignment with a single track for eastbound and a single track for westbound on the Central Avenue bridge over the Mississippi River. The existing structure was constructed in 1916. The structure consists of a concrete arch superstructure with seven main spans and four approach spans. The approach spans have a steel girder superstructure with reinforced concrete deck. The length of the bridge is 1888' (including approach spans) and the deck width is 82'. Traffic is two-way with an 8' sidewalk on each side of the structure. The Central Avenue structure is in good condition, classified as structurally adequate with a sufficiency rating of 78.5. The bridge inventory rating on the structure is for a HS-20 design load. Since the inventory rating is only for HS-20 design load, a 5" concrete overlay on the existing structure is not feasible. The current Structure Inventory Report is not clear where the rating of the weakest point or member of the bridge was taken; thus, it is indeterminable at this preliminary stage whether a retrofit of the bridge is acceptable. A recommendation for streetcar travel on this bridge is to reconstruct a portion of the deck to include the rails of the streetcars and minimize any additional dead load to the bridge. Some other retrofitting may be needed as well, if the HS 20 load rating is to be accommodated. A detailed structural analysis would be needed to affirm this recommendation.

Track Installation Alternatives

Due to the current inventory rating for the Central Avenue (Third Avenue S) bridge over the Mississippi River, it will be necessary to reconstruct the structural deck to accommodate streetcar track. This work will consist of removal and replacement of the structural deck and modifications to the existing structural steel and concrete members which are in alignment with the streetcar tracks. The rail structure will also need to accommodate the transverse expansion joints on the bridge which provide for movement of the structure. The cost estimate assumes the removal and reconstruction of the deck and structural steel members to accommodate a lower rail profile on both bridges.

Construction Costs

The estimated construction cost of Central Avenue (Third Avenue S) bridge over the Mississippi River is $4.1 million in year 2013 dollars to reconstruct the bridge deck with embedded track. The cost includes structural modifications to accommodate streetcar tracks. Track and streetcar system components are not included in these costs.

3.7 Central Avenue Bridge over BNSF RR[1]

Existing Features

The proposed streetcar alignment assumes a single track for the northeast alignment and a single track for the southwest alignment on Central Avenue. The existing structure was constructed in 1981. The structure consists of a two-span steel girder bridge with a reinforced concrete deck. The total length of the Central Avenue bridge over BNSF is 147’ with span lengths of 80.5’ and 58.5’. The deck width for these structures is approximately 78.3’ with a 4’ median, two 14’ lanes in each direction and 8’ sidewalks. The deck thickness is 9” with a 2” wear course. The Central Avenue structure is in good condition, classified as structurally adequate with a sufficiency rating of 91.5. The bridge inventory rating on the structure is for HS-19.80 design load. A 5” concrete overlay on the existing structure is not feasible. A recommendation for streetcar travel on this bridge is to reconstruct a portion of the deck to include the rails of the streetcars and minimize any additional dead load to the bridge. Some other retrofitting may be needed as well, if the HS 20 load rating is to be accommodated. A detailed structural analysis is necessary to affirm this recommendation.

Track Installation Alternatives

Due to the current inventory rating for the Central bridge over BNSF RR, it will be necessary to reconstruct the structural deck to accommodate streetcar track. This work will consist of removal and replacement of the structural deck and replacement of the existing structural steel members which are in alignment with the streetcar tracks. The rails will also need to accommodate the transverse expansion joints on the bridge which provide for movement of the structure.

Construction Costs

The estimated construction cost of Central Avenue Bridge over BNSF RR is $650,000 in year 2013 dollars to reconstruct the bridge deck with embedded track. The cost estimate assumes the removal and reconstruction of

[1] This structure is on the segment of Central Avenue between Seventh Street NE and Third Avenue NE.

the deck and structural steel members to accommodate a lower rail profile on both bridges. Track and streetcar system components are not included in these costs.

3.8 Central Avenue/Broadway Avenue over BNSF RR

Existing Features

The proposed streetcar alignment assumes a single track for the northbound alignment and a single track for the southbound alignment on Central Avenue. The existing structure was constructed in 1987. The structure consists of a two-span rigid monolithic concrete bridge/tunnel. The total length of the longest portion of the Central Avenue / Broadway Avenue bridge is 309' while the shorter structure is 254'. The deck width for this structures is approximately 86' wide. The main span lengths are 43'. The Central Avenue approach crosses the BNSF RR structure at a 27-degree skew with the roadway approaches supported on retained fill. The Central Avenue structure is in good condition, classified as structurally adequate with a sufficiency rating of 91.5. The bridge inventory rating on the structure is for a HS-37 design load; therefore, the existing structure should be able to accommodate additional loading from streetcars and track structures. A minimum 4" wear course is identified on the structure plans with areas likely greater than this due to the intersection grades. The removal of the wear course, installation of embedded rail over the tunnel structure and regrading of the intersection are feasible for this structure.

Track Installation Alternatives

An embedded track design will be needed in order to share operations with general traffic along Central Ave across the bridge structure. Based on the bridge inventory and sufficiency ratings, the Central Avenue/Broadway Avenue structure over BNSF RR can accept an embedded track design. To avoid extensive reconstruction of the structural deck, it is feasible to plane the existing wear course, install the tracks on top of the bridge deck and regrade the intersection to create a new driving surface that matches the top of rail. This approach raises the grade at both bridge approaches and will require minimal additional street reconstruction on the Central Avenue and Broadway Avenue approaches to accommodate the rail profile. No strengthening of the structure is anticipated.

Construction Costs

The estimated construction cost of Central Avenue / Broadway Avenue over BNSF RR is minimal ($30,000 in year 2013 dollars). The cost for intersection reconstruction are not included in the structures costs, but carried in the overall cost estimate. An embedded track design can likely be accommodated with little to no structures modifications.

4.0 Summary of Construction and Project Costs

The following is a summary of estimated construction costs as described in this technical memorandum. These costs represent structure replacement and modifications required to accommodate streetcar tracks. The costs do not include any streetcar elements such as tracks or OCS or utility modification allowances that may be necessary as part of bridge rehabilitation work. The order-of-magnitude cost estimates do not include additional allowances for contractor mobilization, general conditions, traffic control, bridge visual quality and uncertainty in estimating quantities. These allowances are accounted for in the overall capital cost estimate and contingency for the Nicollet-Central streetcar alternatives, documented under separate cover.

Table 1: Summary of Preliminary Bridge Reconstruction Cost Estimates[2]

STRUCTURE	2013 COST ESTIMATE
First Avenue S over Midtown Greenway[3]	*$ 170,000*
Blaisdell Avenue S over Midtown Greenway	*$ 195,000*
Nicollet Avenue over I-94	*$ 205,000*
Hennepin Avenue Bridge over Mississippi River	*$ 915,000*
First Avenue Bridge over Mississippi River	*$ 850,000*
Hennepin Avenue Bridge over Mississippi River	*$ 830,000*
Central Avenue Bridge over the Mississippi River	*$ 4,110,000*
Central Avenue Bridge over BNSF RR	*$ 650,000*
Central Avenue/Broadway Avenue over BNSF RR	*$ 30,000*

Subsequent steps in order to develop a streetcar project in the Nicollet-Central corridor will refine the design approaches and capital cost estimates presented in this document. Design refinement will entail collaboration with appropriate agencies including the City of Minneapolis, Hennepin County and MnDOT.

Attachments A and B include the detailed basis of estimate for the structures presented in this technical memorandum.

[2] Cost estimates are in Year 2013 dollars, rounded, and exclude contingency and professional services. These estimates also do not include streetcar elements such as tracks and OCS, allowances for utility modifications that may be necessary for bridge rehabilitation work; contractor mobilization, general conditions, traffic control, bridge visual quality and uncertainty in estimating quantities.

[3] Estimate does not include bridge reconstruction cost.