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Minnesota Perpetual Pavement Analysis and Review

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July 2016

Research Project
Final Report 2016-33

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16. Abstract (Limit: 250 words)

MnDOT currently owns the record for the most award winners and has received an award every year from 2002 through 2015. This study reviews all the award winning roadways in Minnesota to determine common material, design factors and considerations which may have contributed to the roadways extended life, often exceeding 50 years despite the harsh Minnesota climate. For these projects, all the available information for the 14 award winners and any pertinent supporting information were reviewed including MnDOT Highway Pavement Management Application (HPMA) data and performance histories as well as the construction histories and plans. Findings from this study showed that a combination of many different factors may have contributed to the outstanding performance of these award winning roadways. These factors include constructing the roadways over a longer period of time, performing major subgrade corrections at the time of construction, use of a select granular backfill material which enhanced drainage, use of non-frost susceptible base and subbase materials in underlying layers, placing a layer of prime coat over the aggregate base before placing the asphalt layer(s), use of a staged construction which allowed the foundation to go through seasonal cycles potentially enhancing the overall pavement structural stability, use of a stabilized base in the initial construction which may provide a flexible, fatigue resistant foundation for overlay construction and provides a bound layer which may have reduced the tensile strain levels at the bottom of the upper asphalt layers and therefore increased the pavement fatigue life. Findings also showed a similar resilient modulus of asphalt mixtures at low temperatures which is the dominant temperature condition for much of the year in the state of Minnesota.

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EXECUTIVE SUMMARY

A *perpetual pavement* is an asphalt pavement designed and built to last longer than 50 years without requiring major structural rehabilitation or reconstruction, and needing only periodic surface renewal in response to distresses confined to the top of the pavement. The Asphalt Pavement Alliance (APA) created the Perpetual Pavement Award program in 2001 to recognize state agencies and other pavement owners for designing and constructing pavements that meet the APA's definition of Perpetual Pavement. This program requires that the roadway has at least 35 years of service at the time of award and had experienced no structural failures. In addition, the program limits candidate roadways to those that have not received more than four inches of new asphalt nor have been resurfaced at a frequency exceeding 13 years.

MnDOT currently owns the record for the most award winners and has received an award every year from 2002 through 2015. This study reviews all the award winning roadways in Minnesota to determine common material, design factors and considerations which may have contributed to the roadways extended life, often exceeding 50 years despite the harsh Minnesota climate. For these projects, all the available information for the 14 award winners and any pertinent supporting information were reviewed including MnDOT Highway Pavement Management Application (HPMA) data and performance histories as well as the construction histories and plans.

A more in-depth analysis was performed on the four project locations within the Metro District. To further investigate and characterize these sites, coring and hand auger borings were performed in cracked and un-cracked areas along with Dynamic Cone Penetrometer (DCP) which was performed in selected core holes. The cores were then used to measure thicknesses, densities, and asphalt contents, and to perform extracted gradations and resilient modulus testing at low and intermediate temperatures. The laboratory testing data were used to further refine the Metro award winner information by performing data analysis using the rePave program. This program was developed under SHRP 2 R23 study which provides much-needed guidance for the use of existing pavement in roadway renewal projects.

Findings from this study showed that a combination of many different factors may have contributed to the outstanding performance of these award winning roadways. These factors include constructing the roadways over a longer period of time, performing major subgrade corrections at the time of construction, use of a select granular backfill material which enhanced drainage, use of non-frost susceptible base and subbase materials in underlying layers, placing a layer of prime coat over the aggregate base before placing the asphalt layer(s), use of a staged construction which allowed the foundation to go through seasonal cycles potentially enhancing the overall pavement structural stability, use of a stabilized base in the initial construction which may provide a flexible, fatigue resistant foundation for overlay construction and provides a bound layer which may have reduced the tensile strain levels at the bottom of the upper asphalt layers and therefore increased the pavement fatigue life. Findings also showed a similar resilient modulus of asphalt mixtures at low temperatures which is the dominant temperature condition for much of the year in the state of Minnesota.

CHAPTER 1: INTRODUCTION

The Asphalt Pavement Alliance (APA) originally introduced the concept of *Perpetual Pavements* in 2000 and defined them as:

“an asphalt pavement designed and built to last longer than 50 years without requiring major structural rehabilitation or reconstruction, and needing only periodic surface renewal in response to distresses confined to the top of the pavement”[*1*].

Many asphalt pavements constructed long before 2000 function as Perpetual Pavements, and as a result, the APA created the Perpetual Pavement Award program in 2001. The award program was primarily intended to recognize state agencies and other pavement owners for designing and constructing pavements that met the APA’s definition of Perpetual Pavement.

According to the APA, the Perpetual Pavement Award program has acknowledged 100 long-life pavements in 30 U.S. states and one Canadian province [*2*]. The program requires that the roadways has at least 35 years of service at the time of award and had experienced no structural failures. In addition, the program limits candidate roadways to those that have not received more than four inches of new asphalt nor have been resurfaced at a frequency exceeding 13 years.

MnDOT owns the record for award winners and have received an award every year from 2002 through 2015. Table 1.1 presents all the MnDOT perpetual pavement award winners. MnDOT’s winning project locations cover the state (Figure 1-1).

The purpose of this study is to review all the award winning roadways in Minnesota to determine common material, design factors, and considerations which may have contributed to the roadways extended life, often exceeding 50 years despite the harsh Minnesota climate. For these projects, all the available information and any pertinent supporting information are reviewed including MnDOT Highway Pavement Management Application (HPMA) data and performance histories as well as the construction histories and plans.

Table 1.1 MnDOT's Record 14 APA Perpetual Pavement Award Winners

Year of award	District	Highway	Original Construction
2002	1	I-35	1966
2003	2	USTH 71	1964
2004	Metro	USTH 10	1966
2005	3	TH 18	1959
2006	6	USTH 61	1969
2007	8	USTH 71	1970
2008	Metro	TH 36	1960
2009	4	USTH 10	1973
2010	1	USTH 61	1969
2011	3	USTH 71	1962
2012	6	USTH 61	1969
2013	Metro	TH 95	1961
2014	Metro	TH 47	1966
2015	2	TH 71	1977

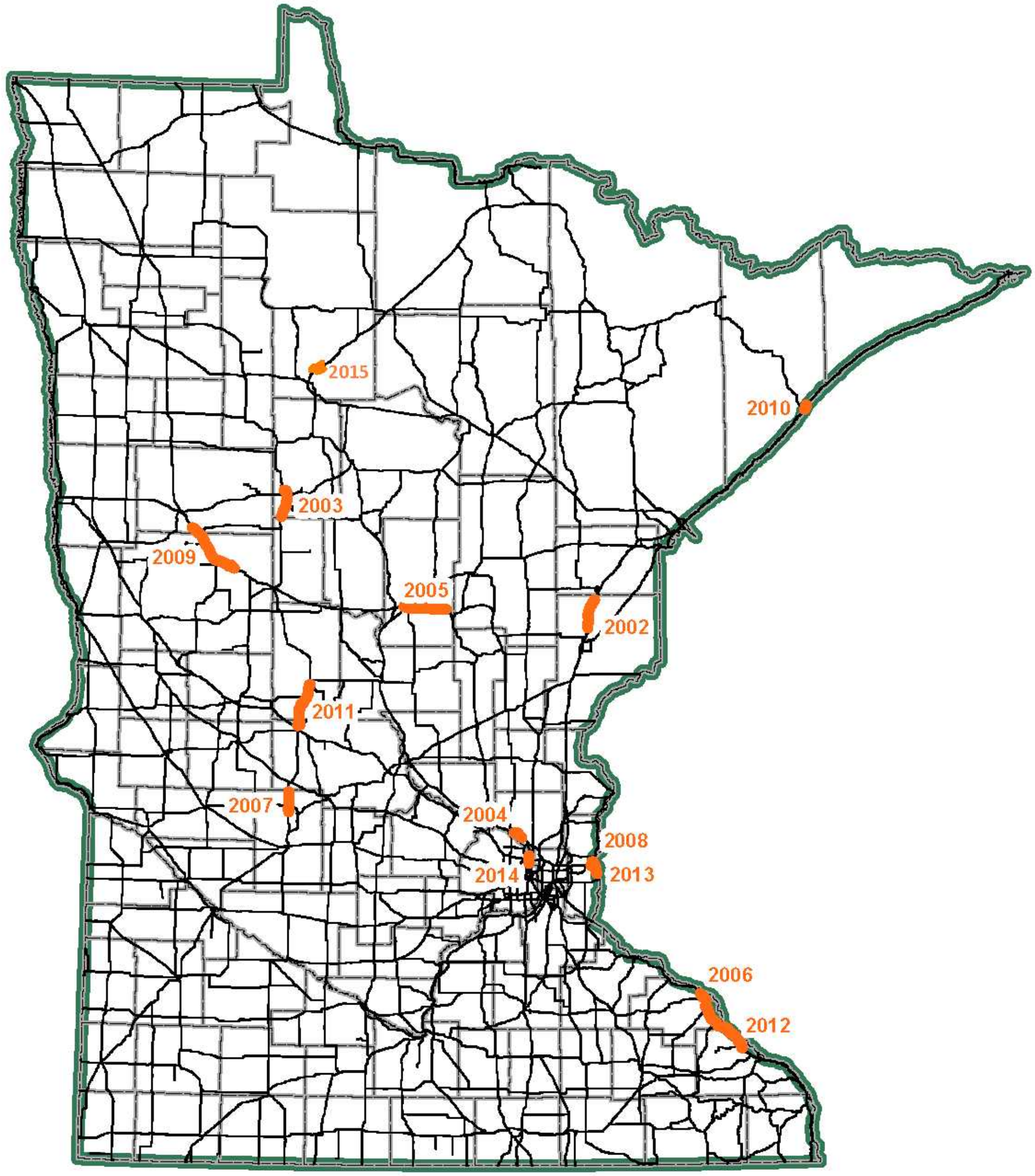

Figure 1-1 MnDOT's Record 14 APA Perpetual Pavement Award Winners

CHAPTER 2: PERPETUAL PAVEMENTS

A perpetual pavement concept has been considered as one of the options to help increase pavement life. These pavements are typically designed to last 40 to 50 years without structural failure and only the surface asphalt layer requires rehabilitation or replacement when necessary. It has shown that the perpetual pavements provide high cost-effectiveness and sustainability [*3*, *4*]. These pavements also have the following benefits [*5*]:

- Providing a more efficient design which eliminates costly overly conservative pavement sections.
- Eliminating reconstruction costs (by not exceeding a pavement's structural capacity.
- Reducing user delay costs due to roadway repair/rehabilitation.
- Reducing the use of non-renewable resources (aggregates and asphalt).
- Diminishing energy costs while the pavement is in service.
- Reducing the overall life-cycle costs of the pavement network.

2.1 Mechanistic-Empirical Method

The idea behind perpetual pavements comes from the general belief that if the imposed traffic loads produce responses that are below a certain threshold value, then the structural damage does not accumulate [*6*]. These pavements are usually designed to resist bottom-up cracking by incorporating thick hot mix asphalt (HMA) layers. This reduces the tensile strain at the bottom of the HMA layer below a threshold value, called the endurance limit (EL).

Early on, Monismith et al. [*7*] proposed an EL of 70 microstrain, which would result in approximately five million cycles to failure. Later, Powell et al. [*8*] defined the EL strain level such that failure occurred at around 50 million cycles. They assumed that the maximum number of equivalent single-axle loads for highway pavements should be 50 million cycles over a 40-year period. With this assumption, by considering a shift factor of 10 for correlating the beam fatigue failure in the laboratory with the field observations, five million cycles can be considered an acceptable threshold value for EL definition. More recent laboratory test data indicate the EL value may range from 70 to 100 microstrain [*9*]. However, to run a single fatigue test with this definition, more than 50 days is needed considering the facilities in most typical asphalt laboratories. Therefore, laboratory testing time is a major challenge in finding EL value for a given mixture. More advanced explorations regarding the concept of EL and the required testing time have been conducted by other researchers in the context of viscoelastic continuum damage (VECD) theory [*10-12*].

This mechanistic-empirical method uses the elements of a rational engineering analysis of the reaction of the pavement in terms of stresses, strains, and displacements in the context of a pavement's expected life. According to perpetual pavement concept, there are limiting strains below which damage does not occur, and therefore, damage is not accumulated [*1*]. Figure 2-1 shows this concept.

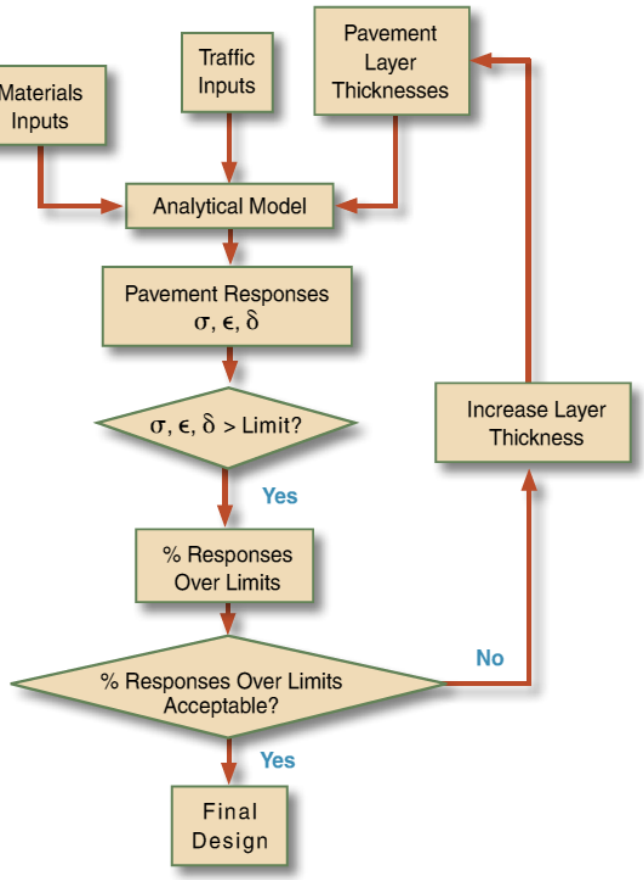

Figure 2-1 Simplified Flowchart of perpetual pavement Design [1]

2.2 Materials

Similar to conventional asphalt pavements, having a strong foundation is a key factor in construction and performance of perpetual pavements. The foundation provides a working platform which supports construction equipment for placing the asphalt layers and also the compactors. This will also help in reaching the desired density in the asphalt layers. Throughout the pavement performance period, the foundation provides support to the traffic loads and is crucial to reducing variability from season to season due to freeze-thaw and moisture changes. Also, when dealing with wet-dry cycles in expansive clays and freeze-thaw cycle in frost-susceptible soils, the proper design and construction of the foundation is the key factor in preventing volume changes [*1*]. Therefore, the perpetual pavement foundation must meet some minimum requirements for stiffness. Sometimes this requirement will not be satisfied unless the subgrade soils or base course materials go through a mechanical or chemical stabilization.

Perpetual pavement asphalt layer is usually consists of three layers: the surface layer, the intermediate layer, and the base layer. Each layer serves specific functions:

- The surface layer should be a high quality hot mix asphalt (HMA), or stone mastic asphalt (SMA), or open graded friction course/bonded wearing course (OGFC)/(BWC) which is designed to withstand the traffic load. This layer should be resistant to fatigue, rutting, and low temperature cracking. It also needs to provide high friction.
- The intermediate layer should provide both durability (moisture resistance) and rutting resistance.
- The base layer experiences the maximum tensile strain from bending under repeated traffic load. This layer must provide excellent durability and the resistance to fatigue cracking. Using a higher designed asphalt content in this layer is a common practice. A higher binder content, lowers the air void content (typically to 2 to 3 percent air voids) and increases the density, thus improving the durability and fatigue resistance.

In general, there are two options in order to limit base related rutting to the upper few inches of the pavements: 1) increasing the structure's thickness or 2) increasing the stiffness of the materials. Both options will help the vertical load get more widely distributed before reaching the subgrade.

The three layer concept of a perpetual pavement asphalt layer is illustrated in Figure 2-2. Various thicknesses and materials have been used in these layers for different perpetual pavement designs. Ongoing research continues to review various examples of different three layer design concepts for achieving a perpetual pavement.

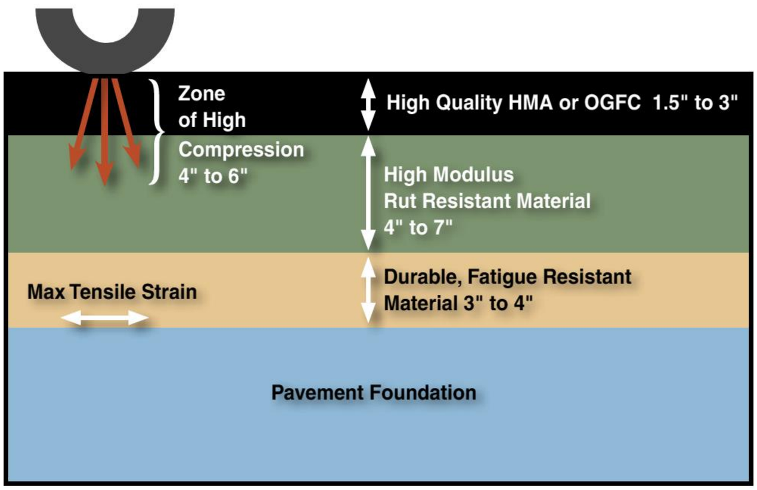

Figure 2-2 Three layer concept of a perpetual pavement asphalt layer [13]

2.3 Construction

Construction of a perpetual pavement does not differ considerably from conventional asphalt pavements, but it does require great attention to detail and a commitment to build it with quality from the bottom up [*1*]. The following key points should also be considered:

- High quality compaction is a critical factor (starting with foundation and including all layers).
- Optimum density and air void contents should be achieved.
- Longitudinal joint issues related to low density should be minimized to prevent moisture infiltration and damage.
- Segregation (temperature segregation within the mixture and/or separation of fine and coarse aggregate during production, transport, and placement) should be avoided.
- Good bonding between layers should be achieved.
- Normal quality control procedures (periodic testing and data analysis with good quality control and inspection techniques) should be followed

2.4 Performance Monitoring

In the perpetual pavement concept all the associated distresses such as top-down fatigue cracking, low temperature cracking, permanent deformation (rutting), and surface wear and raveling should be confined in the top few inches of the pavement. Thus, a periodic monitoring and assessment of pavement condition is a key factor to ensure a long pavement life.

Upon discovering such surface distresses, they should be properly addressed, so they do not turn into structural defects. Mill and fill and/or thin overlay are usually good repair candidates for perpetual pavements.

2.5 Perpetual Pavement Programs

There are a few programs available for design or renewal of perpetual pavements. A brief introduction of these programs are provided in the following sections. The rePave program will also be used to analyze the Metro District projects in Chapter 4. These analyses will determine the alternatives that can be done to keep these long-lived perpetual pavements to serve for another extended period of time, up to 50 years.

2.5.1 <u>rePave</u>

rePave is an interactive web-based pavement design scoping tool provides much-needed guidance for deciding where and under what conditions to use existing pavement as part of roadway renewal projects. It includes approaches for utilizing existing pavements to ensure longer service life for roadways using asphalt, concrete, and innovative materials. The product also identifies new alternatives to renewal approaches; and examines the advantages and disadvantages of each approach, the circumstances under which each should be considered, different construction techniques, and methods for integrating recycled materials with adjacent materials and road structures [*14*].

The rePave program helps transportation agencies make better decisions with regard to pavement renewal projects by using existing pavement as part of the design. As a result, the transportation agencies, drivers, highway workers, contractors, and taxpayers will benefit from time savings based on rapid reuse of existing materials, reduced costs for new pavement, and an accelerated construction process.

This approach delivers long-lasting value by promoting durable and dependable roads, while requiring less new pavement. As an example, Washington DOT has utilized the recommendations offered in this guide, and has realized a 30 percent cost savings and a 50 percent reduction in user delay costs over the life of the new pavement [*14*].

In summary, rePave benefits include:

- Saving materials (less new pavements).
- Shorter construction time, which results in reduced exposure of travelers and construction workers to work zone hazards.
- A better return on investment based on longer pavement service life.

rePave inputs are as follows:

- Project Info: name, route, and location
- Existing section: pavement type, number of through lanes, thicknesses, and year of construction of each layer
- Proposed section: design period, Subgrade resilient modulus (M_R), ESALs, growth rate, current ADT, number of through lanes, and height restrictions
- Exiting pavement conditions (current distresses):
    - Fatigue cracking: % low, % medium, and % high
    - Patching: % wheelpath area, and type of cracking (surface and/or full depth)
    - Rutting: average rut depth
    - Transverse cracking: # of cracks per 100 feet
    - Stripping

Figure 3-5 shows a sample output of rePave program.

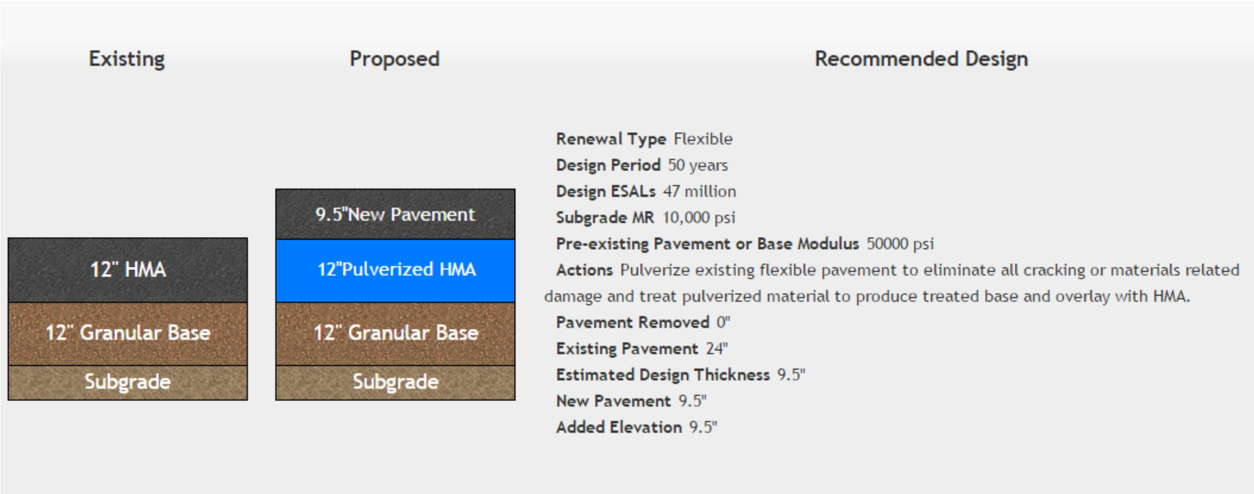

Figure 2-3 rePave sample program output

2.5.2 PerRoad

PerRoad uses the mechanistic-empirical design philosophy. The program couples layered elastic analysis with a statistical analysis procedure (Monte Carlo simulation) to estimate stresses and strains within a pavement. In order to predict the strains which would prove detrimental for fatigue cracking or structural rutting, PerRoad requires the following inputs:

- Seasonal pavement moduli and annual coefficient of variation (COV)
- Seasonal resilient moduli of unbound materials and annual COV
- Thickness of bound materials and COV
- Thickness of unbound materials
- Load spectrum for traffic
- Location for pavement response analysis
- Magnitude of limiting pavement responses
- Transfer functions for pavement responses exceeding the user-specified level for accumulating damage

PerRoad generally follows the M-E design process described in Figure 2. The Monte Carlo simulation is a simple way of incorporating variability into the analysis to more realistically characterize the pavement performance. the output for PerRoad consists of an evaluation of the percentage of load repetitions lower than the limiting pavement responses specified in the input, an estimate of the amount of damage incurred per single axle load, and a projected time to when the accumulated damage is equal to 0.1 (damage of 1.0 is considered failure). On high volume pavements, the critical parameter is the percentage of load repetitions below the limiting strains. It is generally recommended that the designer strive for a value of 90 percent or more on high volume roads [*1*].

The Mechanistic-Empirical Pavement Design Guide (MEPDG) and PerRoad computer programs are both capable of conducting fatigue-based perpetual design for flexible pavements. Though both programs utilize M-E concepts that incorporate similar types of material and traffic characterization, they have fundamental differences in their level of detail pertaining to design and the treatment of reliability. M-E design process is shown in Figure 2-4.

Timm and Davis [*15*] demonstrated that despite some significant differences in their design approaches, the two programs can result in remarkably similar pavement cross-sections for perpetual design. Also, the differences appeared to diminish as the fatigue endurance limit increased. Figure 2-5 presents a sample output of PerRoad program.

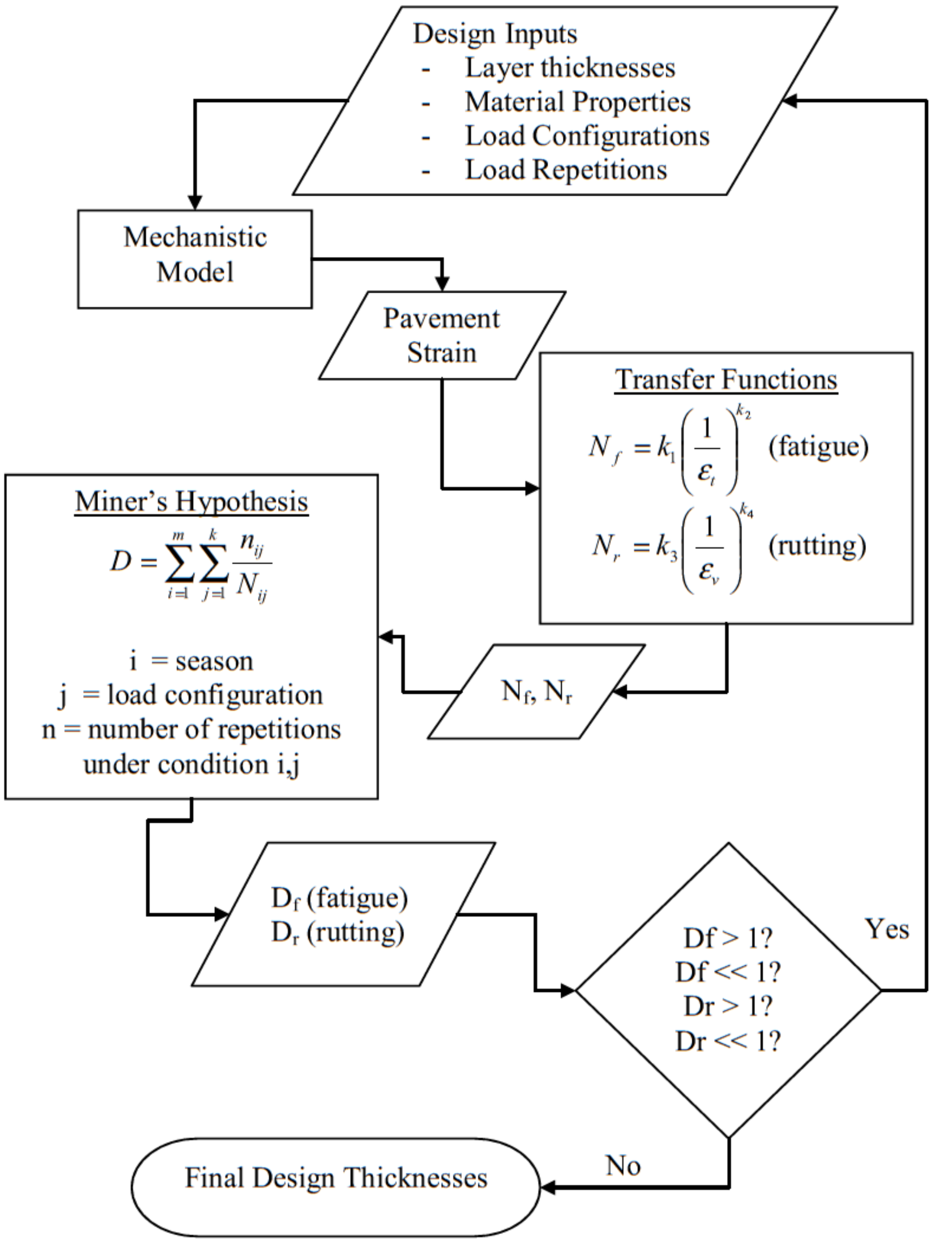

Figure 2-4 M-E Design Process [15]

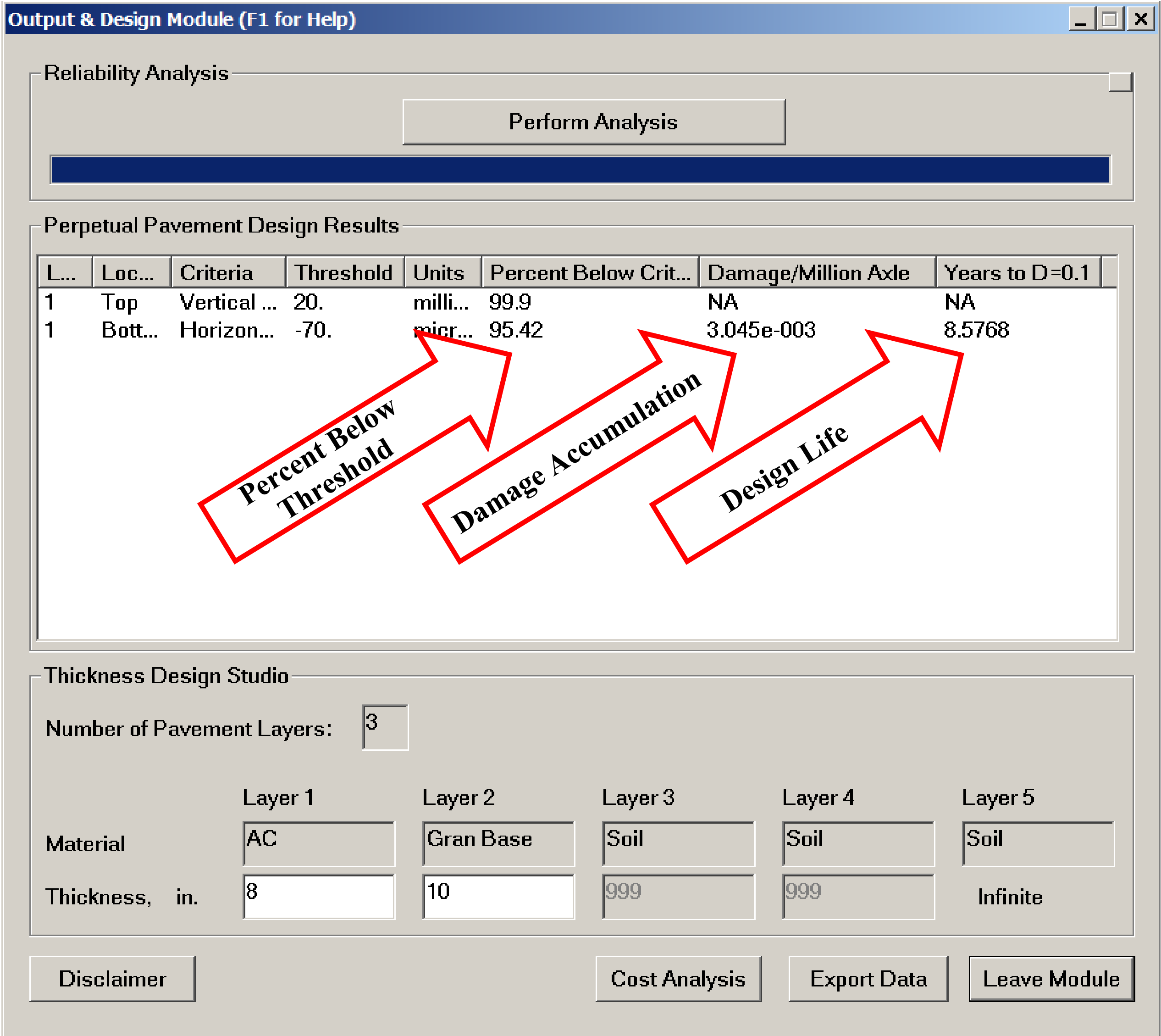

Figure 2-5 PerRoad sample program output

2.6 PerRoadXpress 1.0

PerRoadXpress is an easy-to-use, all-on-one-screen program for designing Perpetual Pavements for low- and medium-volume roads (with AADT of less than 5,000) and parking lots. This program was developed in response to requests by public works officials and owners of commercial property. The program was developed by running a large number of low to medium volume pavement design cases in PerRoad.

In the first step the user chooses a type of asphalt cement. The user then can input the actual values for traffic and soils properties, or to use the program default values if they are unknown. Granular base thicknesses from 0 to 10 inches are included. The software then quickly provides the user with a recommendation for the total thickness of asphalt pavement needed for a particular situation.

The single input screen simply consists of:

- Functional classification of the road (urban or rural collector)
- Two-way Annual Average Daily traffic
- The anticipated traffic growth
- The soil classification and/or soil modulus
- The aggregate base thickness
- The asphalt mixture modulus

It should be noted that in the case of low-volume roads, the perRoad 3.3 approach of using limiting strains would result in overly thick pavements because a low number of heavy vehicles such as garbage trucks and delivery vans would dictate the design [*1*]. Instead, the PerRoadXpress designs were determined by limiting the damage occurring over a 30-year period to a value of 0.1 or less (D=1.0 is the point of failure). The output of the required asphalt layer thickness appears on the same screen as the input.

Figure 2-6 shows a sample output of PerRoadXpress program.

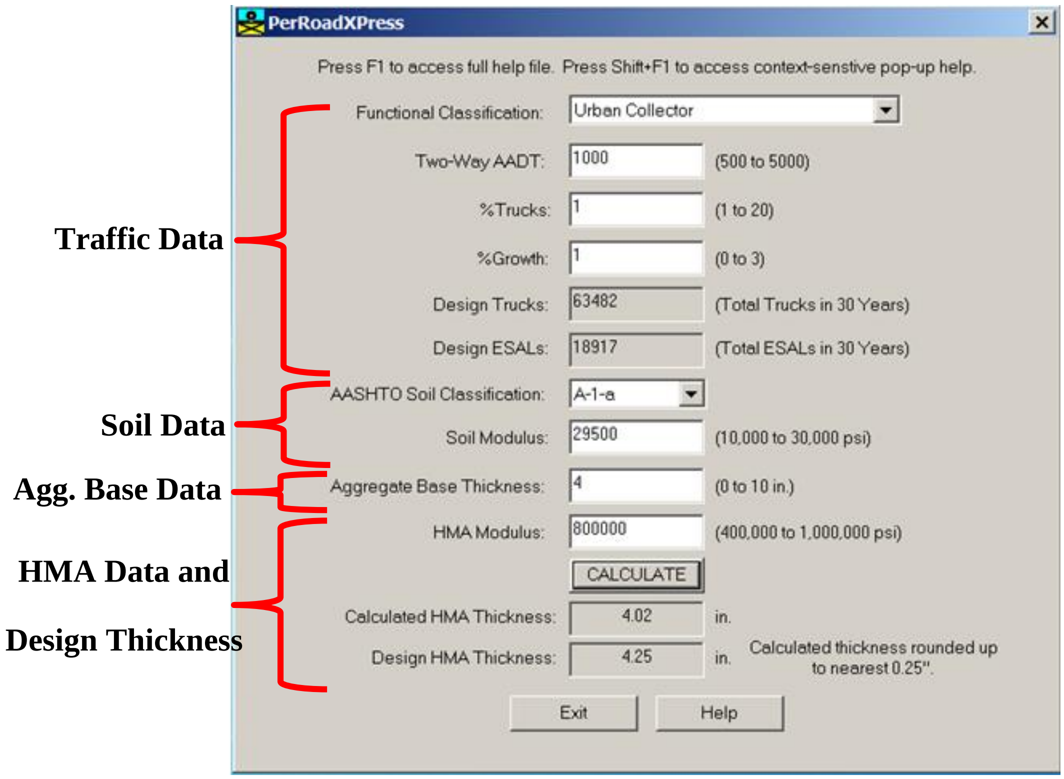

Figure 2-6 PerRoadXpress sample program output

CHAPTER 3: MINNESOTA AWARD WINNERS

In this chapter all the available information from the award winner roadways are gathered and summarized in the following sections. Information from the following sources were reviewed:

- Asphalt Pavement Alliance (APA) website (http://www.asphaltroads.org/)
- Minnesota Asphalt Pavement Association (MAPA) records on Minnesota's award winners
- MnDOT Highway Pavement Management Application (HPMA)
- MnDOT 2007 Roadway History files by District
- MnDOT Pavement Performance data
- Construction plans

Also, traffic analysis was performed on available Average Daily Traffic (ADT) and Heavy Commercial Annual Average Daily Traffic (HCAADT) data. The analysis included fitting the available AADT data with a compound growth function to estimate the traffic at any given time including the time of construction. The growth function is presented below:

$$ADT = ADT_0 \times (1 - {}^{r}/_{100})^{n-1}$$

where,

ADT_0 : traffic at the time of construction,
r : growth rate (%), and
n : number of years.

It should be noted that since the available traffic data were mostly from the current years (after 1990), the growth rates do not consider any likely bumps that have happened in traffic volumes prior to 1990, so the traffic volume at the time of construction (ADT_0) calculated from the present data should be over predicted in most of the cases and have been provided for informational purposes only in this report.

The following sections present the award winners information from 2002 to 2015. This information includes:

- The location of the roadway
- The construction history
- The mainline typical section at the time of construction
- Maintenance activities performed
- Available ADT data
- Available HCAADT data
- Calculated percentage of HCAADT for the available data
- Fitted compound growth function
- Calculated traffic at the time of construction (ADT_0) and the growth rate (r)
- Pavement performance data in the year of award and in 2015, including:

- Ride Quality Index (RQI) for assessing the pavement roughness, on a scale of 0 (very poor) to 5 (very good)
- Surface Rating (SR) for assessing pavement distresses, on a scale of 0 to 4
- Pavement Quality Index (PQI) which is the overall pavement quality on a scale of 0 to 4.5
- International Roughness Index (IRI) in inches per mile
- Average rut depth in inches

3.1 Interstate 35 (2002 winner)

This roadway is a 7-mile section of I-35 in Pine County, from the Willow River to the Carlton/Pine County Line (Figure 3-1 and Figure 3-2). It was built in 1966 by Minnesota Valley Improvement Company during the time when MnDOT was changing its road construction strategy, moving away from the use of thinner asphalt surface treatments to deep-strength asphalt pavement. Figure 3-3 shows I-35 mainline typical section available from 1964 construction plan. Figure 3-4 shows PQI versus time for this section.

Control Section: 5880

Reference Point (RP): 206+00.483 to 213+00.334

Construction history:

Year	State Project Number (SP)	Description
2011	5880-176	8 inches of concrete pavement from 211+00.534 to 213+00.334 (1.830 miles)
1998(1)	5880-159	3 inches mill and 4.5 inches overlay (with 15% RAP) – from 206+00.483 to 211+00.534 (5.051 miles)
1989(2)	5880-126	2 inches mill and 3.5 inches overlay (with 20% RAP) – from 206+00.483 to 211+00.534 (5.051 miles)
1967	5880-62	- 4 inches HMA surface - 4 inches plant-mixed bituminous base - 4 inches bituminous treated gravel base
1966	5880-49	- 12 inches select granular subbase with the upper 3 inches treated with bituminous material - subgrade corrections up to 3 feet, backfilled with granular material from adjacent cuts

(1)9 years after the first overlay
(2)22 years after the initial construction

Other information in 2002:

- Total HMA thickness in 2002: 11 inches
- Traffic load to date of 4.2 million ESALs
- Pavement performance data:
    - RQI= 4.2 (very good)
    - SR= 3.6 (very good)
    - PQI= 3.9 (good)
    - IRI= 38 inches/mile
    - Average rut depth= 0.2 inches

Pavement performance data in 2015:

- RQI= 3.0 (fair)
- SR= 3.4 (good)
- PQI= 3.2 (good)
- IRI= 103 inches/mile
- Rut depth= 0.1 inches

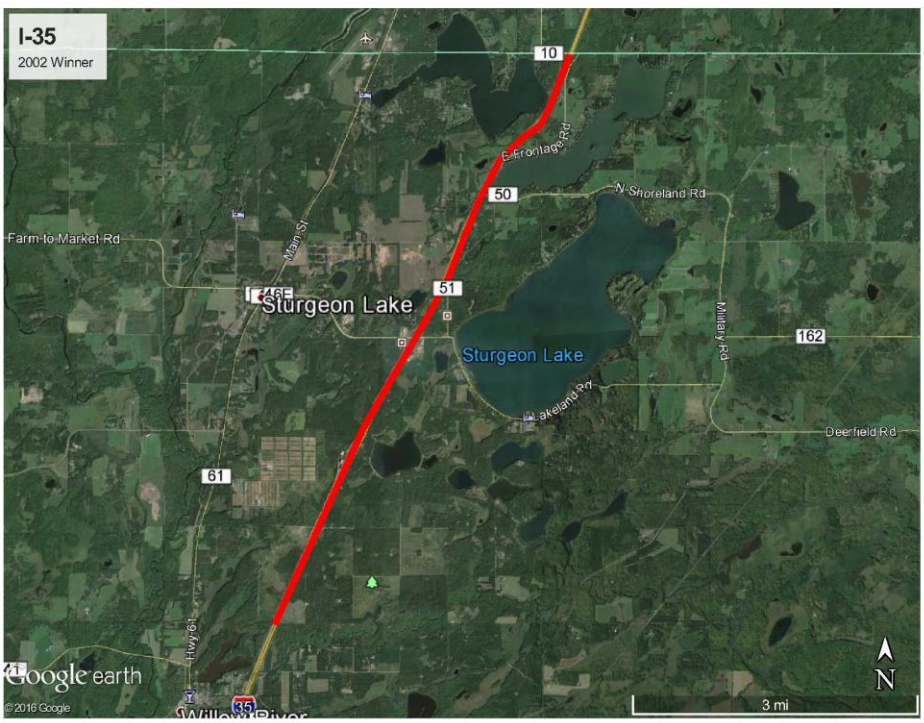

Figure 3-1 I-35 from Willow River to Carlton/Pine County Line

Figure 3-2 I-35 in Pine County

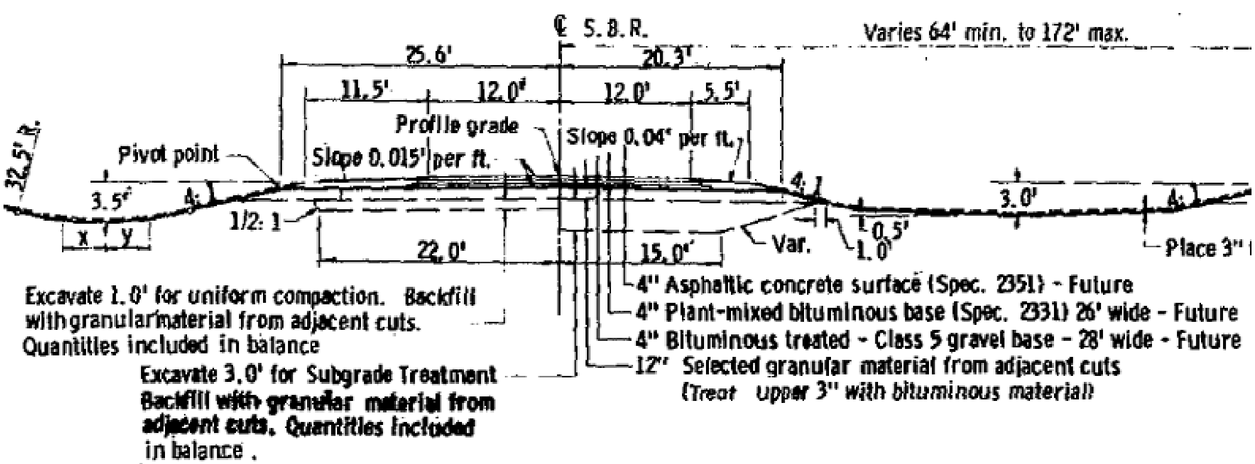

Figure 3-3 I-35 mainline typical section (1964 construction plan)

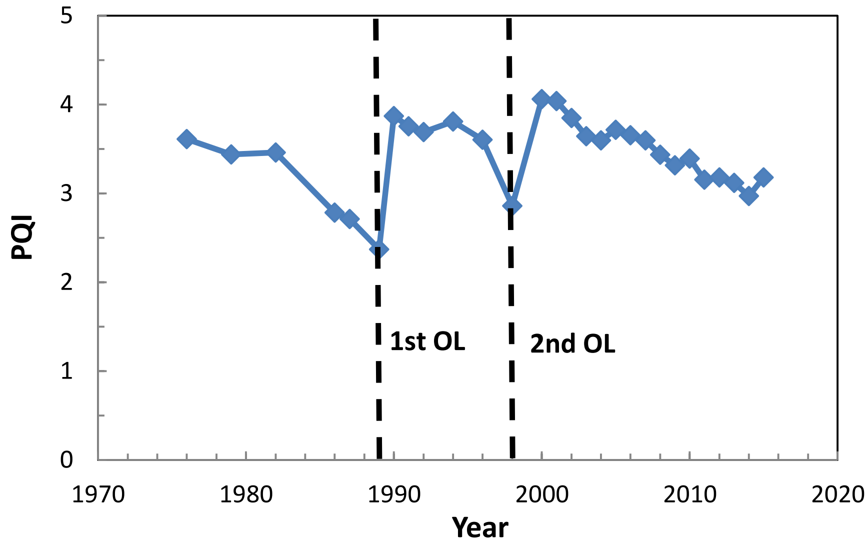

Figure 3-4 PQI vs. year for I-35

3.1.1 <u>I-35 Traffic Analysis</u>

Figure 3-5 shows ADT vs. year for the available I-35 traffic data as well as the best-fit line using compound growth model. Using the model, the traffic in 1966 was calculated to be approximately 10,100 ADT with an increase rate of 0.96%. Figure 3-6 and Figure 3-7 present HCAADT and HCAADT%, respectively. The average HCAADT% was 8.5% from 1994 to 2012.

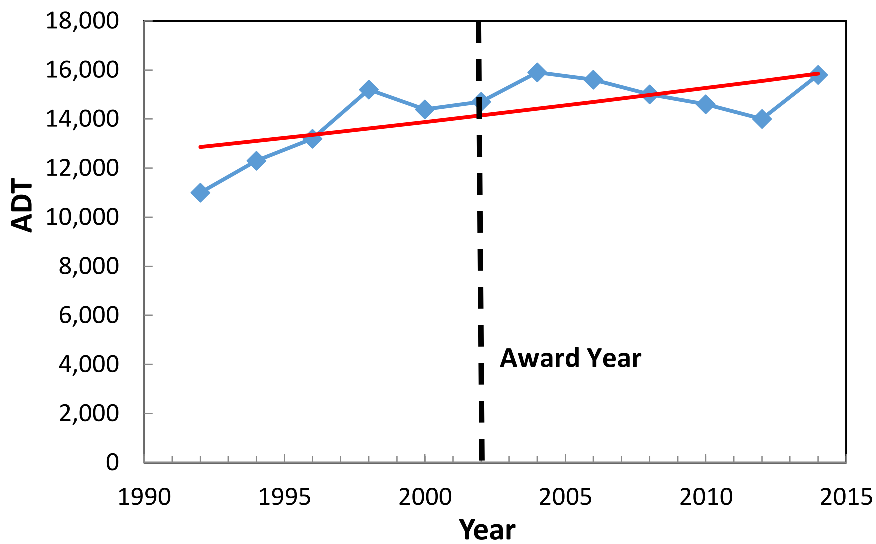

Figure 3-5 ADT vs. year and compound growth fit for I-35

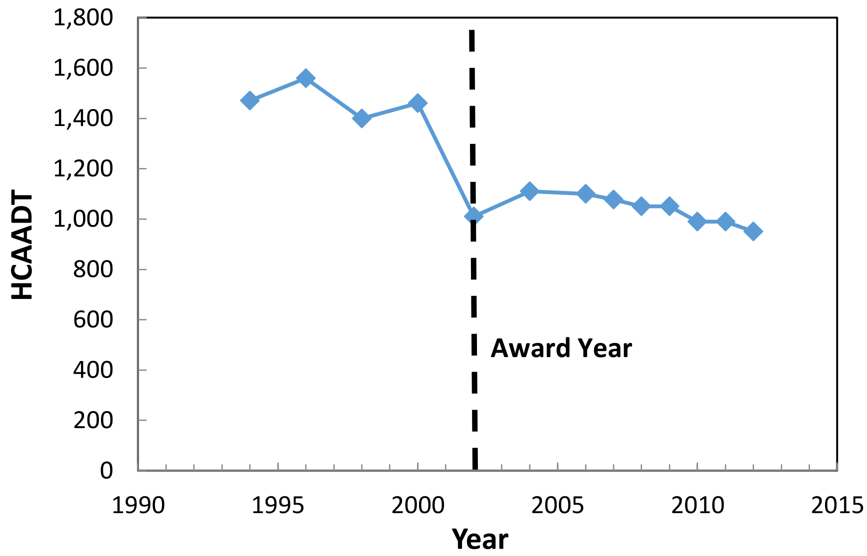

Figure 3-6 HCAADT vs. year for I-35

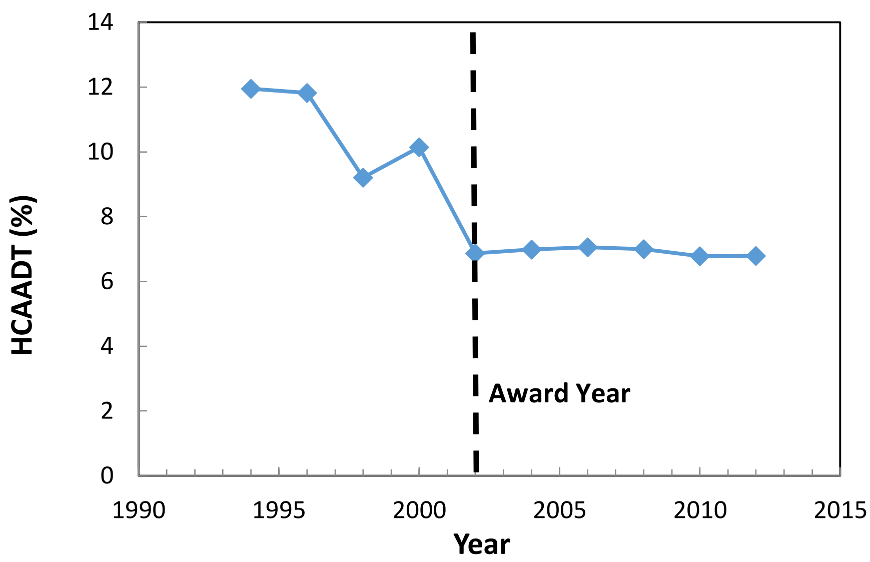

Figure 3-7 HCAADT (%) vs. year for I-35

3.2 Trunk Highway 71 (2003 winner)

The 2003 award winner is a 9-mile section of TH 71 from the South Hubbard County Line to Park Rapids (Figure 3-8 and Figure 3-9). It was built in 1960 by Duininck Brothers/Gilchrist Company. Some subgrade corrections; excavation and backfilling with select granular material was performed. Initial construction also included a 1.5 inch road-mixed bituminous surface over the aggregate base. Figure 3-10 shows TH 71 mainline typical section available from 1959 construction plan. Figure 3-11 shows PQI versus time for this section.

Control Section: 2904

Reference Point (RP): 251+00.366 to 260+00.660

Construction history:

Year	State Project Number (SP)	Description
2009	2904-16	full depth reclamation (FDR) with 6 inches overlay
1998	2904-13	chip seal
1994[1]	2904-12	1.5 inches overlay
1964	2904-09	3 inches plant-mixed bituminous surface
1960	2904-08	- 1.5 inches road-mixed bituminous surface - 4.5 inches of aggregate base - some subgrade corrections; excavation and backfilling with select granular material

[1]30 years after the initial construction

Other information in 2003:

- Total HMA thickness: 6 inches
- Traffic load to date: 2 million ESALs
- Pavement performance data:
    - RQI= 3.2 (very good)
    - SR= 3.1 (good)
    - PQI= 3.1 (good)
    - IRI= 101 inches/mile
    - Average rut depth= 0.2 inches

Pavement performance data in 2015:

- RQI= 3.8 (good)
- SR= 3.8 (very good)
- PQI= 3.8 (good)
- IRI= 54 inches/mile
- Rut depth= 0.2 inches

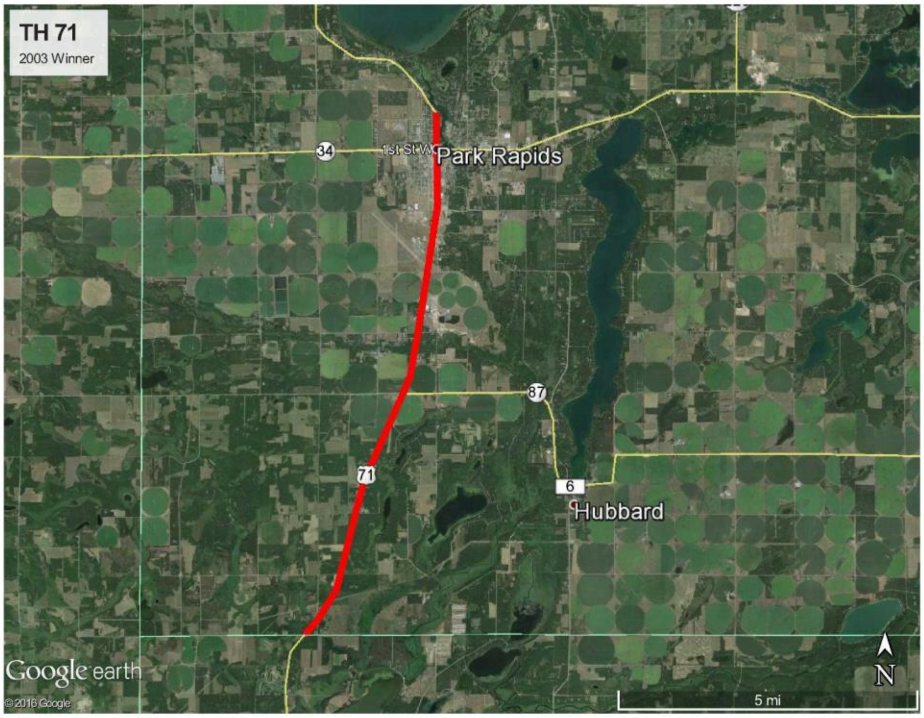

Figure 3-8 TH 71 from South Hubbard County Line to Park Rapids

Figure 3-9 TH 71 in Hubbard County

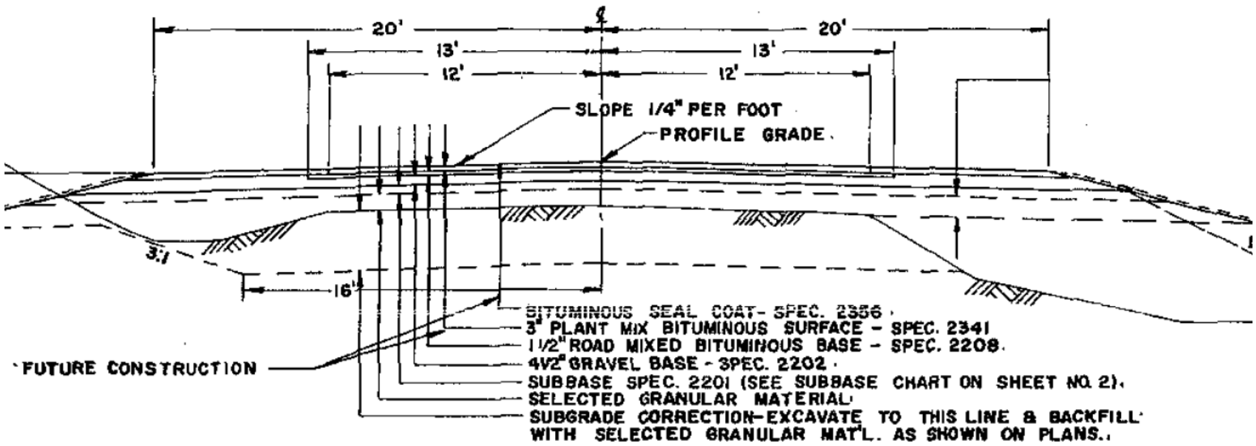

Figure 3-10 TH 71 mainline typical section (1959 construction plan)

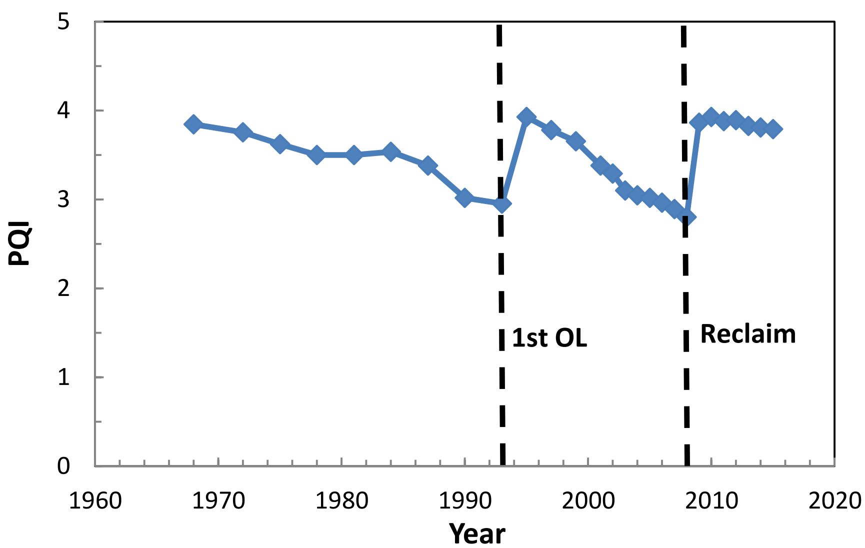

Figure 3-11 PQI vs. year for TH 71

3.2.1 TH 71 Traffic Analysis

Figure 3-12 shows ADT vs. year for the available TH 71 traffic data as well as the best-fit line using the compound growth model. Using the model, the traffic in 1964 was approximately 5,300 ADT with an increase rate of 0.71%. Figure 3-13 and Figure 3-14 present HCAADT and HCAADT%, respectively. The average HCAADT% was 7.8% from 1994 to 2012.

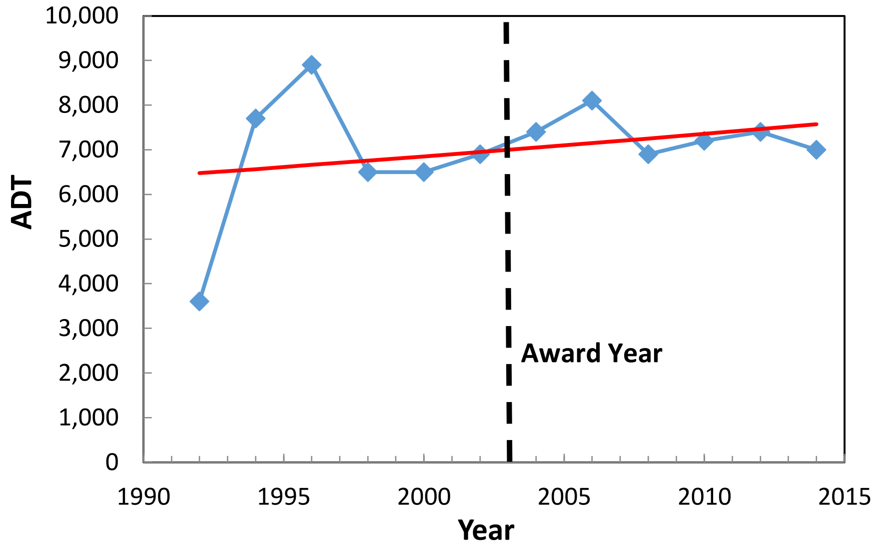

Figure 3-12 ADT vs. year and compound growth fit for TH 71

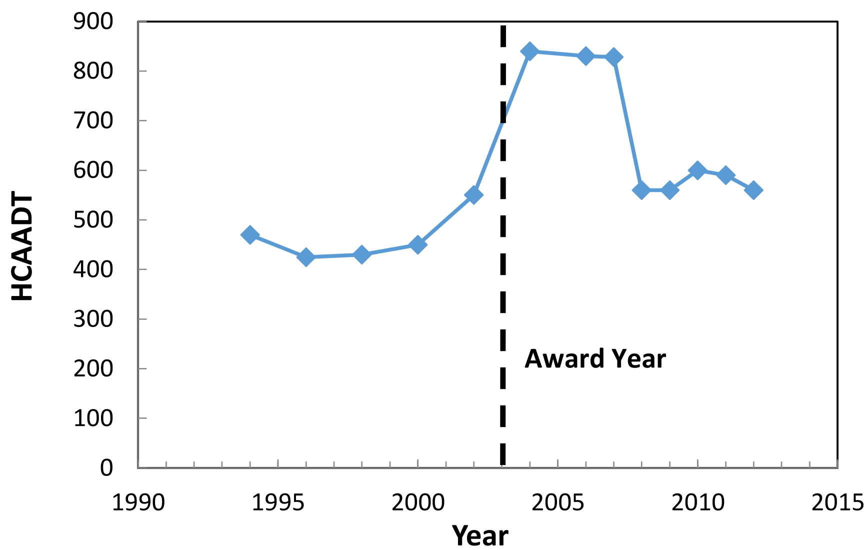

Figure 3-13 HCAADT vs. year for TH 71

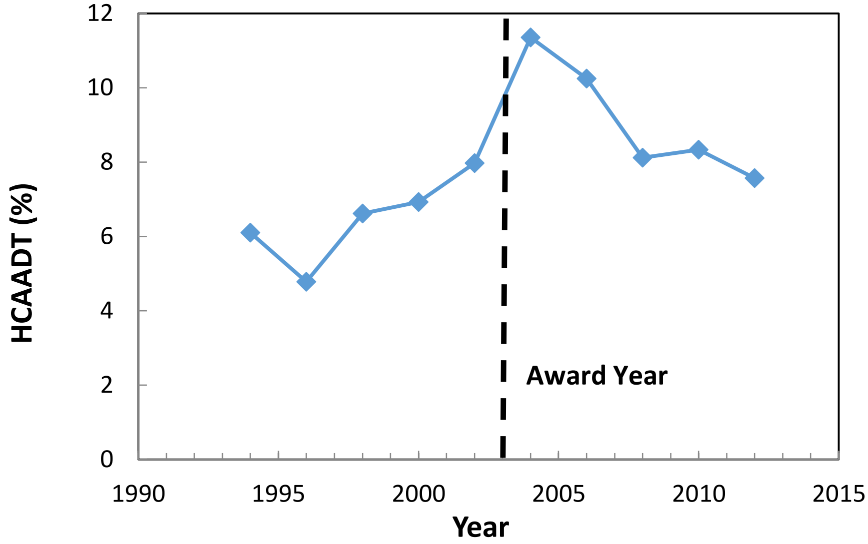

Figure 3-14 HCAADT (%) vs. year for TH 71

3.3 Trunk Highway 10 (2004 winner)

This section is a 3-mile section of TH 10 in Anoka County (Figure 3-15 and Figure 3-16). There was one swamp section on this alignment, approximately 400 feet in length, containing a maximum depth of 7 feet of unstable organic material which was excavated and filled with uniform select granular material. Figure 3-17 shows TH 10 mainline typical section available from 1964 construction plan. Figure 3-18 shows PQI versus time for this section.

Control Section: 0215

Reference Point (RP): 224+00.015 to 227+00.898

Construction history:

Year	State Project Number (SP)	Description
2013[1]	0202-94	5/8 inches ultrathin bonded wearing course (UTBWC)
2013[1]	0215-74	2 inches mill and 2 inches overlay
1994[2]	0215-47	2 inches mill and 3.5 inches overlay
1978[3]	0215-29	3/4 inches overlay
1966	0215-08 0215-09 0215-10	- 1 inch of bituminous wearing course - 3 inches of bituminous binder course - 3 inches of plant-mixed bituminous base - 6 inches of aggregate base - 18 inches of select granular subbase, upper 3 inches treated with bituminous - limited subgrade correction, excavation and backfilling with select granular material

(1)19 years after the second overlay
(2)16 years after the first overlay
(3)12 years after the initial construction

Other information in 2004:

- Total HMA thickness: 9.25 inches
- Traffic load to date: 13.5 million ESALs
- Pavement performance data:
    - RQI= 3.4 (good)
    - SR= 3.6 (very good) –from 2003 data
    - PQI= 3.5 (good)
    - IRI= 79 inches/mile
    - Average rut depth= 0.1 inches

Pavement performance data in 2015:

- RQI= 3.8 (good)
- SR= 3.9 (very good)
- PQI= 3.8 (good)
- IRI= 61 inches/mile
- Rut depth= 0.1 inches

Figure 3-15 TH 10 in Anoka County

Figure 3-16 TH 10 in Anoka County

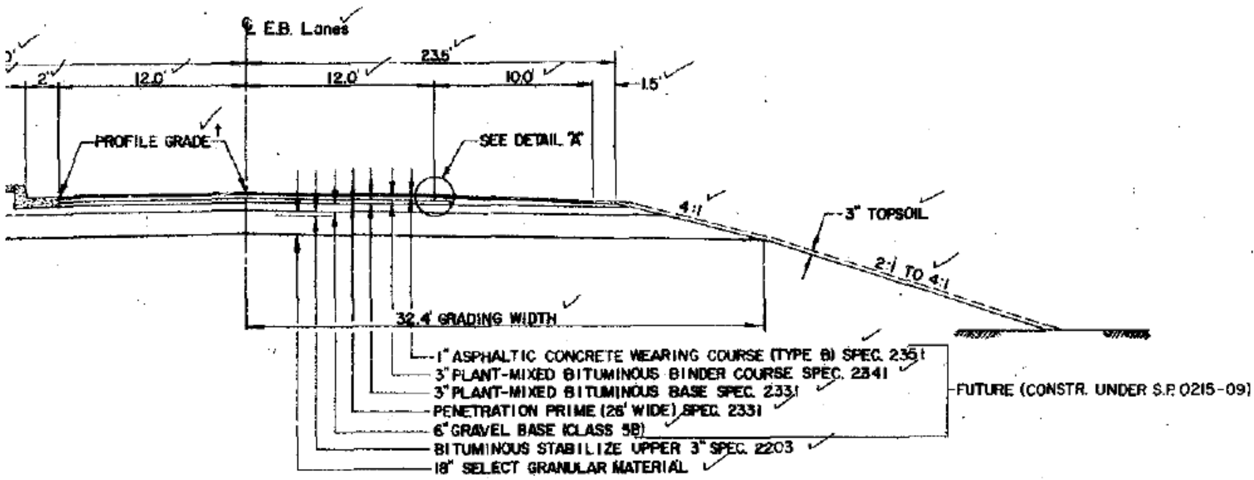

Figure 3-17 TH 10 mainline typical section (1964 construction plan)

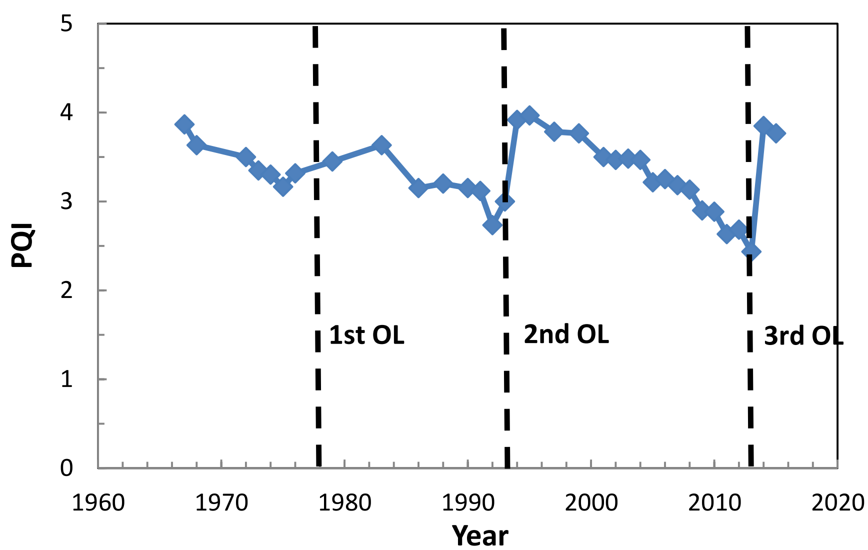

Figure 3-18 PQI vs. year for TH 10

3.3.1 TH 10 Traffic Analysis

Figure 3-12 shows ADT vs. year for the available TH 10 traffic data as well as the best-fit line using the compound growth model. Using the model, the traffic in 1966 was approximately 52,500 ADT with an increase rate of 0.66%. Figure 3-13 and Figure 3-14 present HCAADT and HCAADT%, respectively. The average HCAADT% was 4.7% from 1998 to 2012.

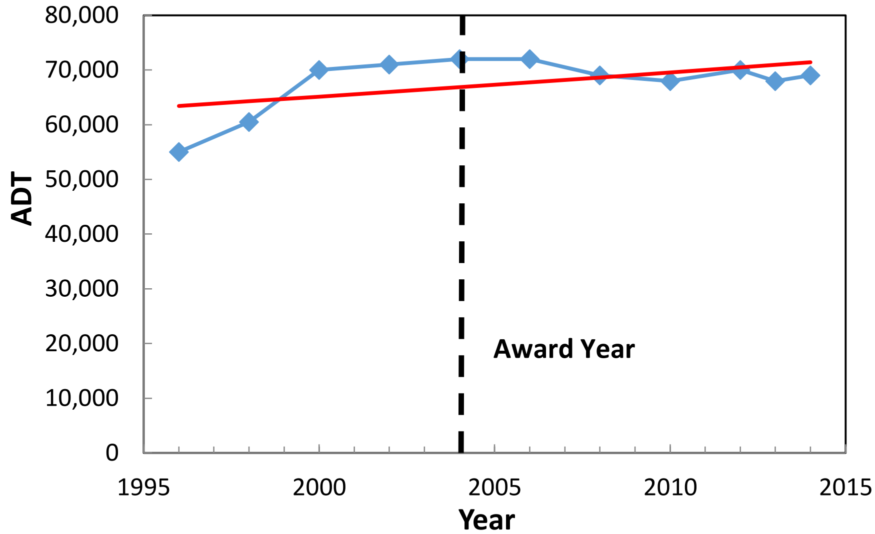

Figure 3-19 ADT vs. year and compound growth fit for TH 10

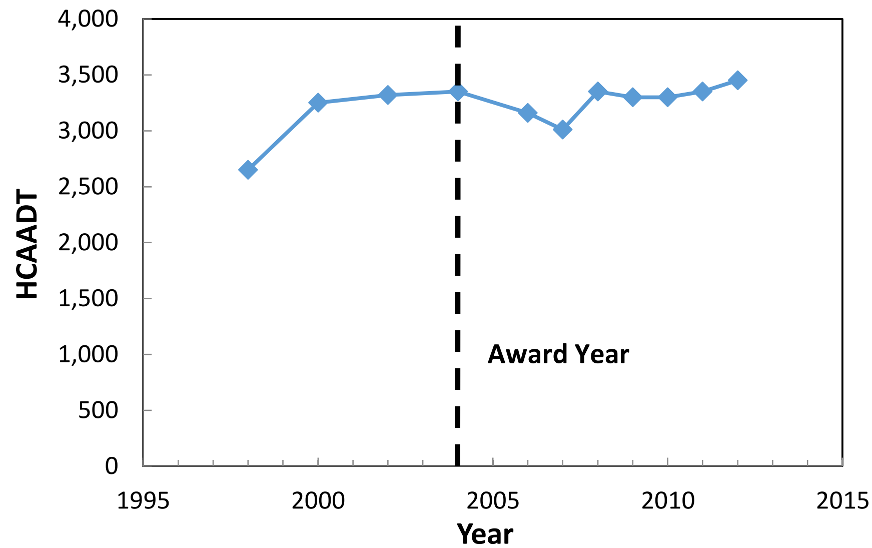

Figure 3-20 HCAADT vs. year for TH 10

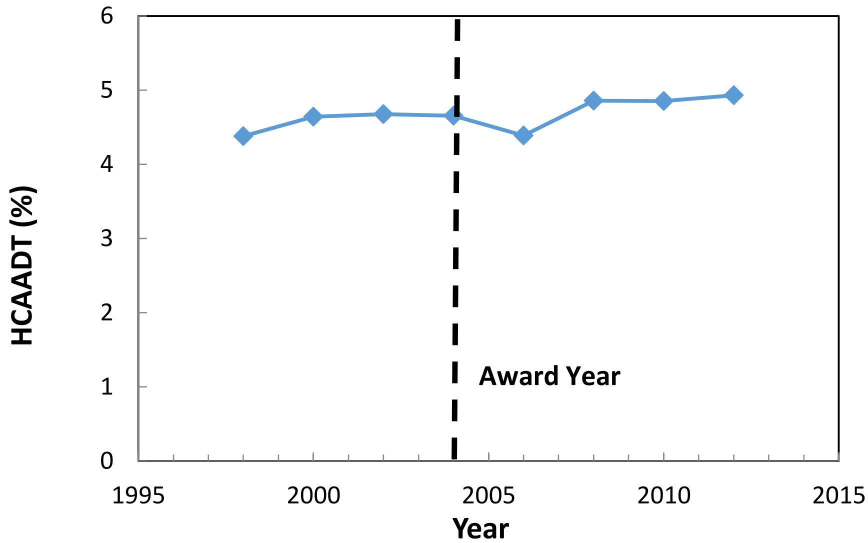

Figure 3-21 HCAADT (%) vs. year for TH 10

3.4 Trunk Highway 18 (2005 Winner)

This section is an 18-mile stretch of TH 18 between Brainerd and Garrison in Crow County (Figure 3-22 and Figure 3-24). In this section swamp areas were cut and filled with select granular material. Also, because of existence high water table, the road was built with a frost-free design to help facilitate drainage. It was built in 1958 by W. Hodgman & Sons Inc. Figure 3-24 shows TH 18 mainline typical section available from 1955 construction plan. Figure 3-25 shows PQI versus time for this section.

Construction of this section was staged over a year, so the subgrade moisture content reaches equilibrium. This allowed the foundation to go through settling in the cycle of seasons and enhanced the overall pavement structure stability. Initial construction also included a 1.5 inch road-mixed bituminous surface over gravel base.

Control Section: 1803

Reference Point (RP): 002+00.327 to 020+00.502

Construction history:

Year	State Project Number (SP)	Description
2006[1]	1803-35	2 inches mill and 3.5 inches overlay
1993[2]	1803-32	1.5 inches overlay
1982[3]	1803-24	2.5 inches overlay
1967	N/A	seal coat
1959	1803-15	3 inches of surface HMA
1958	1803-08	- 1.5 inches of road-mixed bituminous base - 4.5 inches of gravel base - 10 inches of select granular subbase - subgrade correction, excavation and backfilling with select granular material

[1]13 years after the second overlay
[2]11 years after the first overlay
[3]23 years after the initial construction

Other information in 2005:

- Total HMA thickness: 8.5 inches
- Traffic load to date: 1 million ESALs
- Pavement performance data:
  - RQI= 3.0 (fair)
  - SR= 2.9 (fair) – from 2004 data
  - PQI= 3.0 (fair)
  - IRI= 109 inches/mile
  - Average rut depth= 0.2 inches

Pavement performance data in 2015:

- RQI= 3.8 (good)
- SR= 3.5 (good) – from 2014 data
- PQI= 3.6 (good)
- IRI= 56 inches/mile
- Rut depth= 0.1 inches

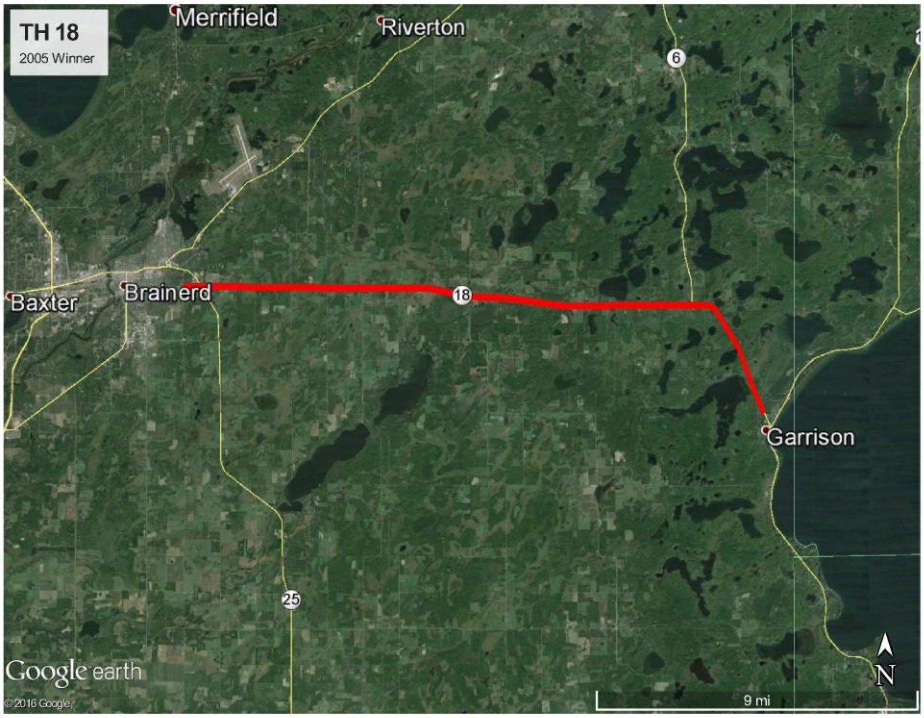

Figure 3-22 TH 18 from Brainerd to Garrison

Figure 3-23 TH 18 in Crow Wing County

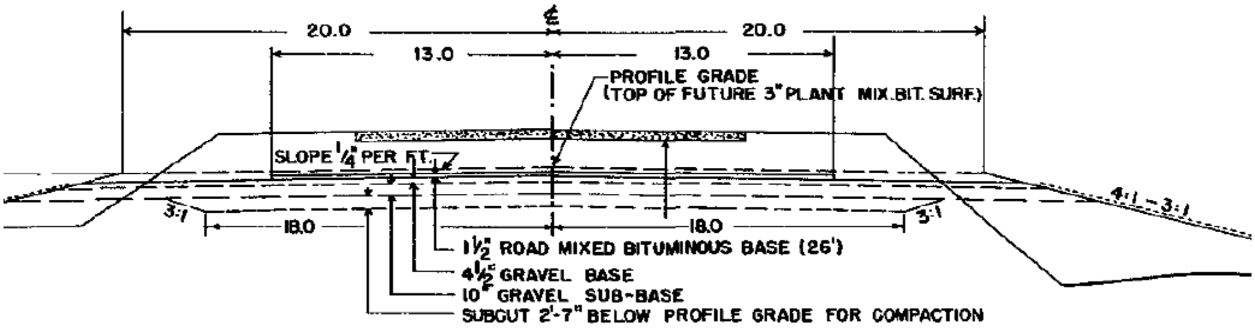

Figure 3-24 TH 18 mainline typical section (1955 construction plan)

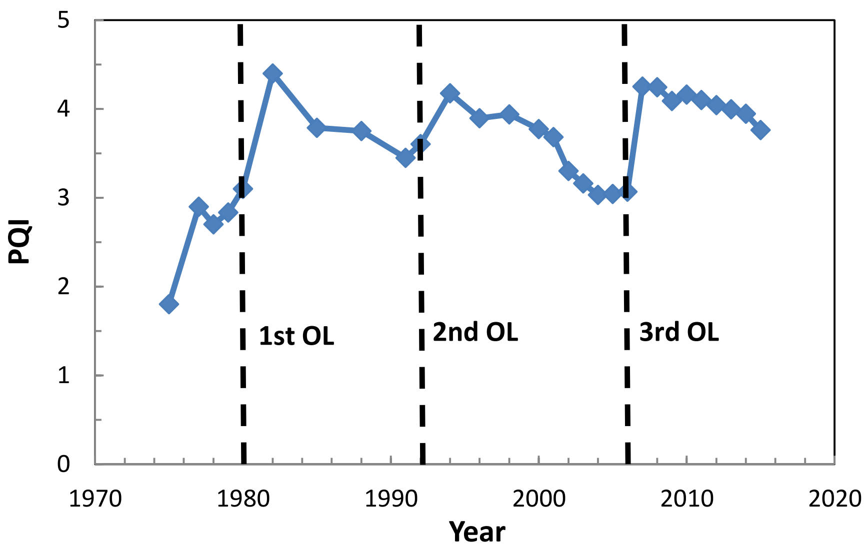

Figure 3-25 PQI vs. year for TH 18

3.4.1 <u>TH 18 Traffic Analysis</u>

Figure 3-26 shows ADT vs. year for the available TH 18 traffic data as well as the best-fit line using the compound growth model. Using the model, the traffic in 1959 was approximately 5,500 ADT with an increase rate of 0.69%. Figure 3-27 and Figure 3-28 present HCAADT and HCAADT%, respectively. The average HCAADT% was 4.8% from 1994 to 2011.

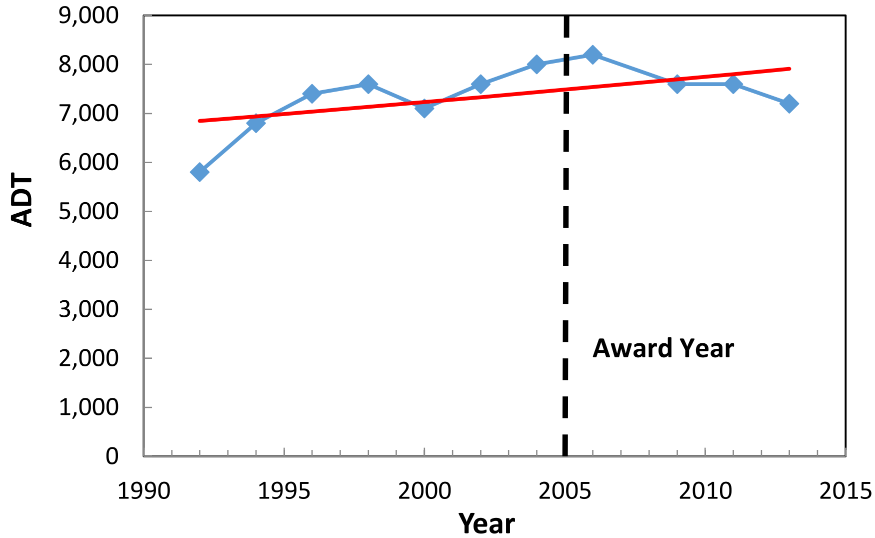

Figure 3-26 ADT vs. year and compound growth fit for TH 18

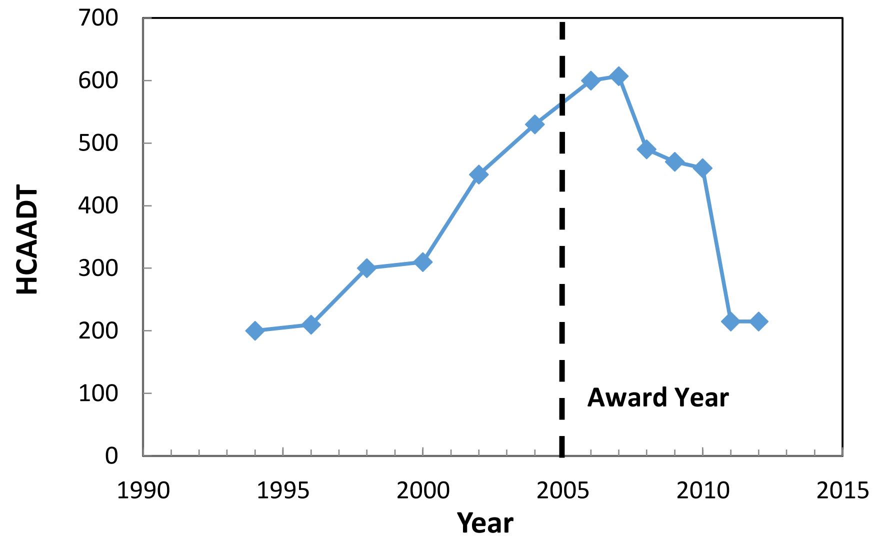

Figure 3-27 HCAADT vs. year for TH 18

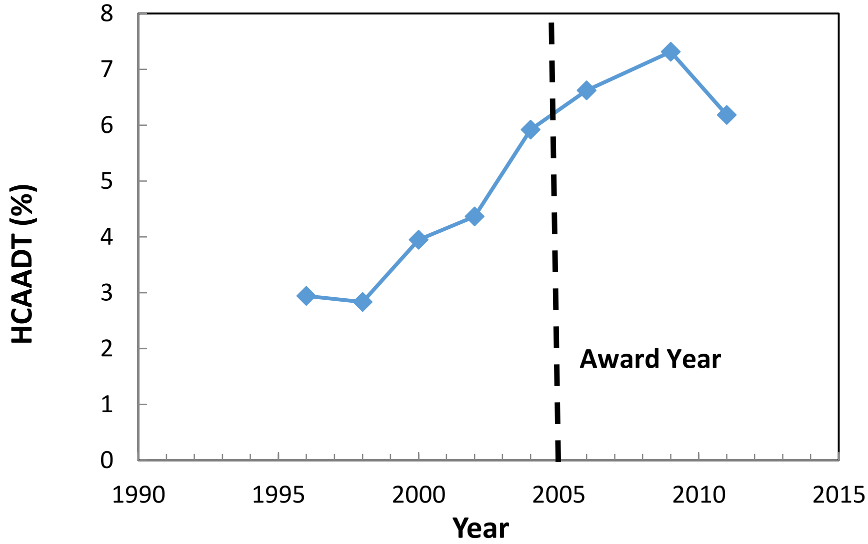

Figure 3-28 HCAADT (%) vs. year for TH 18

3.5 Trunk Highway 61 (2006 Winner)

This section is an 8-mile stretch of TH 61 south bound extended between Wabasha and Kellogg in Wabasha County (Figure 3-29 and Figure 3-30). The initial construction began in 1969 and was completed 3 years later. This staging construction allowed the foundation to go through seasonal cycles which enhanced the overall pavement structural stability. A select granular backfill material was used to create a drainable, strong construction platform to pave against. Also, using a thin HMA overlay has prolonged the service of the roadway. Figure 3-31 shows TH 61 mainline typical section available from 1969 construction plan. Figure 3-37 shows PQI versus time for this section.

Control Section: 7905

Reference Point (RP): 053+00.979 to 061+00.868

Construction history:

Year	State Project Number (SP)	Description
2006	8826-51	chip seal
2000[1]	7905-19	1.5 inches mill and 3 inches overlay
1988[2]	7905-15	2 inches overlay
1973	7905-08	3 inches of plant-mixed asphalt wearing course
1969	7905-06	- 2 inches of plant-mixed asphalt binder course - 6 inches of aggregate base - 12 inches of select granular subbase - some subgrade corrections

(1)12 years after the first overlay
(2)15 years after the initial construction

Other information in 2006:

- Total HMA thickness: 8.5 inches
- Traffic load to date: 3 million ESALs
- Pavement performance data:
    - RQI= 3.8 (good)
    - SR= 3.6 (very good) – from 2005 data
    - PQI= 3.7 (good)
    - IRI= 56 inches/mile
    - Average rut depth= 0.3 inches

Pavement performance data in 2015:

- RQI= 3.0 (fair)
- SR= 3.2 (good)
- PQI= 3.1 (good)
- IRI= 96 inches/mile
- Rut depth= 0.2 inches

Figure 3-29 TH 61 from Wabasha to Kellogg

Figure 3-30 TH 61 in Wabasha County

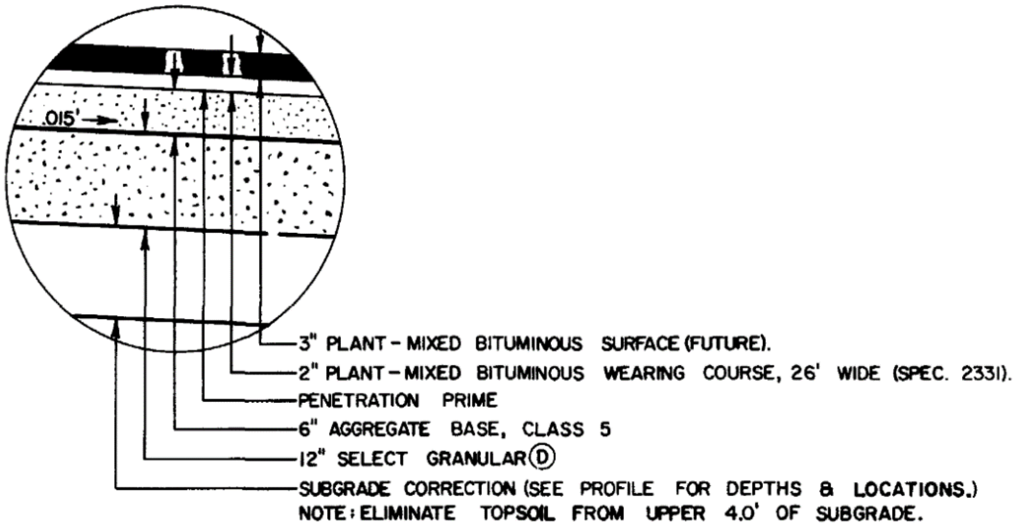

Figure 3-31 TH 61 mainline typical section (1969 construction plan)

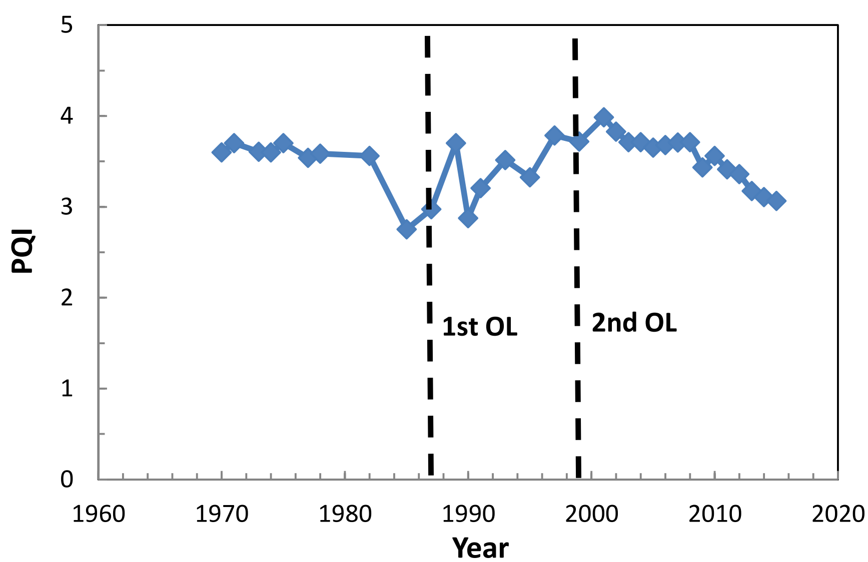

Figure 3-32 PQI vs. year for TH 61

3.5.1 <u>TH 61 Traffic Analysis</u>

Figure 3-33 shows ADT vs. year for the available TH 61 traffic data as well as the best-fit line using the compound growth model. Using the model, the traffic in 1969 was approximately

5,300 ADT with an increase rate of 0.38%. Figure 3-34 and Figure 3-35 present HCAADT and HCAADT%, respectively. The average HCAADT% was 10.7% from 1994 to 2012.

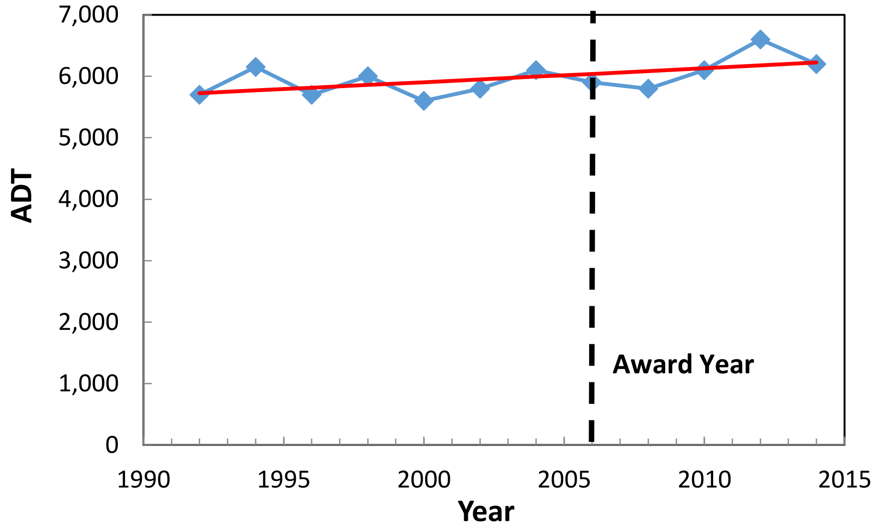

Figure 3-33 ADT vs. year and compound growth fit for TH 61

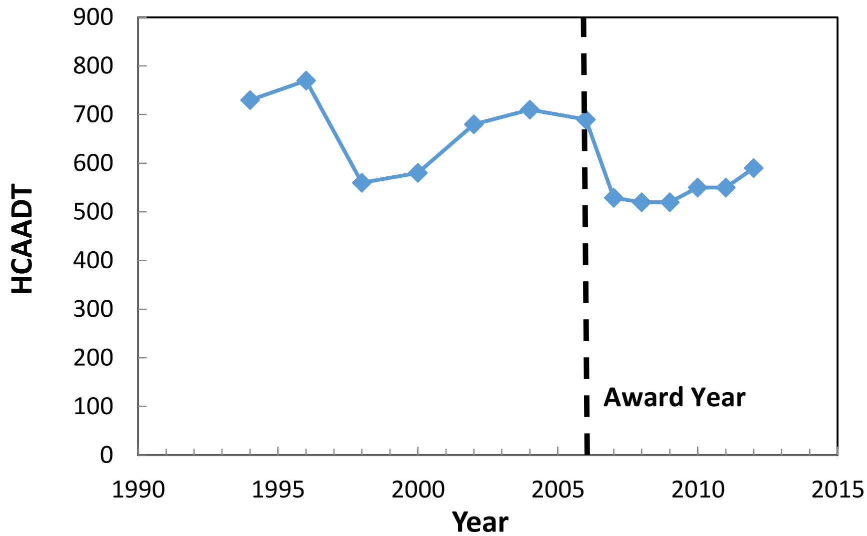

Figure 3-34 HCAADT vs. year for TH 61

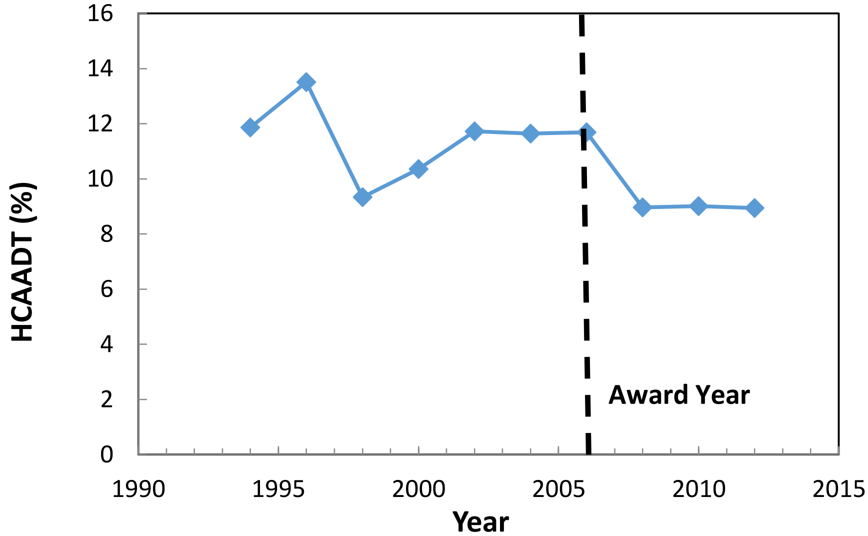

Figure 3-35 HCAADT (%) vs. year for TH 61

3.6 Trunk Highway 71 (2007 Winner)

This is a 6-mile section of TH 71 from Highway 9 near New London north to the Stearns County line (Figure 3-36 and Figure 3-37). The initial construction was completed in 1970. During the construction of this section, a subgrade correction was made to the upper four feet to eliminate topsoil and to increase the uniformity of compacted materials. A select granular backfill material, which was stabilized in some places, was then used to create a drainable, strong construction platform to pave on. Initial construction also included a 1 inch road-mixed bituminous surface over the aggregate base. Figure 3-36 shows TH 71 mainline typical section available from 1967 construction plan. Figure 3-39 shows PQI versus time for this section.

Control Section: 3414

Reference Point (RP): 138+00.732 to 144+00.273

Construction history:

Year	State Project Number (SP)	Description
2013	8828-143	chip seal and fog seal
2005[1]	3414-14	2 inches mill and 4 inches overlay
1991[2]	3414-13	1.5 inches overlay
1967	3414-09	- 1.5 inches of plant-mixed bituminous wearing course - 1.5 inches of plant-mixed bituminous binder course - 1 inch of road-mixed bituminous base course - 5 inches of aggregate base - 12 inches of select granular subbase - subgrade corrections in the upper 4 feet

[1]14 years after the first overlay
[2]22 years after the initial construction

Other information in 2007:

- Total HMA thickness: 6.5 inches
- Traffic load to date: 2 million ESALs
- Pavement performance data:
    - RQI= 3.9 (good)
    - SR= 3.8 (very good) – from 2006 data
    - PQI= 3.8 (good)
    - IRI= 51 inches/mile
    - Average rut depth= 0.1 inches

Pavement performance data in 2015:

- RQI= 3.4 (good)
- SR= 3.3 (good) – from 2014 data
- PQI= 3.3 (good)
- IRI= 79 inches/mile
- Rut depth= 0.1 inches

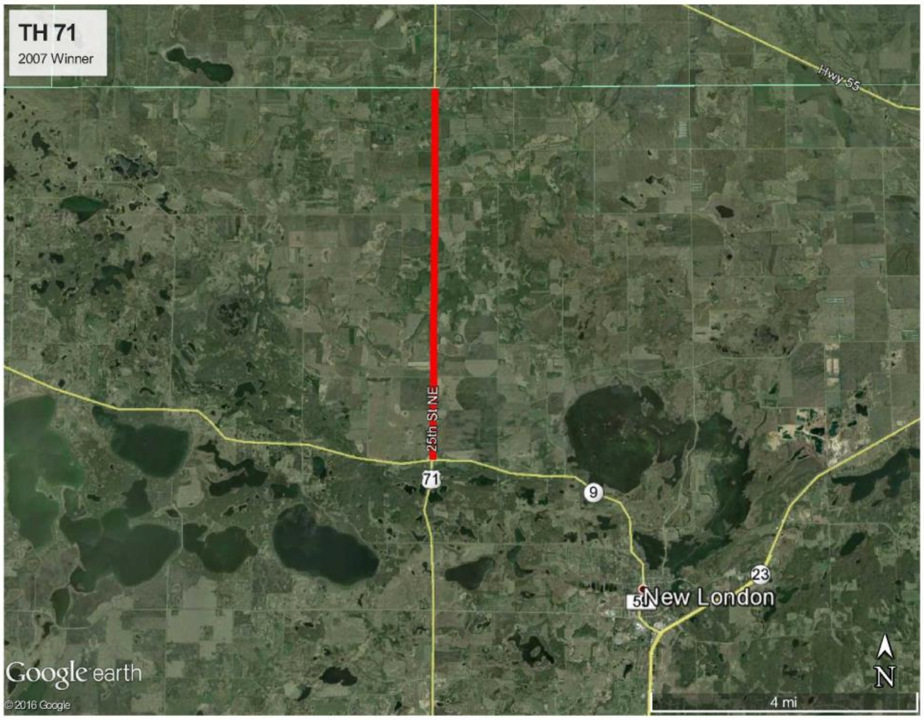

Figure 3-36 TH 71 from near New London north to Stearns County Line

Figure 3-37 TH 71 in Kandiyohi County

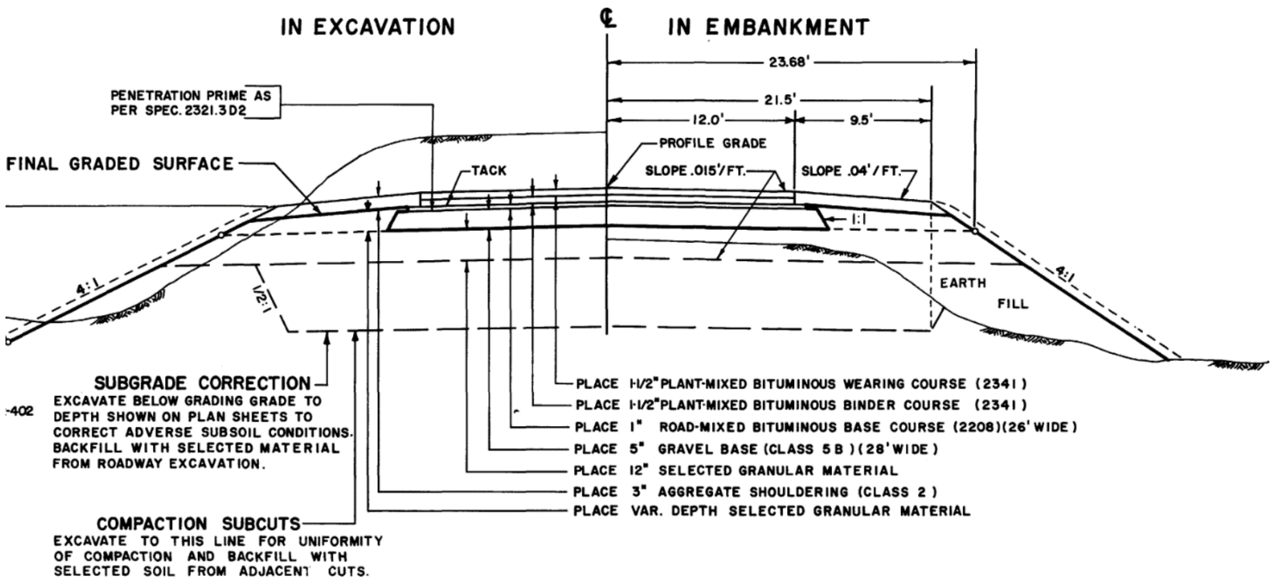

Figure 3-38 TH 71 mainline typical section (1967 construction plan)

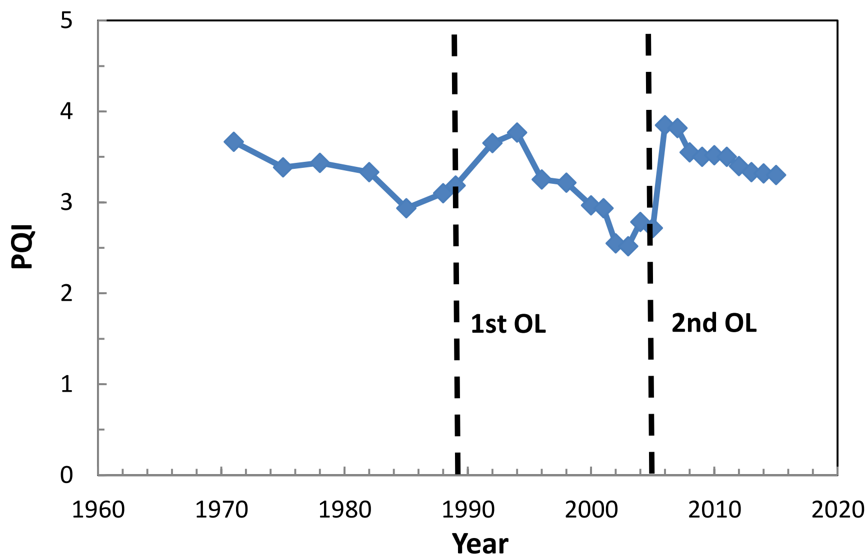

Figure 3-39 PQI vs. year for TH 71

3.6.1 TH 71 Traffic Analysis

Figure 3-40 shows ADT vs. year for the available TH 71 traffic data as well as the best-fit line using the compound growth model. Using the model, the traffic in 1970 was approximately

2,600 ADT with an increase rate of 0.90%. Figure 3-41 and Figure 3-42 present HCAADT and HCAADT%, respectively. The average HCAADT% was 13.1% from 1994 to 2012.

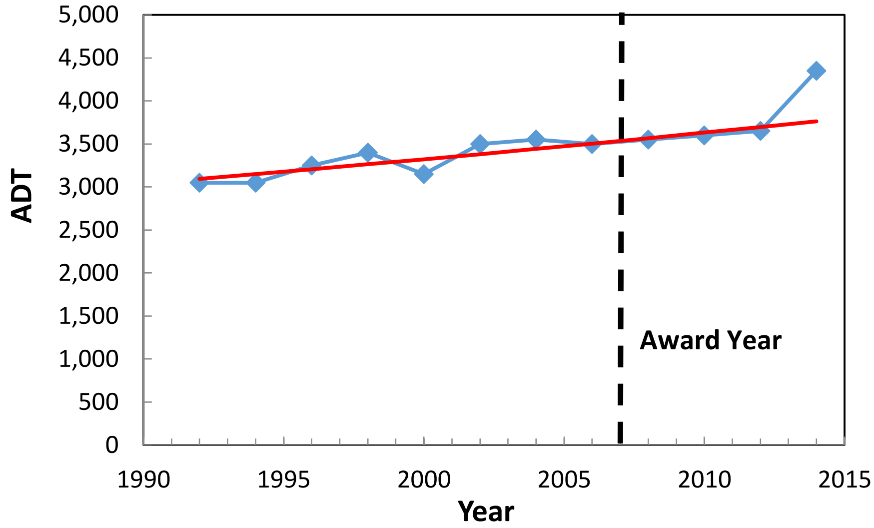

Figure 3-40 ADT vs. year and compound growth fit for TH 71

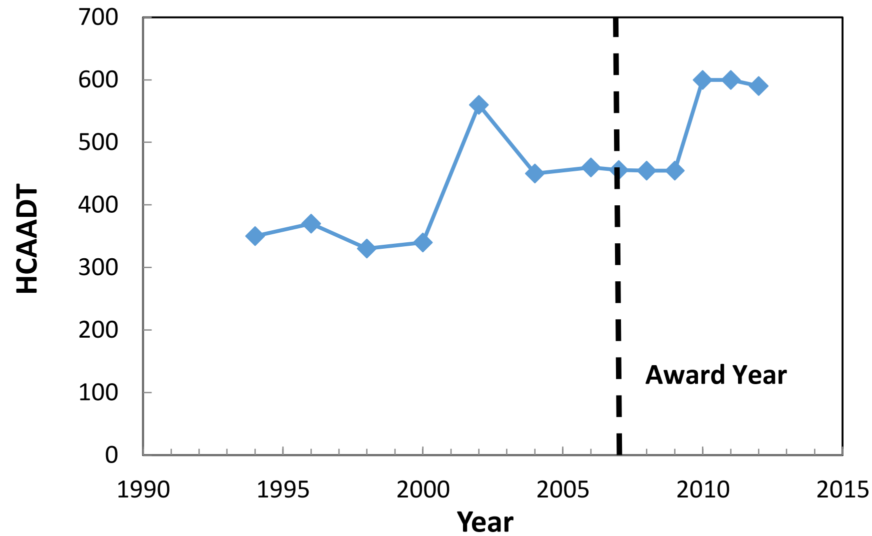

Figure 3-41 HCAADT vs. year for TH 71

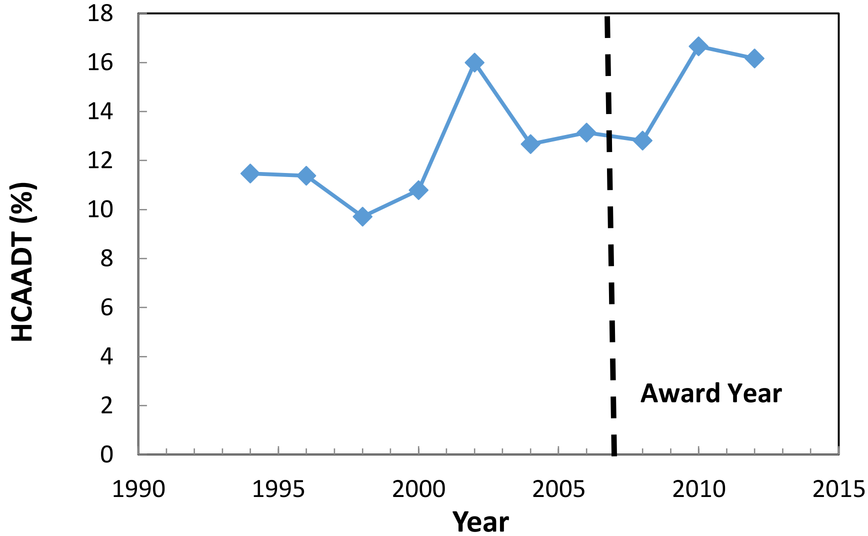

Figure 3-42 HCAADT (%) vs. year for TH 71

3.7 Trunk Highway 36 (2008 Winner)

This is a 2-mile section of TH 36 south of Stillwater in Washington County (Figure 3-43 and Figure 3-44). The initial construction was completed in 1960. During the construction of this section, one to three feet of unsuitable material was excavated and adverse subsoil conditions were corrected which led to an increase in the uniformity of compacted materials. A select granular backfill material was then used to create a drainable, strong construction platform to pave against. Initial construction also included a 1 inch road-mixed bituminous surface over the aggregate base. Figure 3-45 shows TH 36 mainline typical section available from 1958 construction plan. Figure 3-46 shows PQI versus time for this section.

Control Section: 8214

Reference Point (RP): 202+00.120 to 204+00.290

Construction history:

Year	State Project Number (SP)	Description
2015	8214-114	reconstruction as a part of St. Croix Crossing project: - 4 inches wear course mixture - 2.5 inches non-wear course mixture - 6 inches of aggregate base - 12 inches of select granular subbase - 36 inches of granular material
2008	8825-282	microsurfacing
2000[(1)]	8214-133	1.5 inches mill and 1.5 inches overlay
1987[(2)]	8214-97	1.5 inches mill and 1.5 inches overlay
1960	8214-13	- 1.5 inches of plant-mixed bituminous wearing course - 1.5 inches of plant-mixed bituminous binder course - 1 inch of road-mixed bituminous base course - 12 to 20 inches of aggregate base - 12 to 36 inches of select granular subbase - subgrade corrections in the upper one to three feet

[(1)]13 years after the first overlay
[(2)]27 years after the initial construction

Other information in 2008:

- Total HMA thickness: 4 inches
- Traffic load to date: 13.5 million ESALs
- Pavement performance data:
  - RQI= 3.3 (good)
  - SR= 3.3 (good) – from 2007 data
  - PQI= 3.2 (good)
  - IRI= 87 inches/mile
  - Average rut depth= 0.3 inches

Pavement performance data in 2015:

- RQI= 3.4 (good)
- SR= 3.9 (very good)
- PQI= 3.6 (good)
- IRI= 81 inches/mile
- Rut depth= 0.1 inches

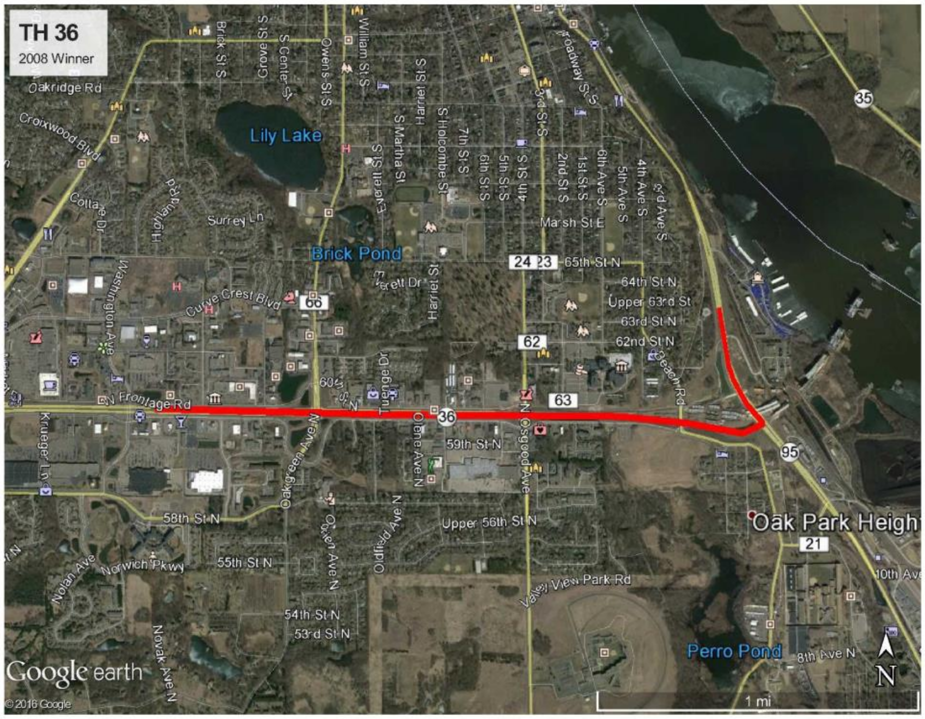

Figure 3-43 TH 36 south of Stillwater

Figure 3-44 TH 36 in Washington County

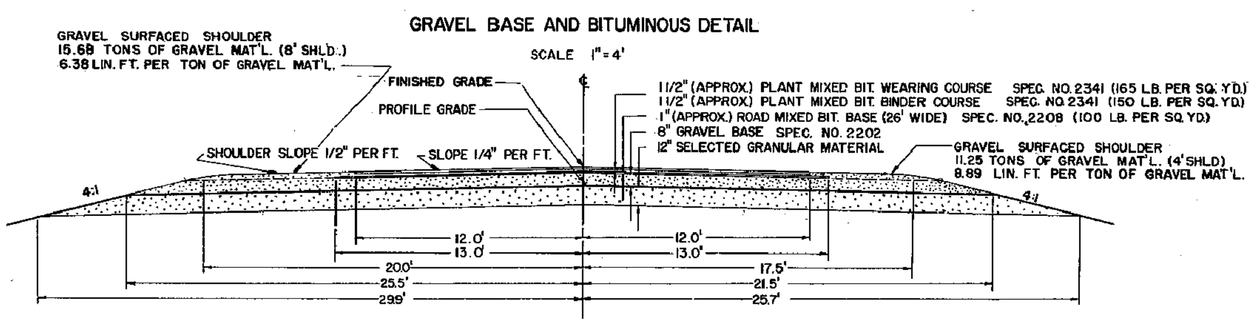

Figure 3-45 TH 36 mainline typical section (1958 construction plan)

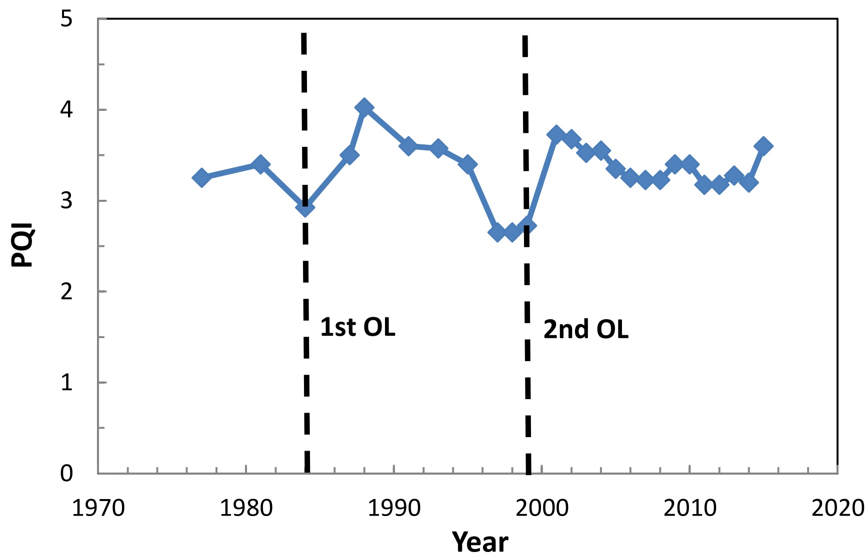

Figure 3-46 PQI vs. year for TH 36

3.7.1 TH 36 Traffic Analysis

Figure 3-47 shows ADT vs. year for the available TH 36 traffic data as well as the best-fit line using the compound growth model. Using the model, the traffic in 1960 was approximately 24,100 ADT with an increase rate of 0.41%. Figure 3-48 and Figure 3-49 present HCAADT and HCAADT%, respectively. The average HCAADT% is 3.7% from 1998 to 2012.

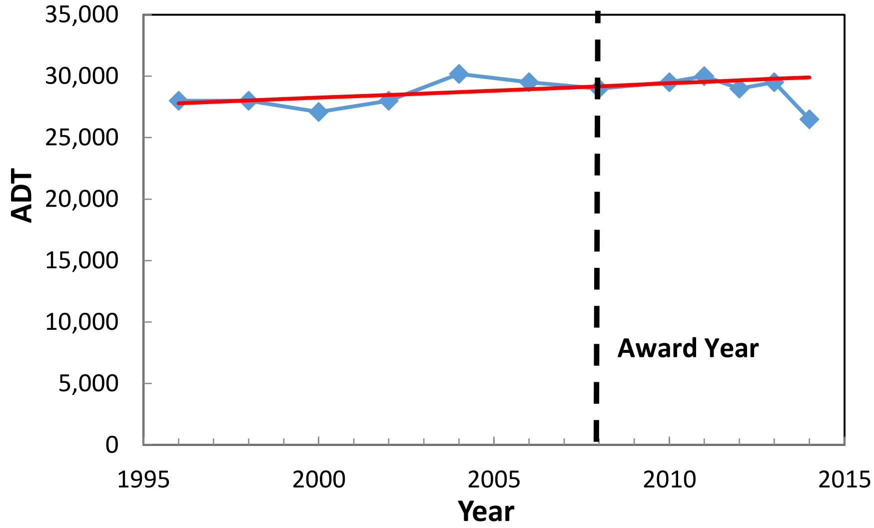

Figure 3-47 ADT vs. year and compound growth fit for TH 36

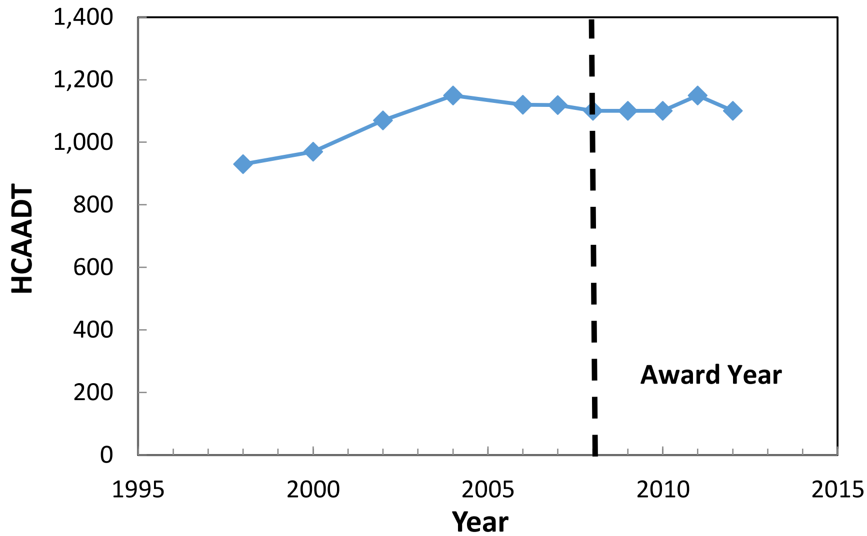

Figure 3-48 HCAADT vs. year for TH 36

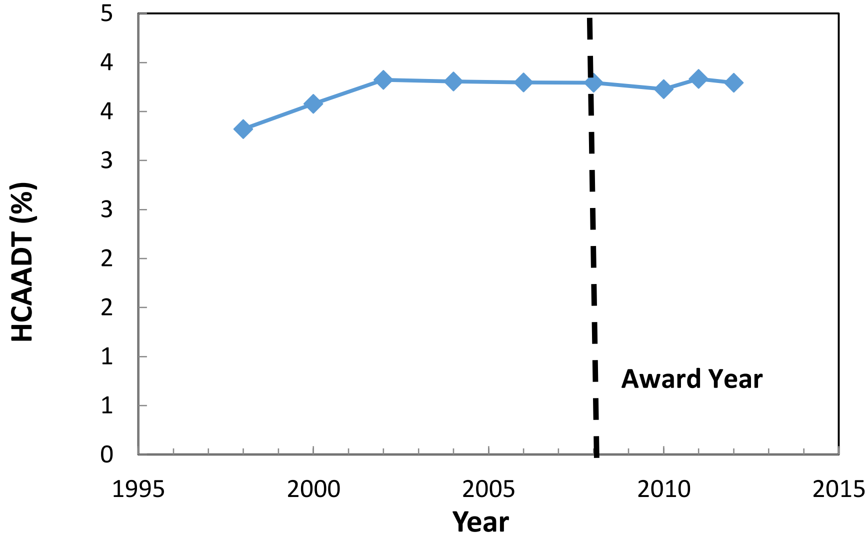

Figure 3-49 HCAADT (%) vs. year for TH 36

3.8 Trunk Highway 10 (2009 Winner)

This is a 15.5-mile section of TH 10 from east of Detroit Lakes to Perham in Becker County (Figure 3-50 and Figure 3-51). The initial construction was completed in 1973. During the construction of this section, one foot of unsuitable material was excavated and adverse subsoil conditions were corrected which led to an increase in the uniformity of compacted materials. A select granular backfill material was then used to create a drainable, strong construction platform to pave against and to provide long-lasting foundation. Figure 3-52 shows TH 10 mainline typical section available from 1973 construction plan. Figure 3-53 shows PQI versus time for this section.

Control Section: 5607

Reference Point (RP): 056+00.144 to 071+00.741

Construction history:

Year	State Project Number (SP)	Description
2001[(1)]	5607-36 5606-40	2 inches mill and 3.5 inches overlay
1993[(2)]	5607-32	1.5 inches mill and 1.5 inches overlay (west bound)
1973	5607-22 5606-20	- 1.5 inches of plant-mixed bituminous wearing course - 2 inches of plant-mixed bituminous binder course - 6 inch of plant-mixed bituminous base course - 12 inches of select granular subbase with stabilized upper one inch - subgrade corrections in the upper one foot

[(1)]8 years after the first overlay
[(2)]20 years after the initial construction

Other information in 2009:

- Total HMA thickness: 11 inches
- Traffic load to date: 9 million ESALs
- Subgrade soils vary between sandy loam to sand
- Pavement performance data:
    - RQI= 3.7 (good)
    - SR= 3.5 (good) – from 2008 data
    - PQI= 3.6 (good)
    - IRI= 57 inches/mile
    - Average rut depth= 0.1 inches

Pavement performance data in 2015:

- RQI= 3.3 (good)
- SR= 3.4 (good)
- PQI= 3.4 (good)
- IRI= 85 inches/mile
- Rut depth= 0.1 inches

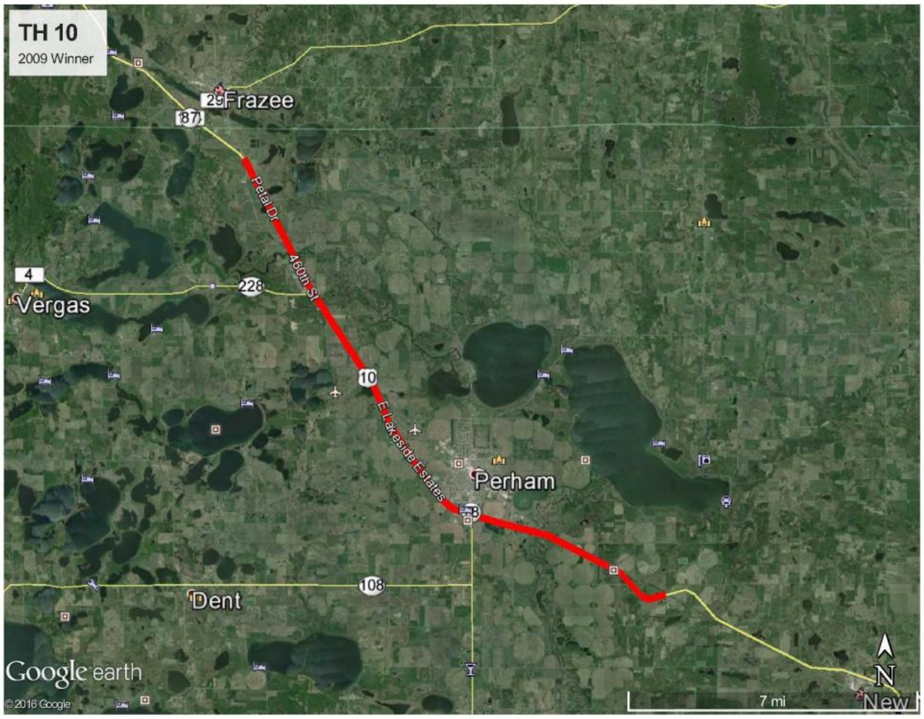

Figure 3-50 TH 10 from east of Detroit Lakes to Perham

Figure 3-51 TH 10 near Perham in Becker County

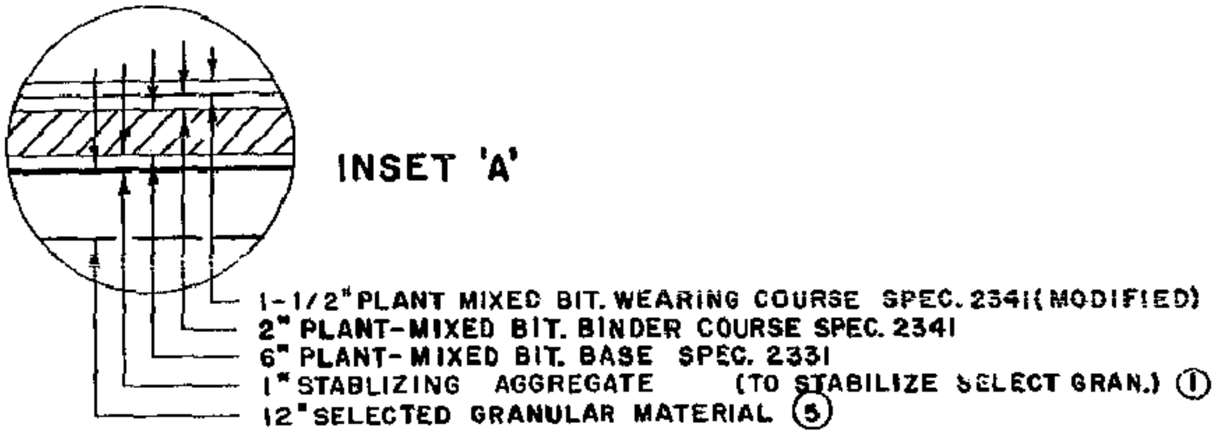

Figure 3-52 TH 10 mainline typical section (1973 construction plan)

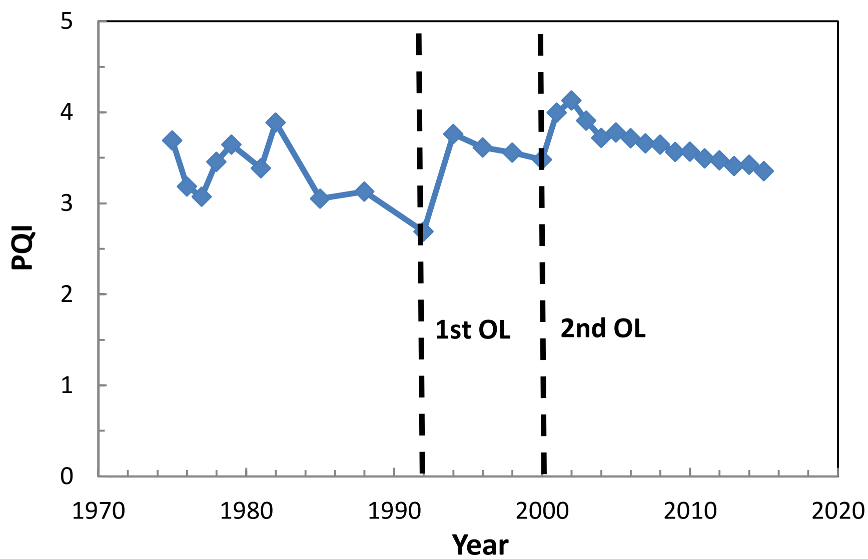

Figure 3-53 PQI vs. year for TH 10

3.8.1 <u>TH 10 Traffic Analysis</u>

Figure 3-54 shows ADT vs. year for the available TH 10 traffic data as well as the best-fit line using the compound growth model. Using the model, the traffic in 1973 was approximately 3,900 ADT with an increase rate of 2.0% over 40 years. Figure 3-55 and Figure 3-56 present HCAADT and HCAADT%, respectively. The average HCAADT% was 10.3% from 1994 to 2011.

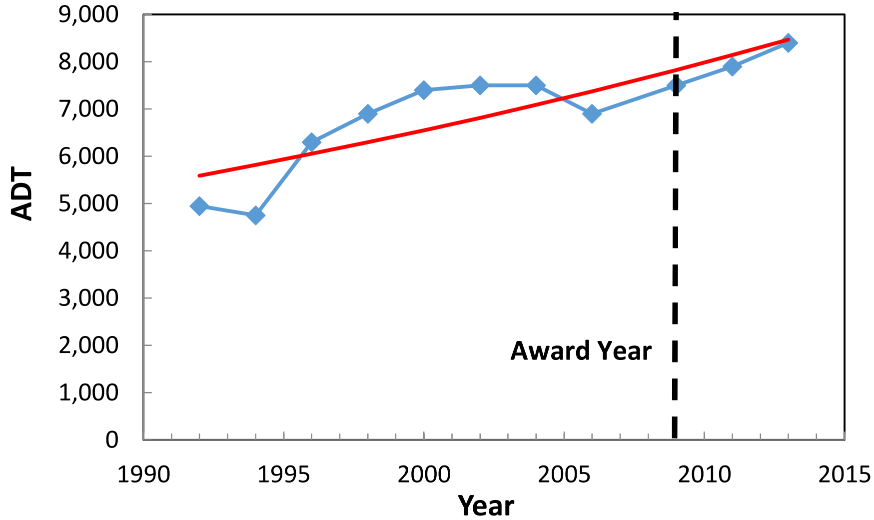

Figure 3-54 ADT vs. year and compound growth fit for TH 10

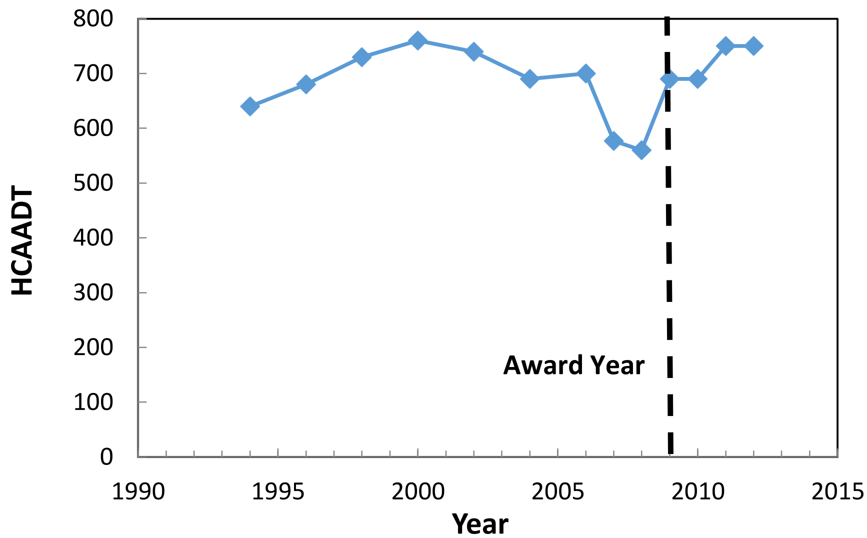

Figure 3-55 HCAADT vs. year for TH 10

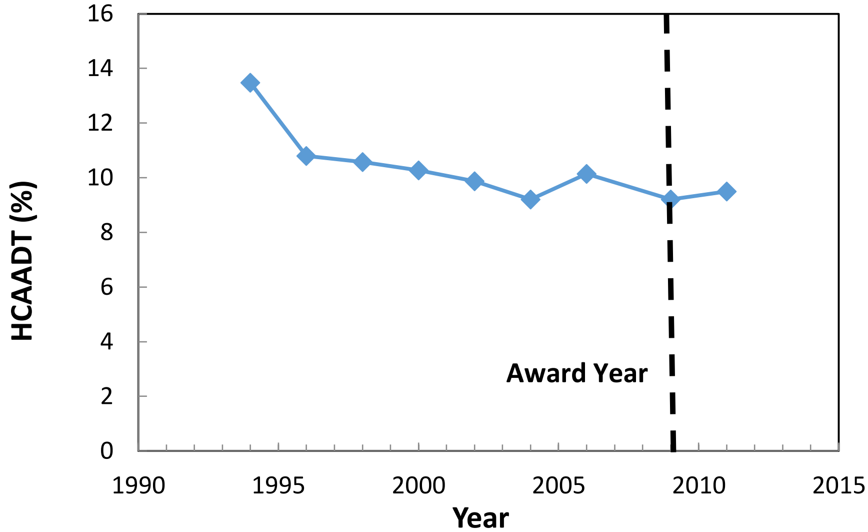

Figure 3-56 HCAADT (%) vs. year for TH 10

3.9 Trunk Highway 61 (2010 Winner)

This is a 5-mile section of TH 61 in Lake County (Figure 3-57 and Figure 3-58). The initial construction was completed in 1969. During the construction of this section, four feet of unsuitable material was excavated and adverse subsoil conditions were corrected which led to an increase in the uniformity of compacted materials. A select granular backfill material was then used to create a drainable, strong construction platform to pave against and to provide long-lasting foundation. Figure 3-59 shows TH 10 mainline typical section available from 1967 construction plan. Figure 3-60 shows PQI versus time for this section.

Control Section: 3807

Reference Point (RP): 057+00.591 to 062+00.523

Construction history:

Year	State Project Number (SP)	Description
2001[(1)]	8821-46	2 inches mill and 3.5 inches overlay
1969	3807-23	- 1.5 inches of plant-mixed bituminous wearing course - 2.5 inches of plant-mixed bituminous binder course - 6 inches of aggregate base with stabilized upper 1.5 inches - subgrade corrections in the upper four feet

[(1)]32 years after the initial construction

Other information in 2010:

- Total HMA thickness: 5.5 inches
- Traffic load to date: 1 million ESALs
- Pavement performance data:
  - RQI= 3.5 (good)
  - SR= 3.6 (very good) – from 2009 data
  - PQI= 3.6 (good)
  - IRI= 67 inches/mile
  - Average rut depth= 0.3 inches

Pavement performance data in 2015:

- RQI= 2.9 (fair)
- SR= 3.2 (good)
- PQI= 3.1 (good)
- IRI= 100 inches/mile
- Rut depth= 0.2 inches

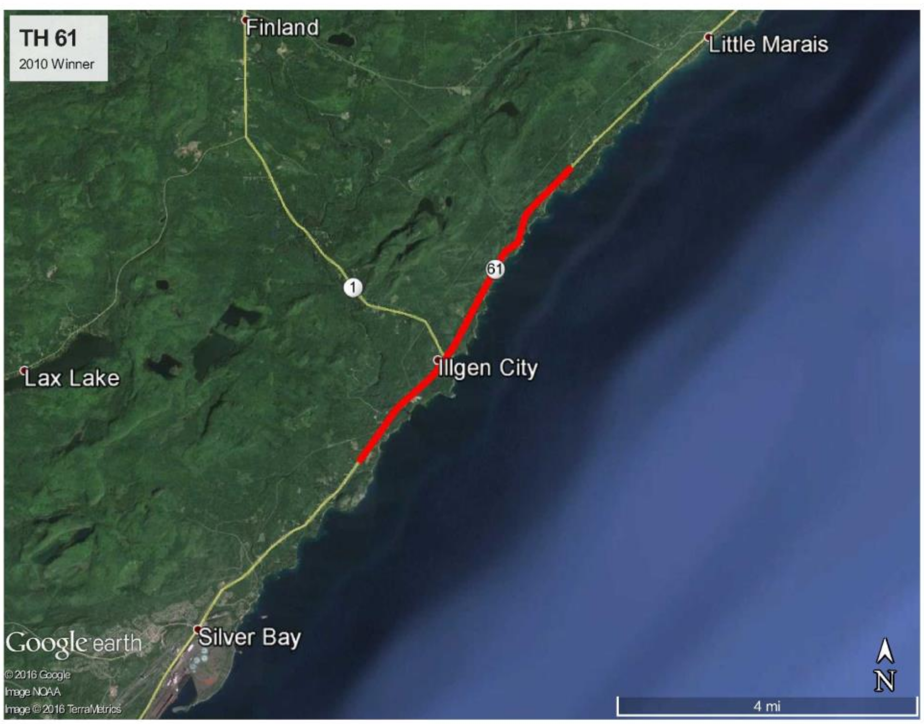

Figure 3-57 TH 61 north of Silver Bay

Figure 3-58 TH 61 in Lake County

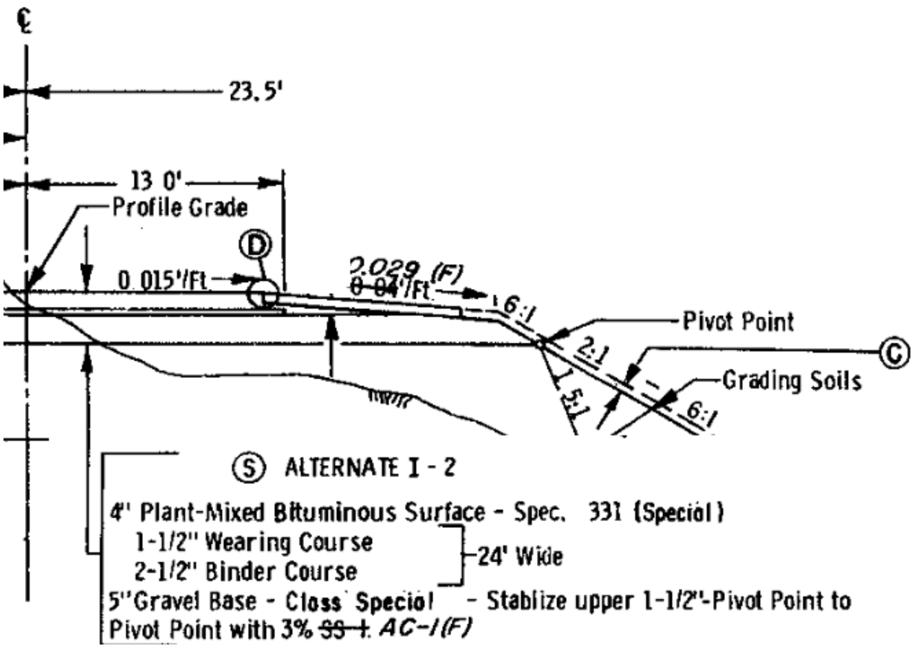

Figure 3-59 TH 61 mainline typical section (1967 construction plan)

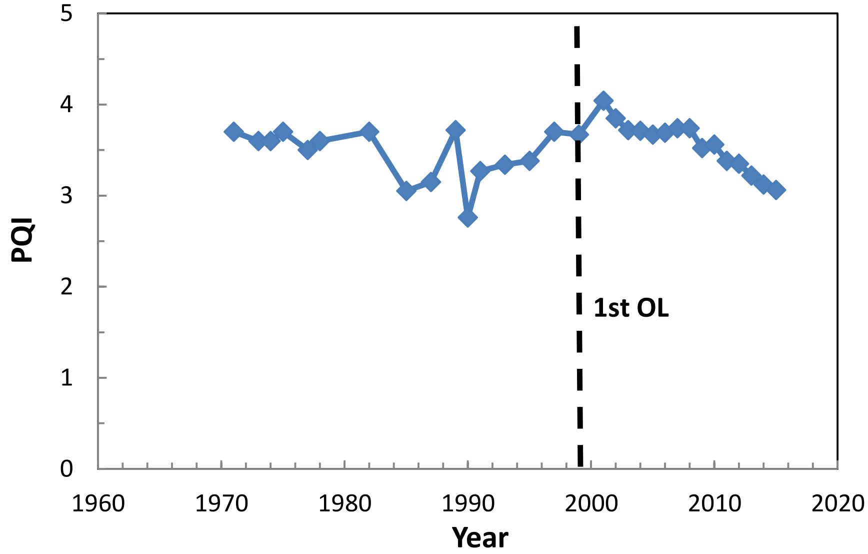

Figure 3-60 PQI vs. year for TH 61

3.9.1 <u>TH 61 Traffic Analysis</u>

Figure 3-61 shows ADT vs. year for the available TH 61 traffic data as well as the best-fit line using the compound growth model. Using the model, the traffic in 1969 was approximately 2,800 ADT with an increase rate of 0.47%. Figure 3-62 and Figure 3-63 present HCAADT and HCAADT%, respectively. The average HCAADT% was 10.3% from 1994 to 2012.

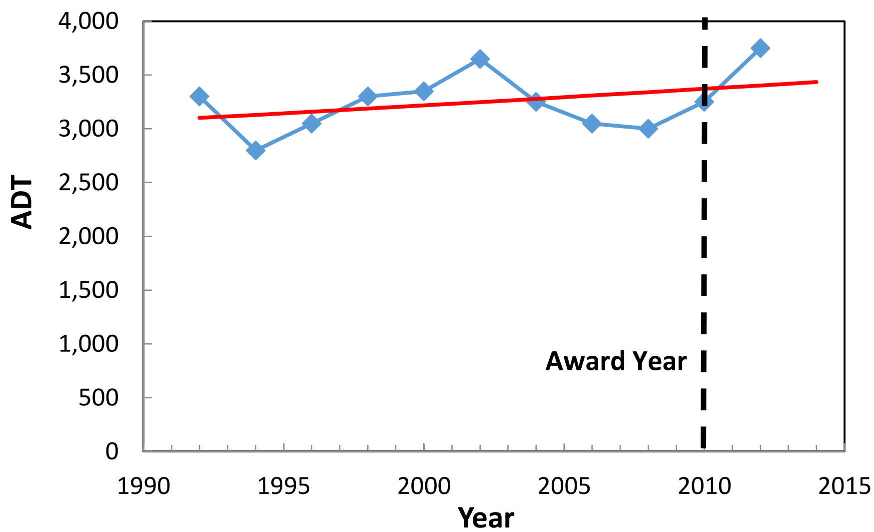

Figure 3-61 ADT vs. year and compound growth fit for TH 61

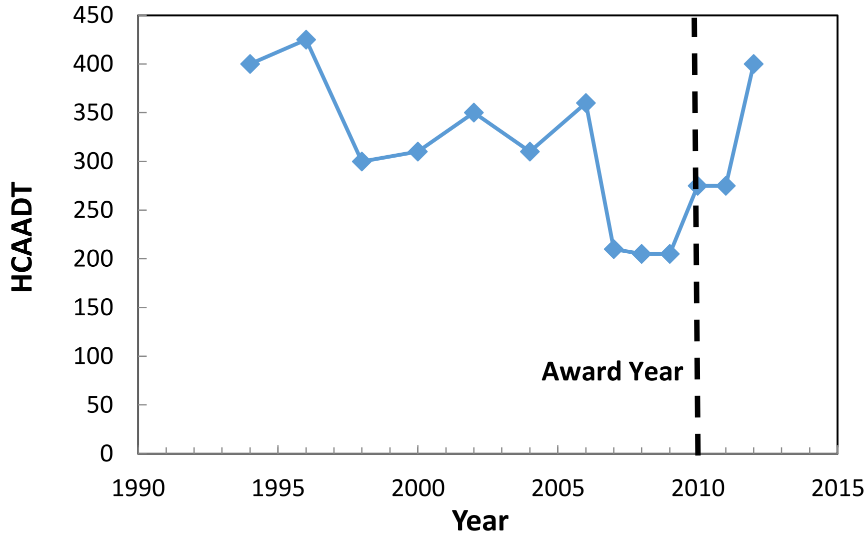

Figure 3-62 HCAADT vs. year for TH 61

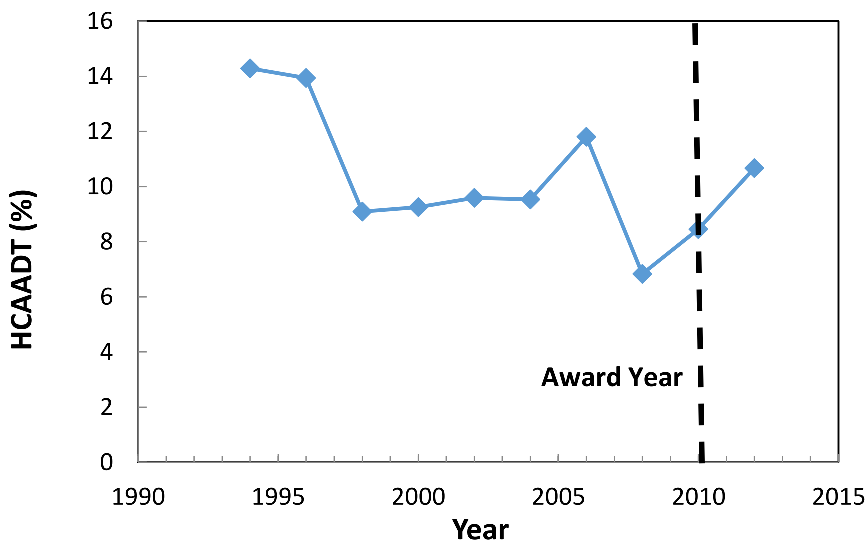

Figure 3-63 HCAADT (%) vs. year for TH 61

3.10 Trunk Highway 71 (2011 Winner)

This is a 17-mile section of TH 71 from Sauk Centre to Long Prairie in Stearns County and Todd County (Figure 3-64 and Figure 3-65). TH 71 is part of the international route which connects southern Louisiana to Canadian border. The initial construction was completed in 1962 by Duininck Construction and BAB Construction. During construction, 12 inches of sand fill was placed in some areas to replace existing soil that was unsuitable for construction. Initial construction also included a 1.5 inch road-mixed bituminous surface over the aggregate base. Figure 3-66 shows TH 71 mainline typical section available from 1956 construction plan. Figure 3-67 shows PQI versus time for this section.

Control Section: 7707

Reference Point (RP): 169+00.035 to 185+00.744

Construction history:

Year	State Project Number (SP)	Description
2008	8823-120	seal coat
2002[(1)]	7319-34	2 inches mill and 3.5 inches overlay
1987[(2)]	7319-22	1.5 inches overlay
1967	NA	chip seal
1962	7707-13	3 inches of plant-mixed bituminous wearing course
1957	7707-09	- 1.5 inches of road-mixed bituminous base - 5 inches of aggregate base - some subgrade corrections

[(1)]15 years after the first overlay
[(2)]25 years after the initial construction

Other information in 2011:

- Total HMA thickness: 6 inches
- Traffic load to date: 1.5 million ESALs
- Pavement performance data:
    - RQI= 3.9 (good)
    - SR= 3.6 (very good) – from 2010 data
    - PQI= 3.7 (good)
    - IRI= 54 inches/mile
    - Average rut depth= 0.1 inches

Pavement performance data in 2015:

- RQI= 3.6 (good)
- SR= 3.4 (good) – from 2014 data
- PQI= 3.5 (good)
- IRI= 68 inches/mile
- Rut depth= 0.2 inches

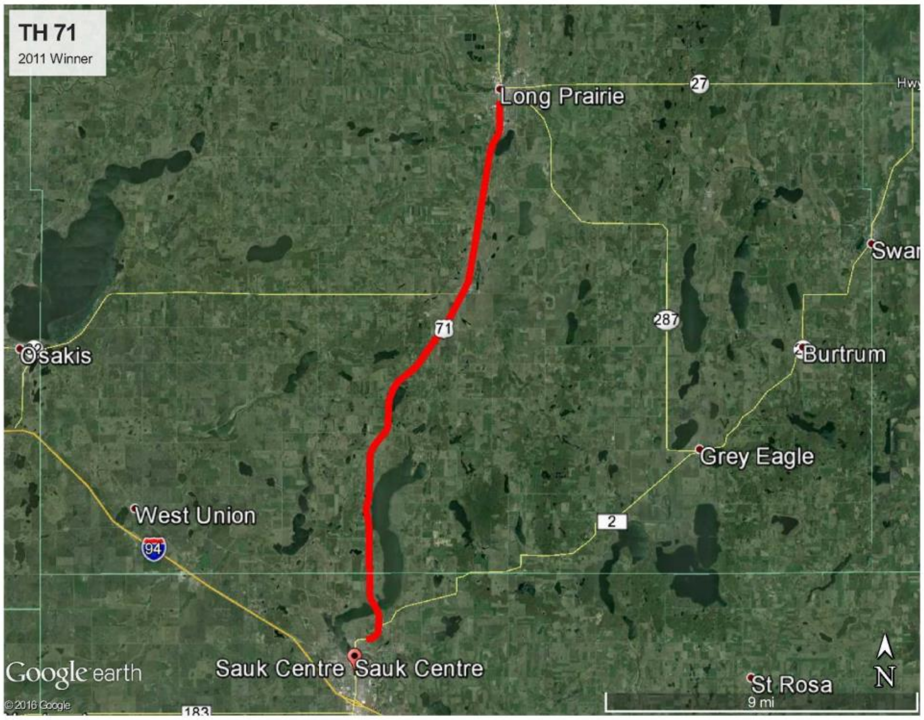

Figure 3-64 TH 71 from Sauk Centre to Long Prairie

Figure 3-65 TH 71 in Todd County

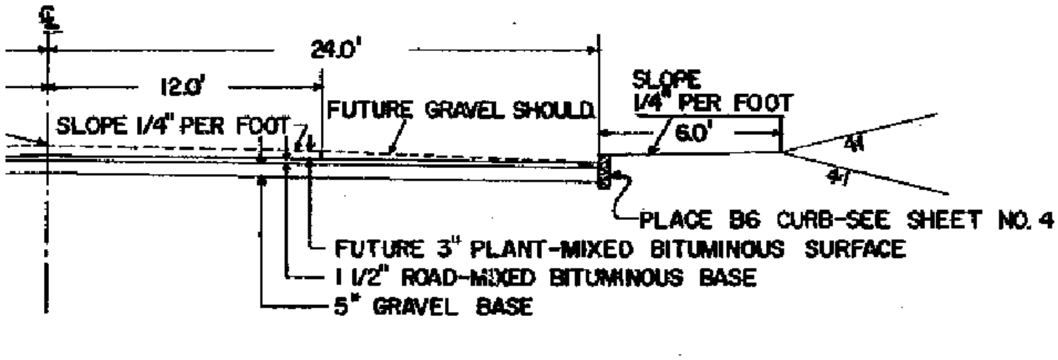

Figure 3-66 TH 71 mainline typical section (1956 construction plan)

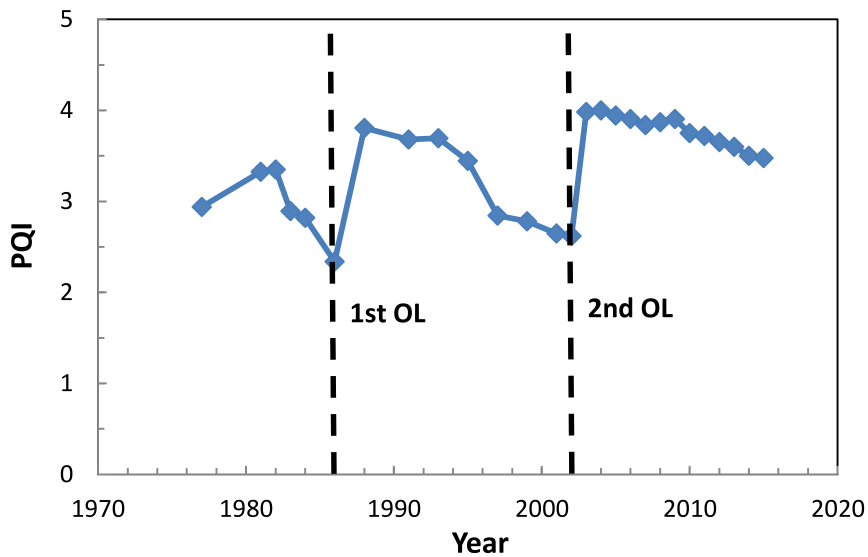

Figure 3-67 PQI vs. year for TH 71

3.10.1 TH 71 Traffic Analysis

Figure 3-68 shows ADT vs. year for the available TH 71 traffic data as well as the best-fit line using the compound growth model. Using the model, the traffic in 1962 was approximately 7,600 ADT with an increase rate of 0.52%. Figure 3-69 and Figure 3-70 present HCAADT and HCAADT%, respectively. The average HCAADT% is 9.6% from 1994 to 2012.

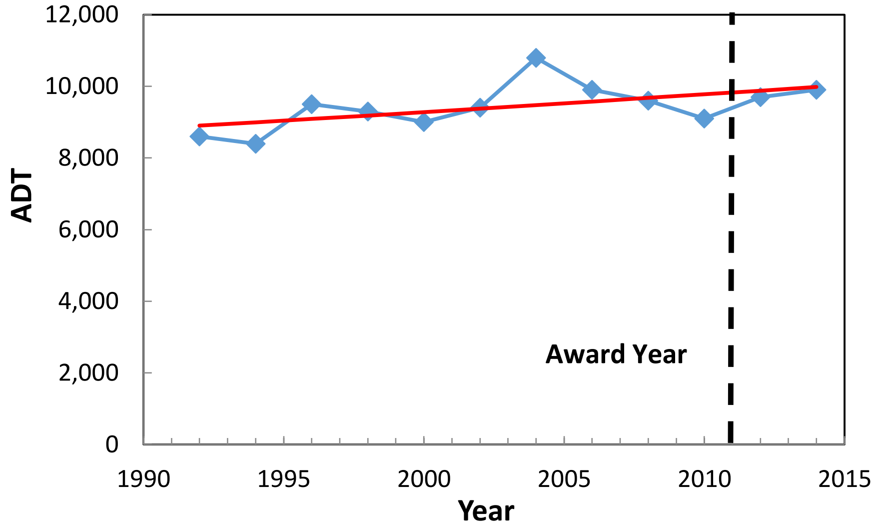

Figure 3-68 ADT vs. year and compound growth fit for TH 71

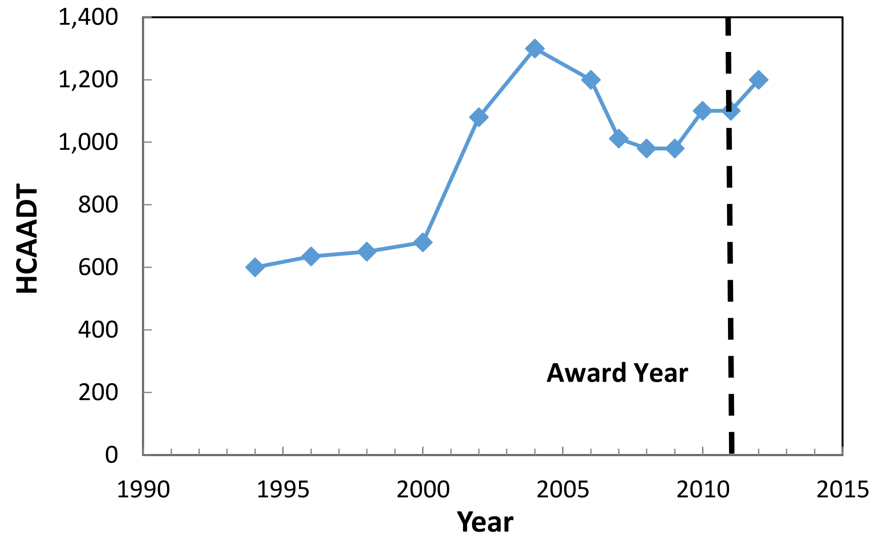

Figure 3-69 HCAADT vs. year for TH 71

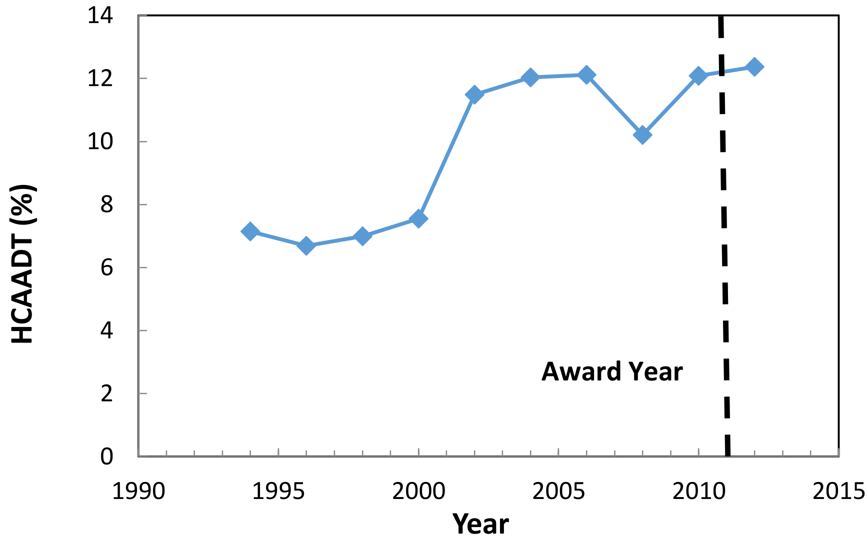

Figure 3-70 HCAADT (%) vs. year for TH 71

3.11 Trunk Highway 61 (2012 Winner)

This is a 20-mile section of TH 61 from Kellogg to Minnesota City in Wabasha County and Winona County (Figure 3-71 and Figure 3-72). The initial construction was completed in 1969. During the construction of this section, two to three feet of unsuitable material was excavated and adverse subsoil conditions were corrected which led to an increase in the uniformity of compacted materials. A select granular backfill material was then used to create a drainable, strong construction platform to pave against and to provide long-lasting foundation. Figure 3-73 shows TH 61 mainline typical section available from 1966 construction plan. Figure 3-74 shows PQI versus time for this section.

Control Section: 7904

Reference Point (RP): 034+00.352 to 053+00.979

Construction history:

Year	State Project Number (SP)	Description
2009[1]	7904-39 8506-68	mill and overlay (variable depths): 3 inches mill and 3 inches overlay in urban sections. 1.5 to 2 inches mill and 3 to 3.5 inches overlay in rural sections.
2005	8826-38	seal coat
2000[2]	7904-38	2 inches mill and 3 inches overlay (south bound)
1990[3]	8506-57	1 inch mill and 3 inches overlay (north bound)
1988[4]	7904-31	2.5 inches overlay (south bound)
1969	7904-18 8506-37	- 5 inches of plant-mixed bituminous - 7 inches of aggregate base - 12 inches of select granular subbase - subgrade corrections in the upper 2 to 3 feet

(1)19 years after the north bound first overlay, 9 years after the south bound second overlay
(2)12 years after the first overlay (south bound)
(3)21 years after the initial construction
(4)19 years after the initial construction

Other information in 2012:

- Total HMA thickness: ~7 to 10 inches
- Traffic load to date: 3.5 million ESALs
- Pavement performance data:
  - RQI= 3.9 (good)
  - SR= 3.7 (very good) – from 2010 and 2011 data
  - PQI= 3.8 (good)
  - IRI= 51 inches/mile
  - Average rut depth= 0.1 inches

Pavement performance data in 2015:

- RQI= 3.6 (good)
- SR= 3.6 (very good)
- PQI= 3.6 (good)
- IRI= 62 inches/mile
- Rut depth= 0.1 inches

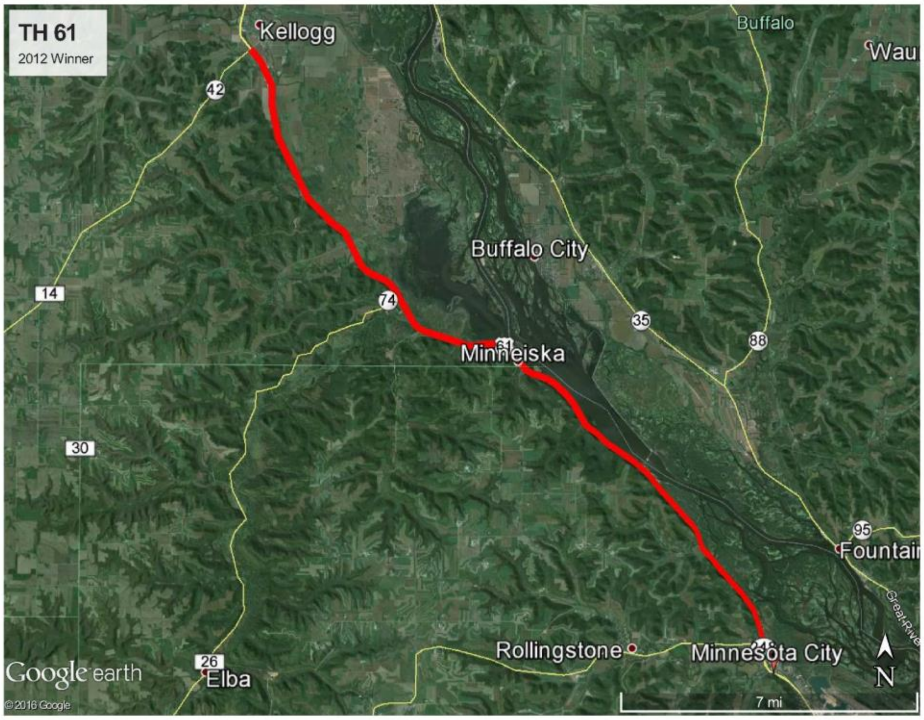

Figure 3-71 TH 61 from Kellogg to Minnesota City

Figure 3-72 TH 61 in Wabasha County and Winona County

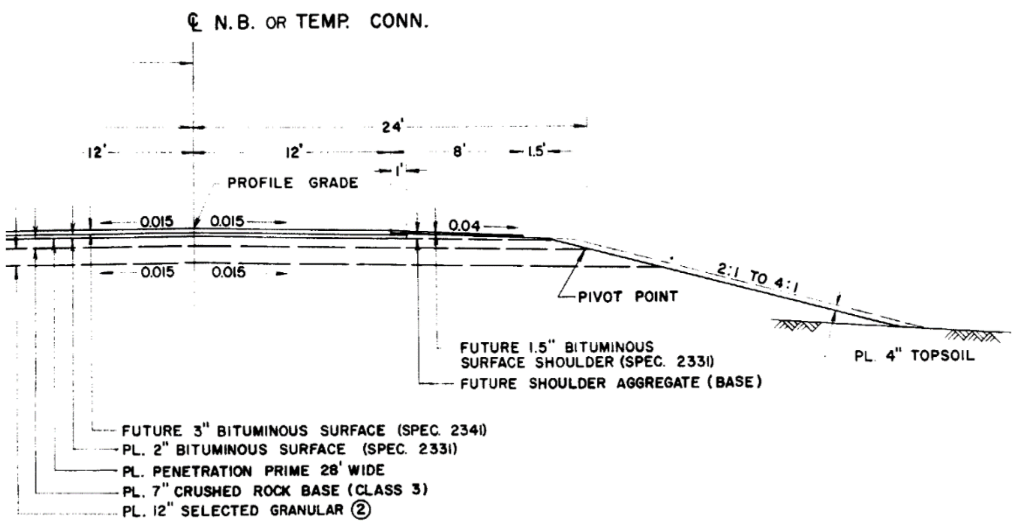

Figure 3-73 TH 61 mainline typical section (1966 construction plan)

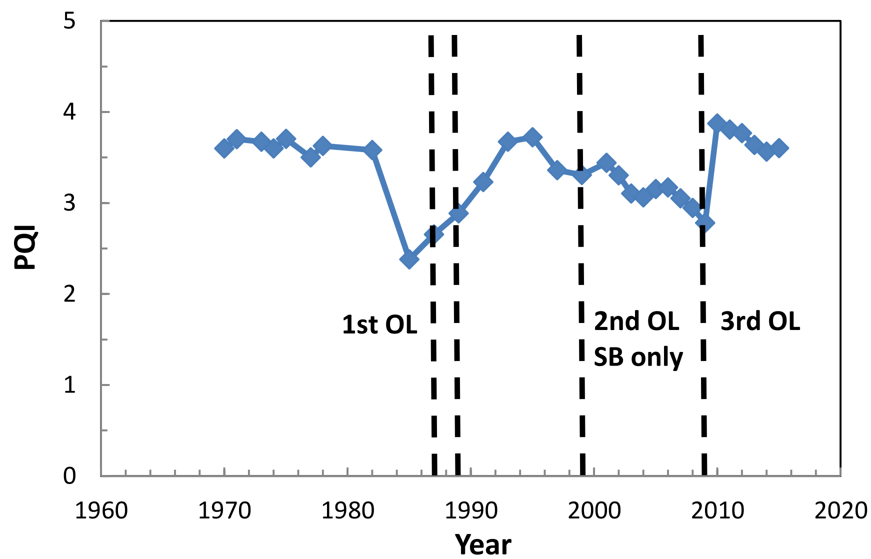

Figure 3-74 PQI vs. year for TH 61

3.11.1 TH 61 Traffic Analysis

Figure 3-75 shows ADT vs. year for the available TH 61 traffic data as well as the best-fit line using the compound growth model. Using the model, the traffic in 1969 was approximately 5,100 ADT with an increase rate of 0.91%. Figure 3-76 and Figure 3-77 present HCAADT and HCAADT%, respectively. The average HCAADT% was 9.4% from 1994 to 2011.

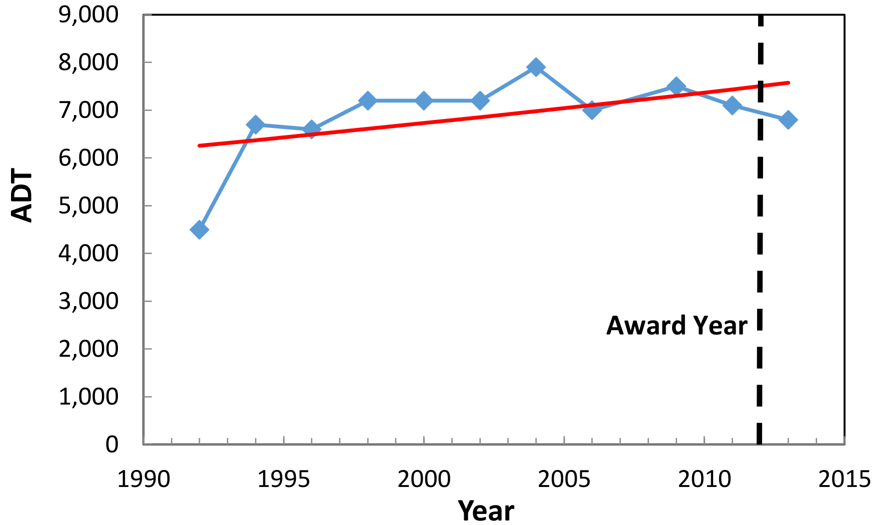

Figure 3-75 ADT vs. year and compound growth fit for TH 61

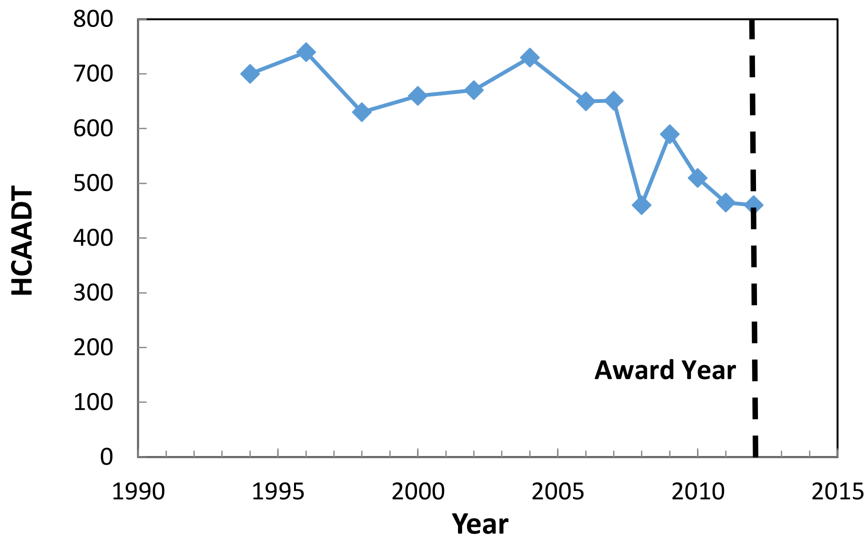

Figure 3-76 HCAADT vs. year for TH 61

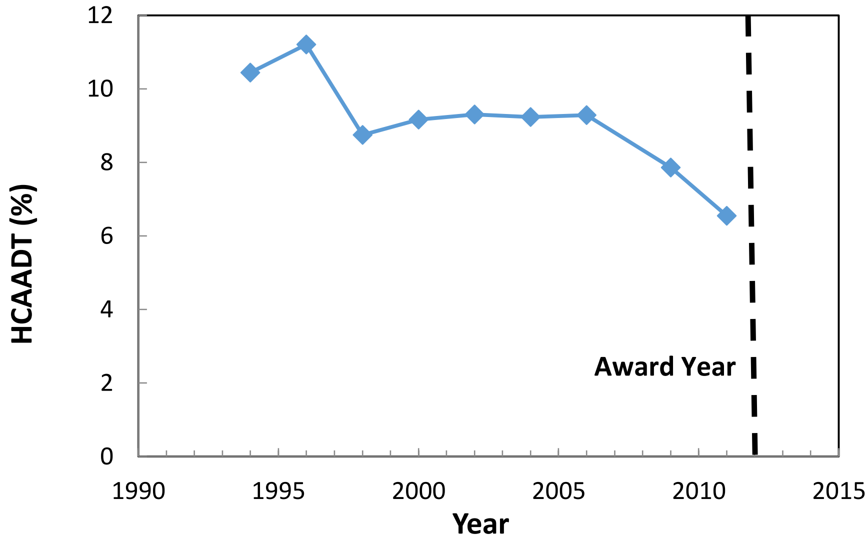

Figure 3-77 HCAADT (%) vs. year for TH 61

3.12 Trunk Highway 95 (2013 Winner)

This is a 5-mile section of TH 95 from south of Stillwater to Bayport in Washington County (Figure 3-78 and Figure 3-82). The initial construction was completed in 1960. During the construction of this section, in certain areas, the in-place material was subcut and backfilled with select granular material to an unknown depth to improve drainage in the structure. Initial construction also included a prime coat and 1.5 inch road-mixed bituminous surface over the aggregate base. Figure 3-80 shows TH 95 mainline typical section available from 1959 construction plan. Figure 3-94 shows PQI versus time for this section.

Control Section: 8209

Reference Point (RP): 105+00.389 to 110+00.360

Construction history:

Year	State Project Number (SP)	Description
2000[1]	8209-41	2 inches mill and 2 inches overlay
1992[2]	NA	3 inches overlay
1961	8209-18	3 inches of plant-mixed bituminous wearing course
1960	8209-17	- 1.5 inches of road-mixed bituminous base - 7.5 inches of aggregate base - 12 inches of select granular subbase - some subgrade corrections

[1]8 years after the first overlay
[2]31 years after the initial construction

Other information in 2013:

- Total HMA thickness: 6 inches
- Traffic load to date: 2 million ESALs
- Pavement performance data:
    - RQI= 3.1 (good)
    - SR= 2.8 (fair) – from 2005 data
    - PQI= 3.0 (fair)
    - IRI= 101 inches/mile
    - Average rut depth= 0.1 inches

Pavement performance data in 2015:

- RQI= 3.0 (fair)
- SR= 2.8 (fair)
- PQI= 2.8 (fair)
- IRI= 104 inches/mile
- Rut depth= 0.1 inches

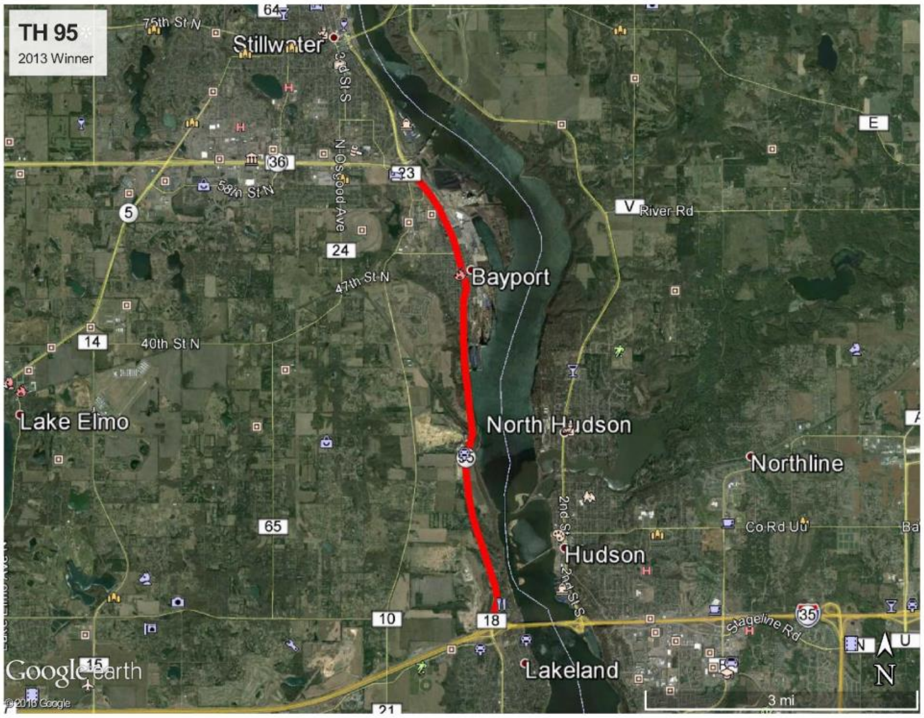

Figure 3-78 TH 95 from south of Stillwater to Bayport

Figure 3-79 TH 95 in Washington County

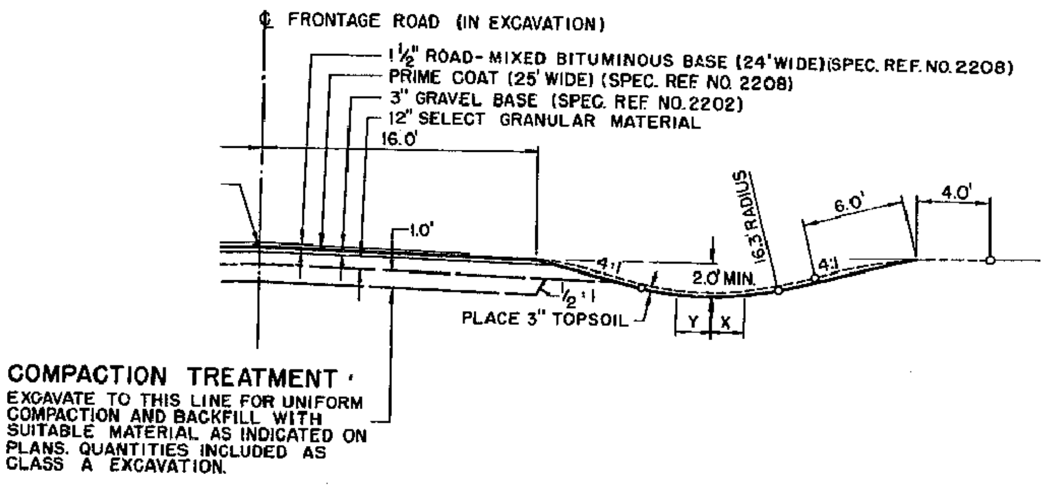

Figure 3-80 TH 95 mainline typical section (1959 construction plan)

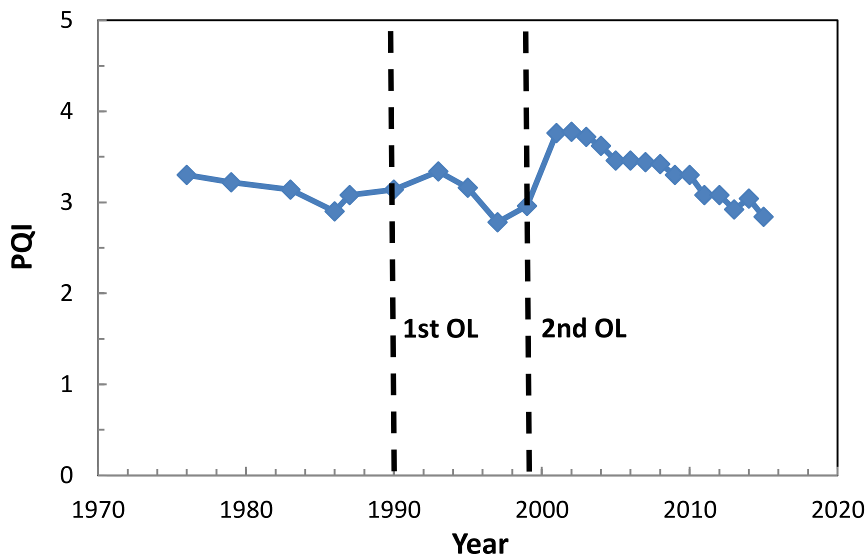

Figure 3-81 PQI vs. year for TH 95

3.12.1 <u>TH 95 Traffic Analysis</u>

Figure 3-82 shows ADT vs. year for the available TH 95 traffic data as well as the best-fit line using the compound growth model. Using the model, the traffic in 1961 was approximately 9,400 ADT with an increase rate of 0.66%. Figure 3-83 and Figure 3-84 present HCAADT and HCAADT%, respectively. The average HCAADT% is 5.6% from 1998 to 2012.

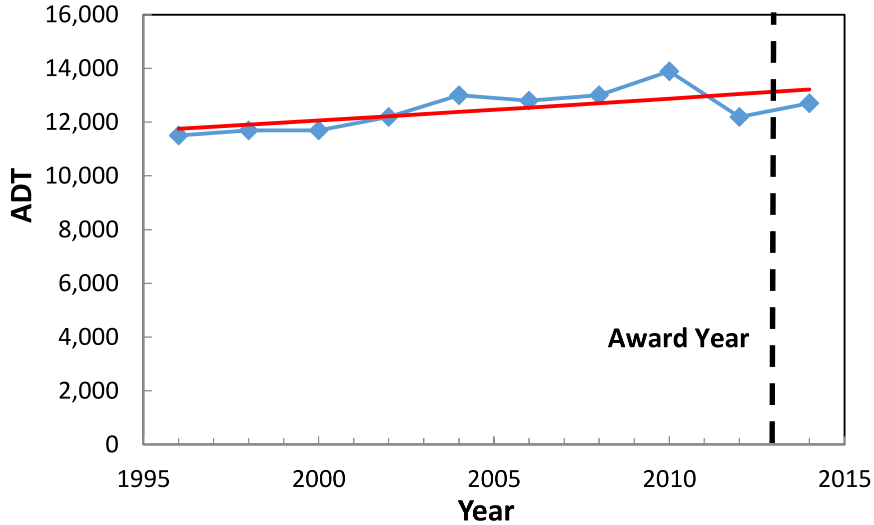

Figure 3-82 ADT vs. year and compound growth fit for TH 95

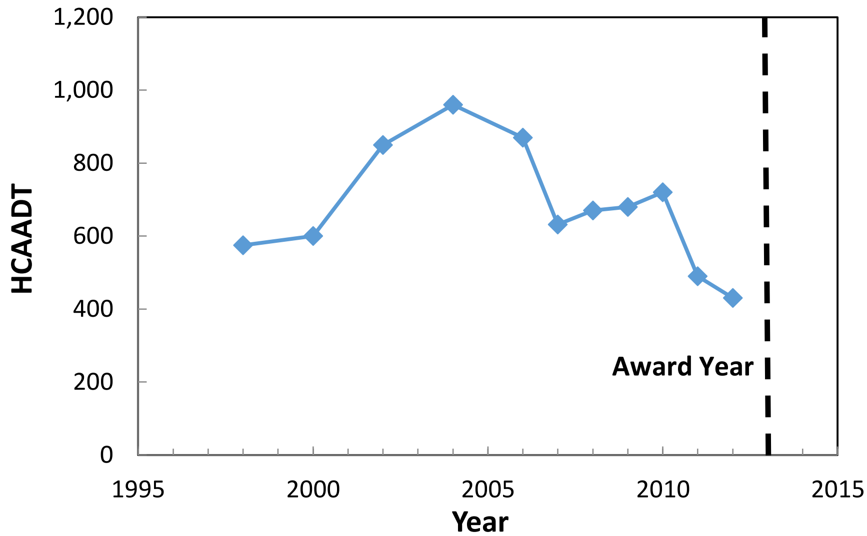

Figure 3-83 HCAADT vs. year for TH 95

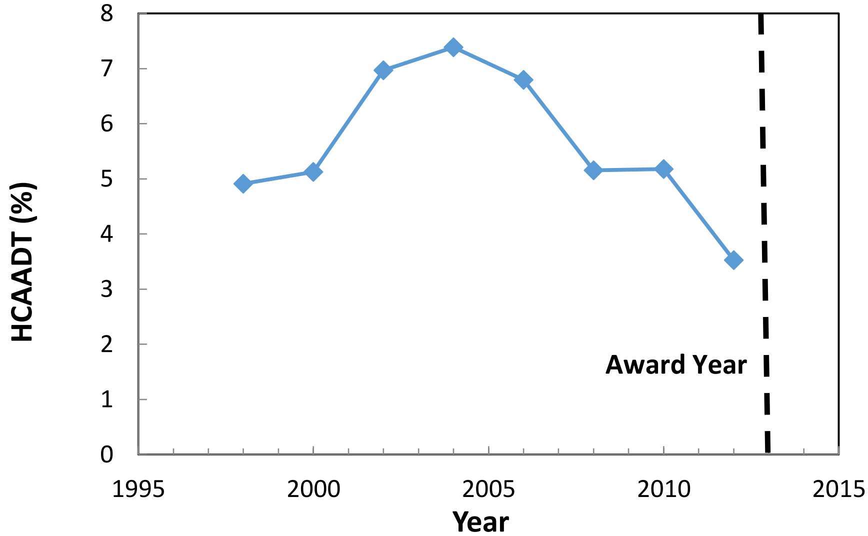

Figure 3-84 HCAADT (%) vs. year for TH 95

3.13 Trunk Highway 47 (2014 Winner)

This is a 5-mile section of TH 47 from Columbia Heights to Fridley in Anoka County (Figure 3-85 and Figure 3-86). The initial construction was completed in 1966. During the construction of this section, 12 to 36 inches of the in-place material was subcut and backfilled with select granular material to provide better drainage. Figure 3-87 shows TH 47 mainline typical section available from 1964 construction plan. Figure 3-88 shows PQI versus time for this section.

Control Section: 0205

Reference Point (RP): 005+00.900 to 010+00.642

Construction history:

Year	State Project Number (SP)	Description
2009[1]	0205-84	mill and overlay the same depth (2 to 6 inches)
1989 (1991) (1994)[2]	0205-56 (0205-59) (0205-67)	2 inches mill and 3 to 3.5 inches overlay
1972	0205-41	seal coat
1966 (1967)	0205-15 (0205-18)	- 1 inch of asphalt wearing course - 3 inches of asphalt binder course - 3 inches of plant-mixed bituminous base - 18 inches of granular subbase with upper 6 inches treated with bituminous - subgrade corrections in the upper one to three feet

[1]15 to 20 years after the first overlay
[2]22 to 27 years after the initial construction

Other information in 2014:

- Total HMA thickness: 8 to 8.5 inches
- Traffic load to date: 3.4 million ESALs
- Pavement performance data:
    - RQI= 3.6 (good)
    - SR= 3.5 (good)
    - PQI= 3.5 (good)
    - IRI= 61 inches/mile
    - Average rut depth= 0.3 inches

Pavement performance data in 2015:

- RQI= 3.5 (good)
- SR= 3.5 (good) – from 2014 data
- PQI= 3.5 (good)
- IRI= 64 inches/mile
- Rut depth= 0.1 inches

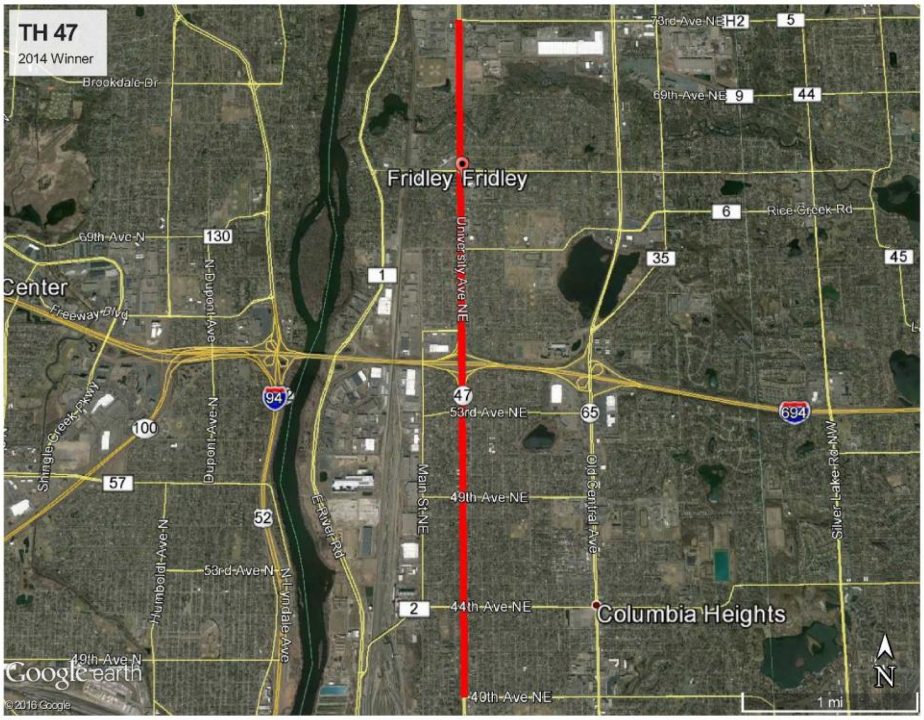

Figure 3-85 TH 47 from Columbia Heights to Fridley

Figure 3-86 TH 47 in Anoka County

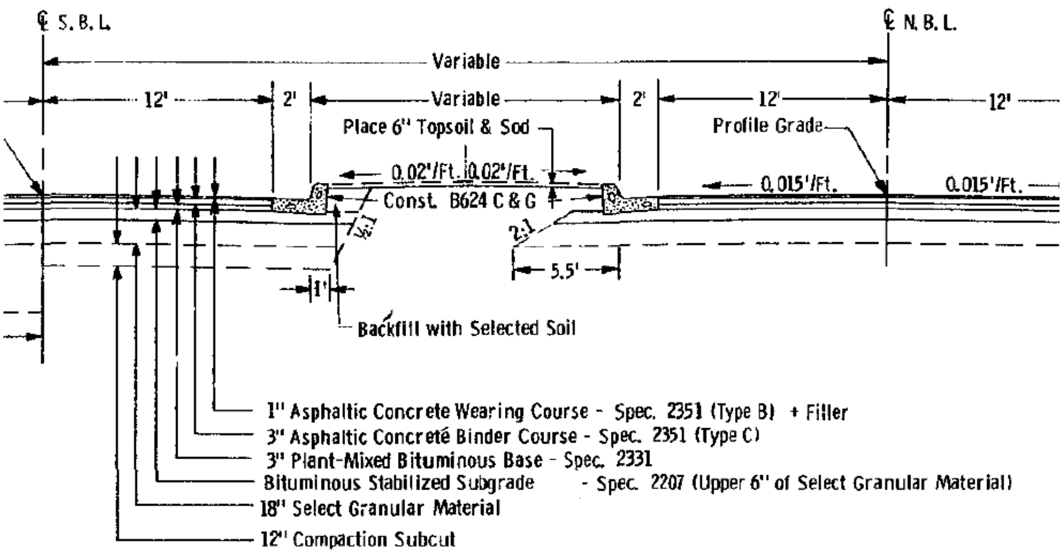

Figure 3-87 TH 47 mainline typical section (1964 construction plan)

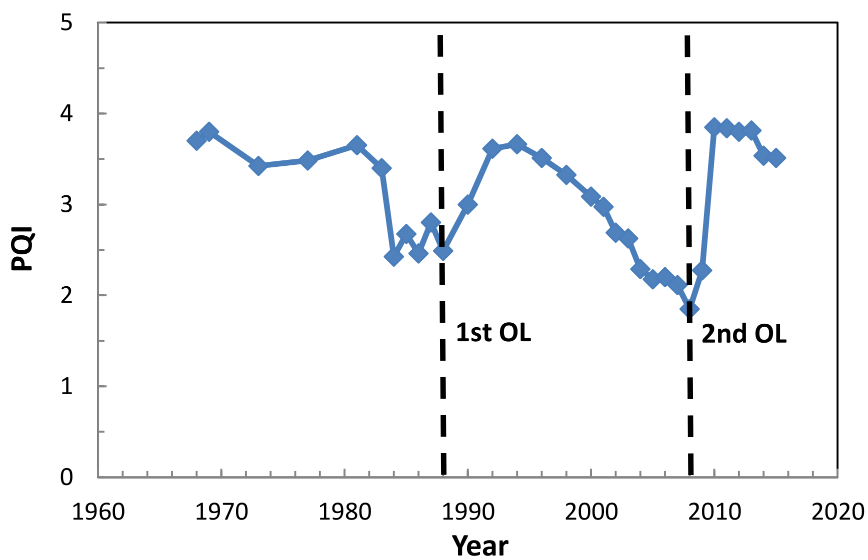

Figure 3-88 PQI vs. year for TH 47

3.13.1 TH 47 Traffic Analysis

Figure 3-89 shows ADT vs. year for the available TH 47 traffic data as well as the best-fit line using the compound growth model. Using the model, the traffic in 1966 was approximately 33,400 ADT with an increase rate of 0.31%. Figure 3-90 and Figure 3-91 present HCAADT and HCAADT%, respectively. The average HCAADT% is 3.4% from 1998 to 2012.

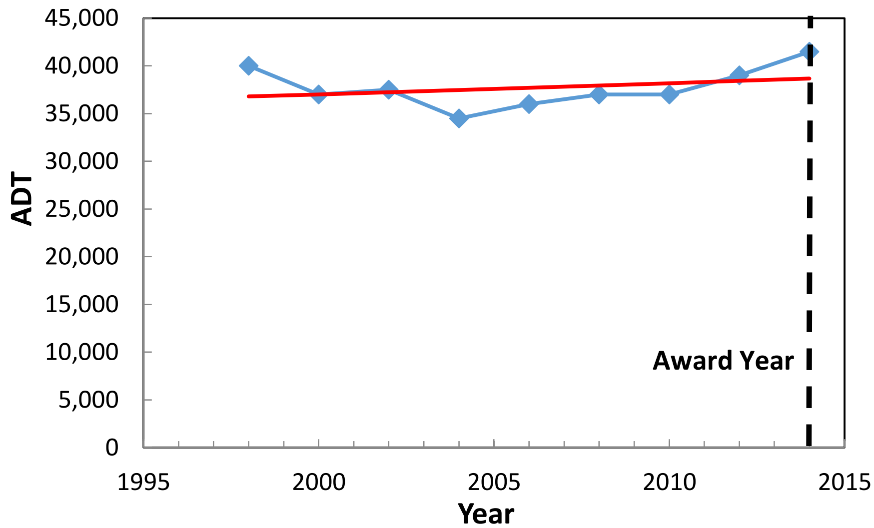

Figure 3-89 ADT vs. year and compound growth fit for TH 47

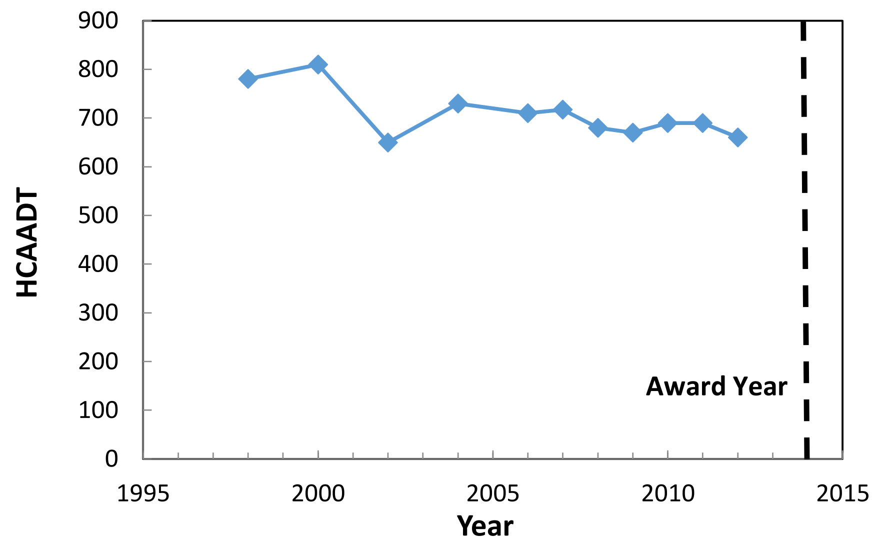

Figure 3-90 HCAADT vs. year for TH 47

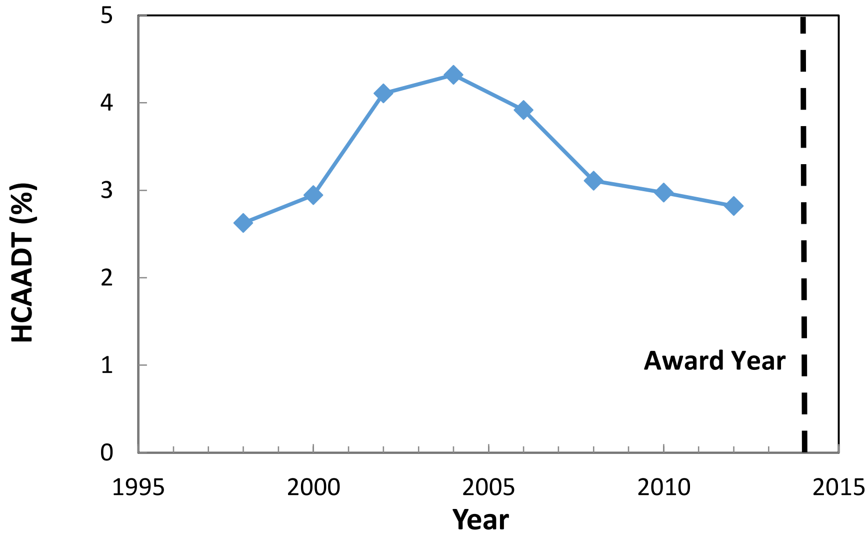

Figure 3-91 HCAADT (%) vs. year for TH 47

3.14 Trunk Highway 71 (2015 Winner)

This is a 3.2-mile section of TH 71 north of Bemidji in Beltrami County (Figure 3-92 and Figure 3-93). The initial construction was completed in 1975. During the construction of this section, in-place material was subcut to various depths and then backfilled with select granular material to provide better drainage in some areas to allow for better drainage and stability. Figure 3-94 shows TH 71 mainline typical section available from 1975 construction plan. Figure 3-95 shows PQI versus time for this section.

Control Section: 0410

Reference Point (RP): 317+00.313 to 320+00.518

Construction history:

Year	State Project Number (SP)	Description
2006[1]	0410-45	1.5 inches mill and 3 inches overlay
1992[2]	0410-35	1.5 inches overly
1977	0410-23	- 1.5 inch of asphalt wearing course - 1.5 inches of asphalt binder course - 4 inches of aggregate base
1975	0410-24	- 1 inch of stabilized aggregate - 12 inches of select granular subbase - some subgrade corrections

(1)14 years after the first overlay
(2)15 years after the initial construction

Other information in 2015:

- Total HMA thickness: 6 inches
- Traffic load to date: 1.5 million ESALs

Pavement performance data in 2015:

- RQI= 3.4 (good)
- SR= 2.6 (fair)
- PQI= 3.0 (fair)
- IRI= 73 inches/mile
- Rut depth= 0.2 inches

Figure 3-92 TH 71 north of Bemidji

Figure 3-93 TH 71 in Beltrami County

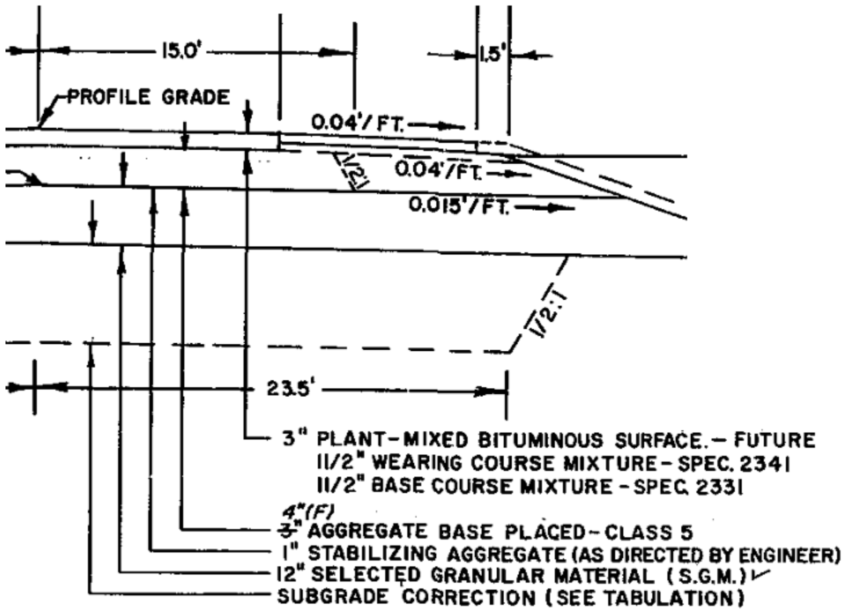

Figure 3-94 TH 71 mainline typical section (1975 construction plan)

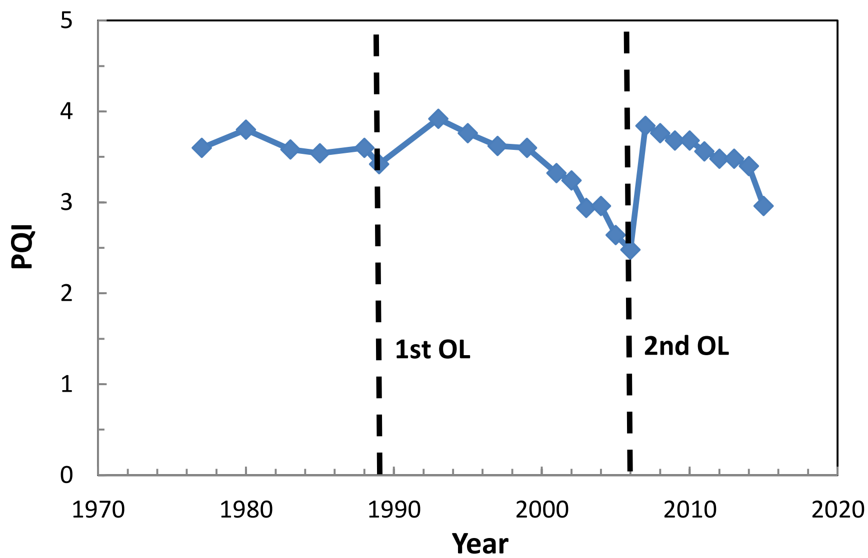

Figure 3-95 PQI vs. year for TH 71

3.14.1 TH 71 Traffic Analysis

Figure 3-96 shows ADT vs. year for the available TH 71 traffic data as well as the best-fit line using the compound growth model. Using the model, the traffic in 1966 was approximately 2,700 ADT with an increase rate of 0.91%. Figure 3-97 and Figure 3-98 present HCAADT and HCAADT%, respectively. The average HCAADT% is 8.4% from 1998 to 2010.

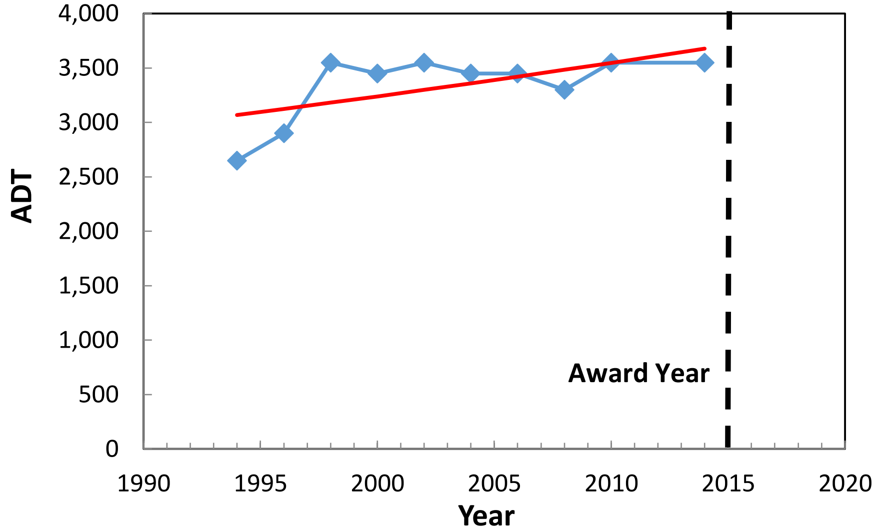

Figure 3-96 ADT vs. year and compound growth fit for TH 71

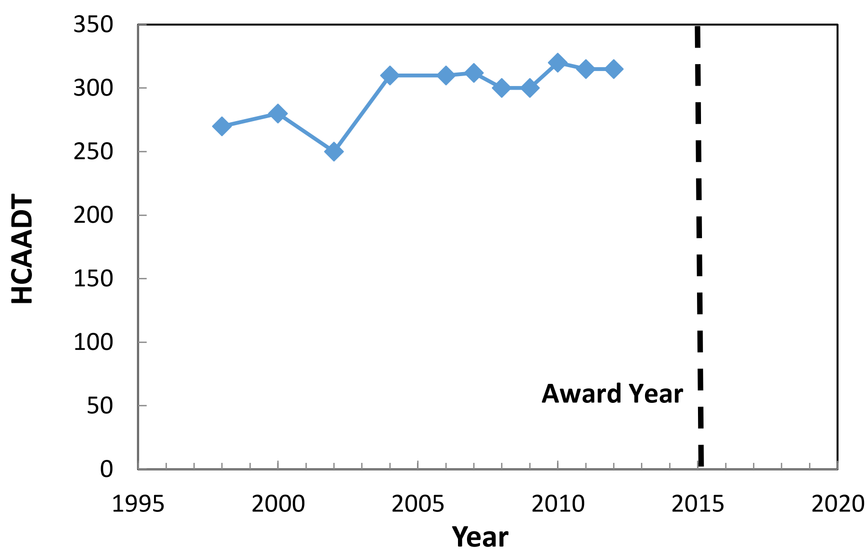

Figure 3-97 HCAADT vs. year for TH 71

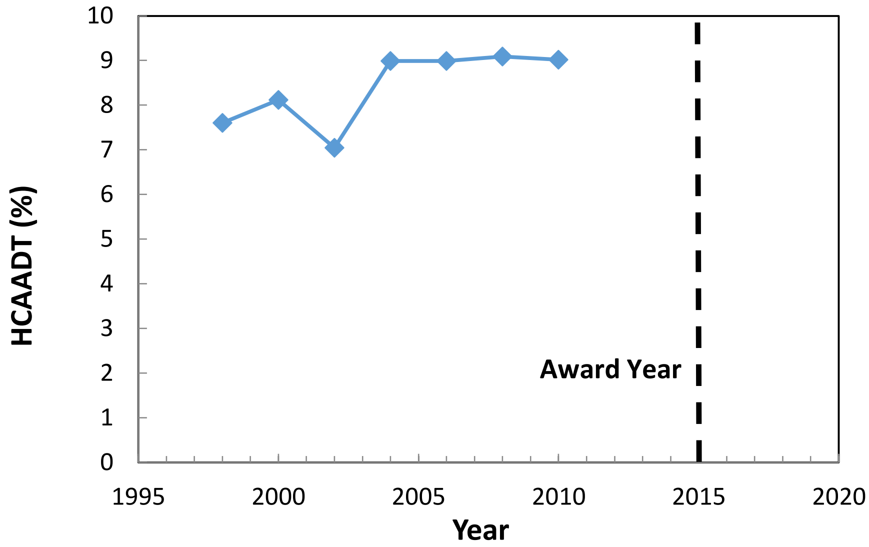

Figure 3-98 HCAADT (%) vs. year for TH 71

3.15 Summary and Discussion

From reviewing the Minnesota perpetual pavement award winner sections, the following common factors were identified:

- Most of the sections were constructed in the 1960s when the rate of construction was probably low. This might have resulted in better compaction, and therefore, performance improvements.[1]

- In most of the cases subgrade corrections were performed. Unsuitable material was excavated and adverse subsoil conditions were corrected. This could have led to an increase in the uniformity of compacted materials.

- After subgrade excavation, a select granular backfill material was used in subgrade correction areas which created a drainable, strong construction platform to pave against and provided long-lasting foundations.

- Use of non-frost susceptible base and subbase materials in underlying layers have improved the drainage resulting in improved performance.

- In some cases the upper portion of the granular subbase or aggregate base was treated with bituminous which has strengthened the foundation.

[1] Comment made by a Technical Advisory Panel member, Thomas Wood.

- In some cases a layer of prime coat was placed over the aggregate base before placing the asphalt layer(s). This has increased the integrity of the granular base and can reduce dust during construction.[2]

- In some cases the construction was extended over a year or more. This staged construction may have allowed the foundation to go through seasonal cycles and thus enhanced the overall pavement structural stability.

- Even though these projects were not designed as perpetual pavements, several projects had a road-mixed bituminous base material providing a flexible fatigue resistant base layer called for in the three layer perpetual pavement design. Road-mixed base could provide similar characteristics as current emulsion base stabilization materials used at MnRoad and various other projects throughout the state that have shown exceptional performance. Base stabilization not only provides a strong foundation for construction of perpetual pavements, but also creates a bound layer, thus transferring the maximum tensile strains deeper into the pavement structure which has shown to reduce the strain levels at the bottom of the upper HMA layers. Research has demonstrated that reduction of stress and strain to below a certain level at the bottom of the HMA layer increases the pavement fatigue life.

The above considerations in conjunction with good inspection and construction practices in the field at the time of placement, have enabled the award winner projects to service to the public for many years.

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[2] According to a Technical Advisory Panel member, Jill Thomas, placing a prime coat was making the construction process difficult and was discontinued later.

CHAPTER 4: IN-DEPTH ANALYSIS & EVALUATION (METRO)

This chapter focuses on the four project locations within the Metro District (District 5). These projects were selected because their information was expected to be more readily available and also for their ease of access for field sampling. These projects include:

- TH 10, 2004 winner
- TH 36, 2008 winner
- TH 95. 2013 winner
- TH 47, 2014 winner

To further investigate and characterize these sites and refine the rePave data analysis, the following field and laboratory testing were performed on these projects:

- Field testing: coring, hand auger borings, and Dynamic Cone Penetrometer (DCP) test in the selected core holes

- Laboratory testing:
    - Thickness and density
    - Asphalt content
    - Extracted gradation
    - Resilient Modulus (ASTM D 7369)

4.1 Field Testing

4.1.1 Coring and Hand Auger

Three sets of cores were taken from each roadway resulting in a total of 12 sets of cores from all the Metro District projects. Each core set contained three cores with different location characteristics:

- Cracked, wheelpath (CWP)
- Uncracked, wheelpath (UCWP)
- Uncracked, non-wheelpath (UNWP)

Figure 4-1 presents the coring plan layout at each coring location.

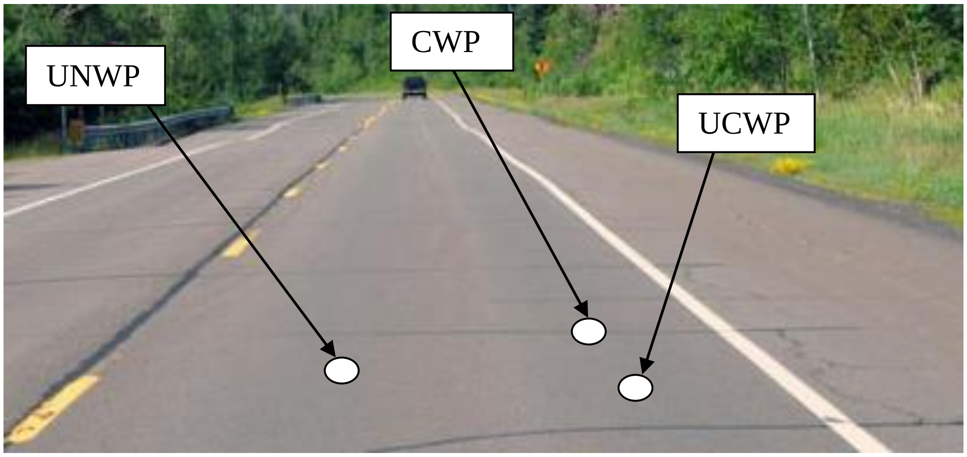

Figure 4-1 Coring Plan Layout

Among the Metro District projects TH 36, which was reconstructed in 2015, was in good condition and did not have any surface cracks in the wheelpath area in the proximity of the coring locations, so the core sets from this project had two cores from the uncracked locations only (UNWP and UCWP).

Table 4.1 presents the individual cores thicknesses, as well as the averages core thicknesses for each core set and each project. A total of 33 cores were obtained in this study. The individual core photos can be found in Appendix A of this report. As the core photos show, the core bottoms are generally in good physical condition even though they were in service for 40+ years.

The average core thicknesses in Table 4.1 are very close to the expected HMA thicknesses from the construction plans and maintenance histories presented in Chapter 3:

- TH 10 (2004): 9.9 inches from the plans, 9.9 inches from coring
- TH 36 (2008): 6.5 inches from the plans, 6.5 inches from coring
- TH 95 (2013): 6 inches from the plans, 5.4 inches from coring
- TH 47 (2014): 8 to 8.5 inches from the plans, 7.9 inches from coring

Table 4.1 Metro District projects core thickness data

Roadway	Set #	Core #	Core Location	Thickness (in.)	Avg. Thickness (in.)	Avg. Thickness (in.)
TH 10 (2004 winner)	Set 1	1	CWP	10	10.3	9.9
		2	UNWP	10 3/4		
		3	UWP	10		
	Set 2	4	CWP	6	8.7	
		5	UWP	10		
		6	UNWP	10		
	Set 3	7	CWP	10 1/4	10.8	
		8	UNWP	11 1/4		
		9	UWP	10 3/4		
TH 36 (2008 winner)	Set 4	19	UWP	7	6.9	6.5
		20	UNWP	6 3/4		
	Set 5	21	UWP	6 1/2	6.5	
		22	UNWP	6 1/2		
	Set 6	23	UWP	6 1/4	6.3	
		24	UNWP	6 1/4		
TH 95 (2013 winner)	Set 7	25	CWP	5	5.0	5.4
		26	UNWP	5 1/4		
		27	UWP	4 3/4		
	Set 8	28	CWP	6 1/4	6.3	
		29	UNWP	6 1/2		
		30	UWP	6		
	Set 9	31	CWP	4	5.0	
		32	UNWP	5		
		33	UWP	6		
TH 47 (2014 winner)	Set 10	10	CWP	8 1/2	8.8	7.9
		11	UNWP	9 1/2		
		12	UWP	8 1/4		
	Set 11	13	CWP	5 1/2	6.5	
		14	UNWP	8		
		15	UWP	6		
	Set 12	16	CWP	8	8.3	
		17	UNWP	8		
		18	UWP	9		

4.1.2 DCP testing

Three DCP tests were performed in each Metro District project to measure the strength of in-situ materials. DCP tests were performed in selected core holes (one test per coring location).

DCP test results are usually expressed in terms of Dynamic Penetration Index (DPI), defined as the vertical movement of the DCP cone produced by one drop of hammer, expressed in inch per blow. Figure 4-2 through Figure 4-4 show the DPI versus penetration depth for the four tested sections. As these graphs show, in almost all the cases, the DPI values are less than 0.3 inch/blow which is an indication of the in-situ materials being strong. The DCP penetration depth ranges between 5 to 11 inches, with an average of 8 inches.

Figure 4-6 compares the averaged DPI versus penetration depth for all the four projects on the same graph. As this graph suggests, the roadways are very similar in terms of in-situ material's strength with TH 47 being slightly weaker than the others.

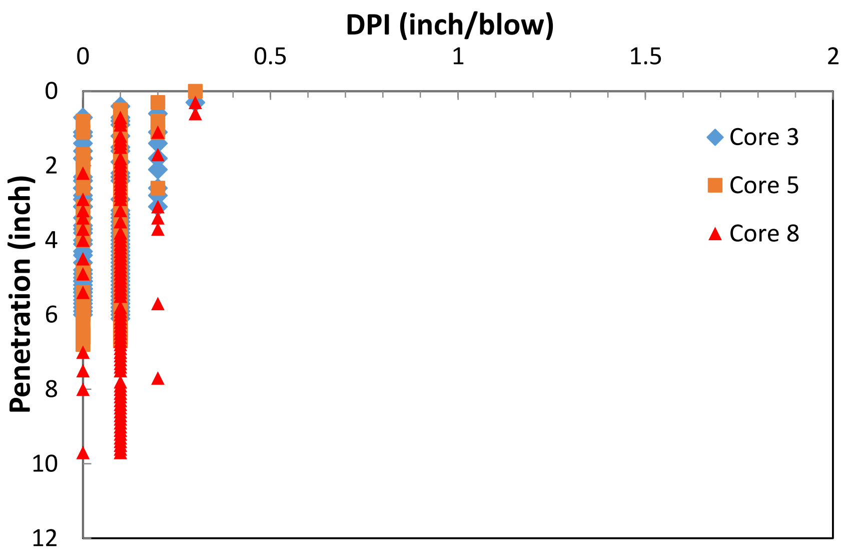

Figure 4-2 DPI versus penetration depth for TH 10 (2004 winner)

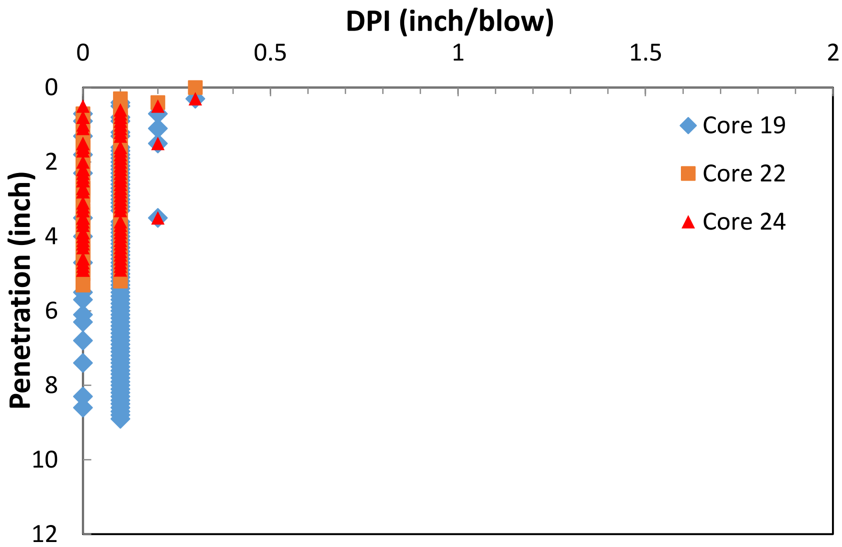

Figure 4-3 DPI versus penetration depth for TH 36 (2008 winner)

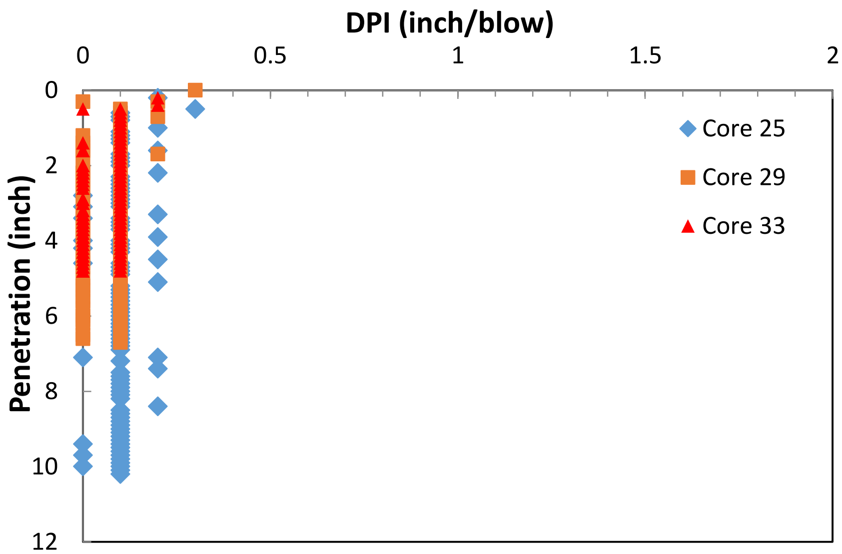

Figure 4-4 DPI versus penetration depth for TH 95 (2013 winner)

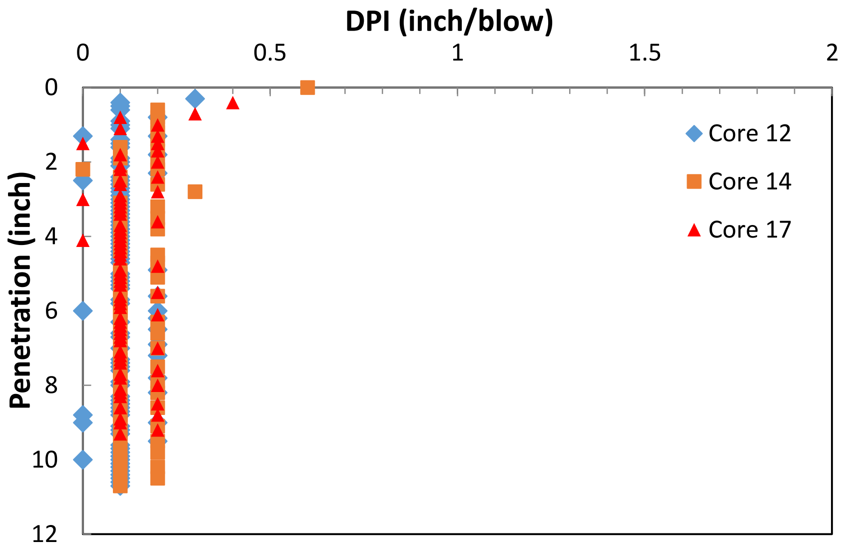

Figure 4-5 DPI versus penetration depth for TH 47 (2014 winner)

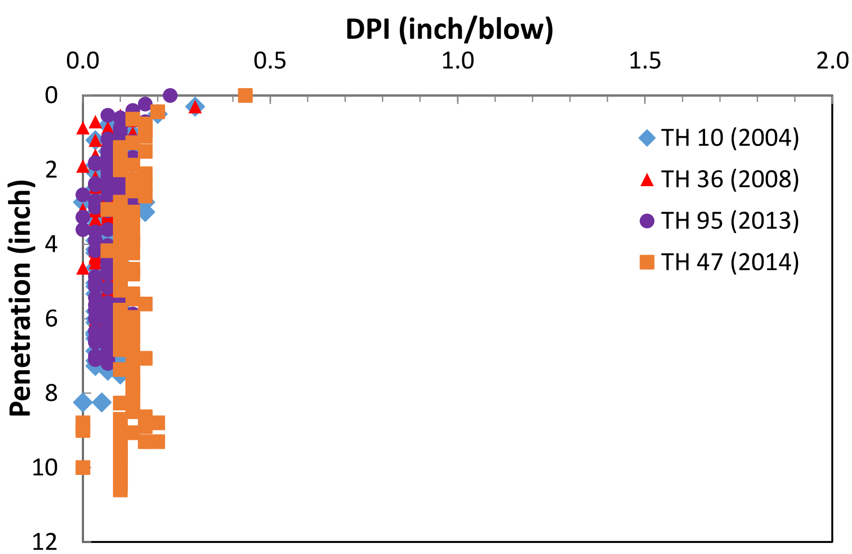

Figure 4-6 DPI versus penetration depth comparison for all the tested roadways

DPI can be converted to California Bearing Ratio (CBR) using the formula suggested by US Army Corps of Engineers (for CBR's greater than 10):

$$CBR = \frac{292}{DPI^{1.12}}$$

where,

DPI= Penetration Index in mm/blow.

Using the average DPI value for each roadway and the above formula, CBR can be calculated for each project:

- TH 10 (2004): CBR=100
- TH 36 (2008): CBR=100
- TH 95 (2013): CBR=100
- TH 47 (2014): CBR=84

As expected, all the projects resulted in high CBR values.

4.2 Laboratory Testing

4.2.1 Core Densities and Asphalt Contents

UWP and UNWP core densities were measured which Table 4.2 presents the results. The densities were measured on the whole cores. The CWP cores were cracked and crumbled in most of the cases, so their densities could not be measured.

As Table 4.2 shows, the individual densities generally range from 92 to 95%. Also, the average densities are very similar among the projects and range between 93 to 94%.

For each project a representative sample of asphalt mixture was tested for asphalt content. Surprisingly, the binder content was 5.3% for all the four projects. The theoretical maximum densities (Rice densities) were as follows:

- TH 10 (2004): 2.505
- TH 36 (2008): 2.538
- TH 95 (2013): 2.527
- TH 47 (2014): 2.506

Table 4.2 Metro District projects core densities

Roadway	Set #	Core #	Core Location	Relative Density (%)	Avg. Density (%)	Avg. Density (%)
TH 10 (2004)	Set 1	2A[1]	UNWP	93.6	92.6	93.3
		2B[1]	UNWP	91.5		
		3	UWP	92.6		
	Set 2	5	UWP	93.2	93.1	
		6	UNWP	92.9		
	Set 3	8	UNWP	94.6	94.4	
		9A[1]	UWP	96.0		
		9B[1]	UWP	92.6		
TH 36 (2008)	Set 4	19	UWP	94.2	93.5	93.4
		20	UNWP	92.8		
	Set 5	21	UWP	93.5	92.7	
		22	UNWP	91.8		
	Set 6	23	UWP	94.4	94.2	
		24	UNWP	93.9		
TH 95 (2013)	Set 7	26	UNWP	95.0	95.3	93.9
		27	UWP	95.6		
	Set 8	29	UNWP	92.8	93.8	
		30	UWP	94.7		
	Set 9	32	UNWP	92.4	92.7	
		33	UWP	93.0		
TH 47 (2014)	Set 10	11	UNWP	93.8	94.2	94.0
		12	UWP	94.5		
	Set 11	14	UNWP	93.7	94.1	
		15	UWP	94.5		
	Set 12	17	UNWP	93.3	93.8	
		18	UWP	94.3		

[1]two-piece core

4.2.2 Extracted Gradations

Table 4.3 shows percent passing for different sieve sizes for all the four projects. Figure 4-7 through Figure 4-10 present the same data on the gradation charts. All the projects had a Nominal Maximum Aggregate Size (NMAS) of 1/2 inches. The Superpave gradation control points (through which aggregate gradations must pass) are also shown on these graphs to see if the gradations meet Superpave guidelines. As Figure 4-7 through Figure 4-10 show, even though the majority of the in-place asphalt mixtures were produced before the Superpave mix design method was developed, all the gradations satisfy Superpave control points. An appropriate aggregate gradation helps with the stability and durability of asphalt mixture and could be one reason for these sections to have lasted for extended periods of time.

Figure 4-11 compares all the gradations on the same graph. As this graph suggests, the gradations are about the same with TH 36 (2008 winner) being a little coarser, and TH 10 (2004) being a little finer than the other mixtures.

Figure 4-12 shows all the gradations on the same graph with MnDOT type B aggregate gradation (maximum aggregate size of 3/4 inches) control points. As this graph shows all the mixture are equal to Type B aggregate according to MnDOT Specification 3139.2.B (2016).

Table 4.3 Extracted gradations

Sieve Size	%Passing			
	TH 10 (2004)	TH 36 (2008)	TH 95 (2013)	TH 47 (2014)
3/4 in	100	100	100	100
1/2 in	93	95	97	95
3/8 in	87	85	87	85
No. 4	68	64	67	61
No. 8	53	47	51	48
No. 16	40	33	39	36
No. 30	28	23	26	23
No. 50	16	14	14	12
No. 100	8	7	7	6
No. 200	5.1	5.1	4.7	3.6

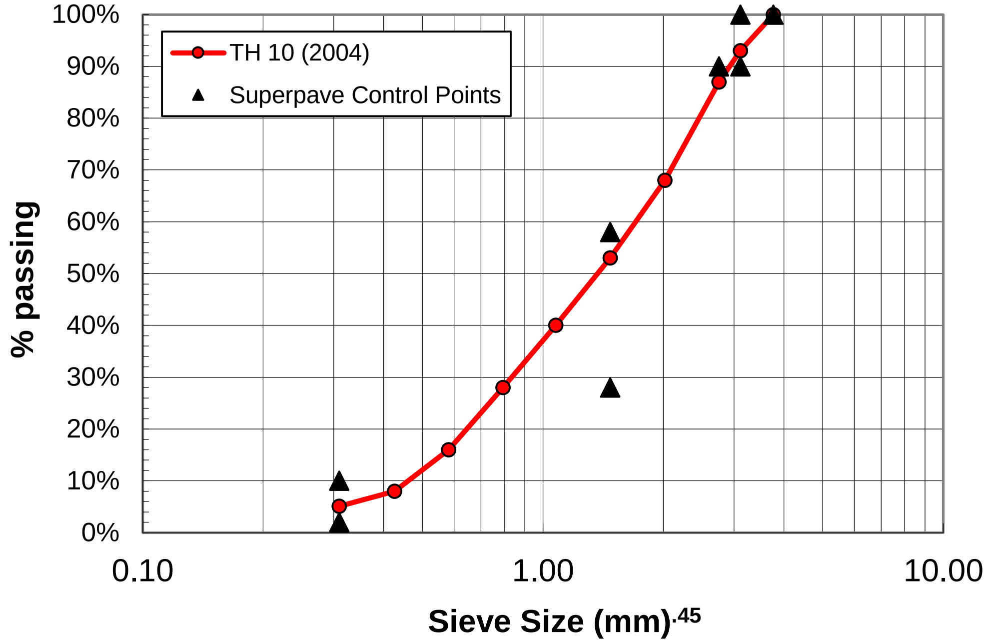

Figure 4-7 Extracted gradation; TH 10 (2004 winner)

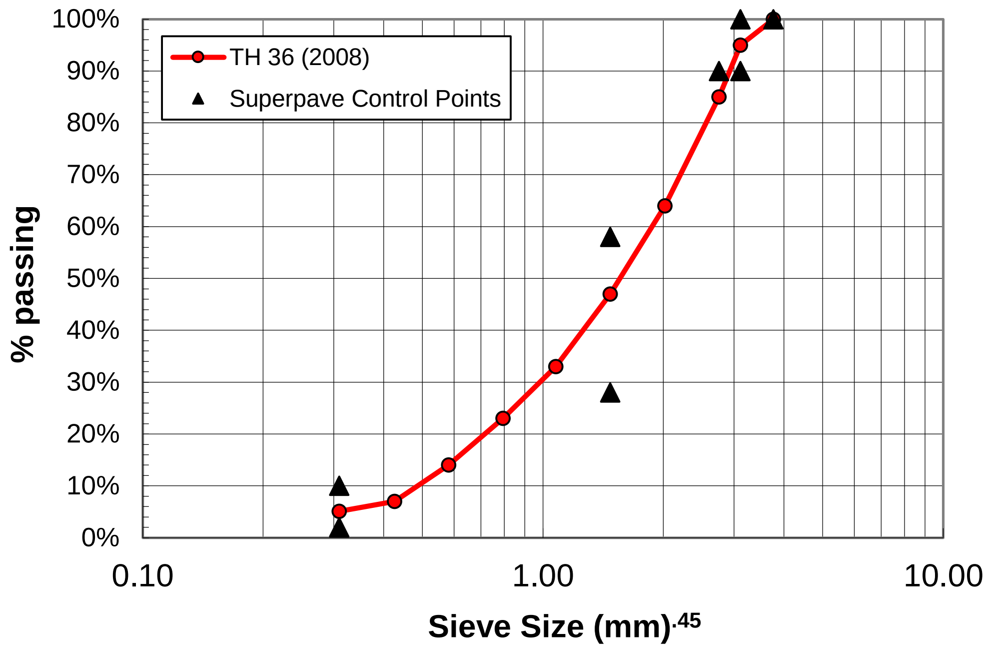

Figure 4-8 Extracted gradation; TH 36 (2008 winner)

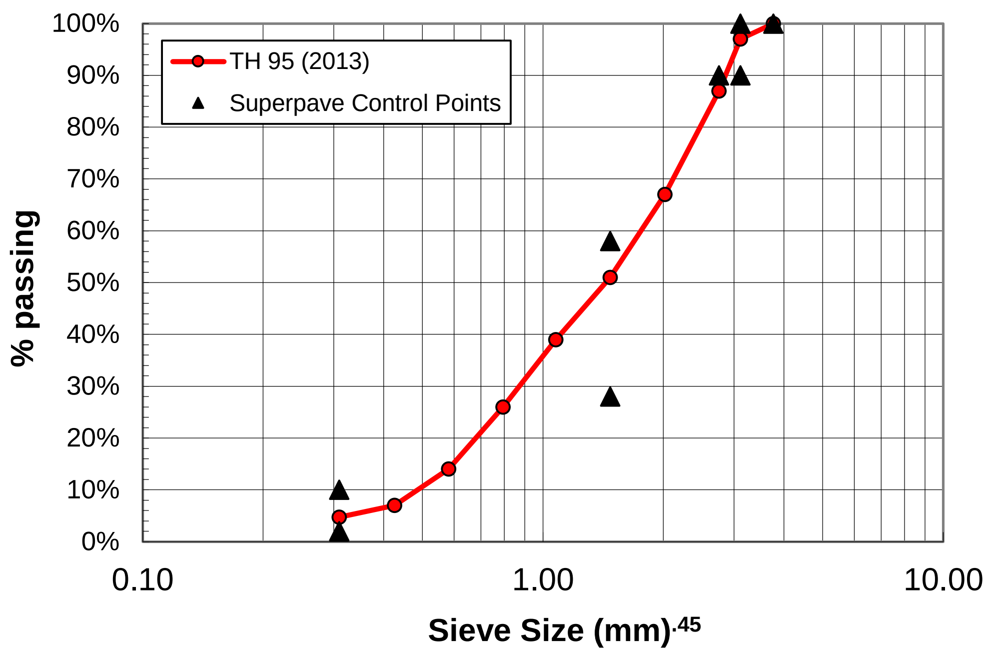

Figure 4-9 Extracted gradation; TH 95 (2013 winner)

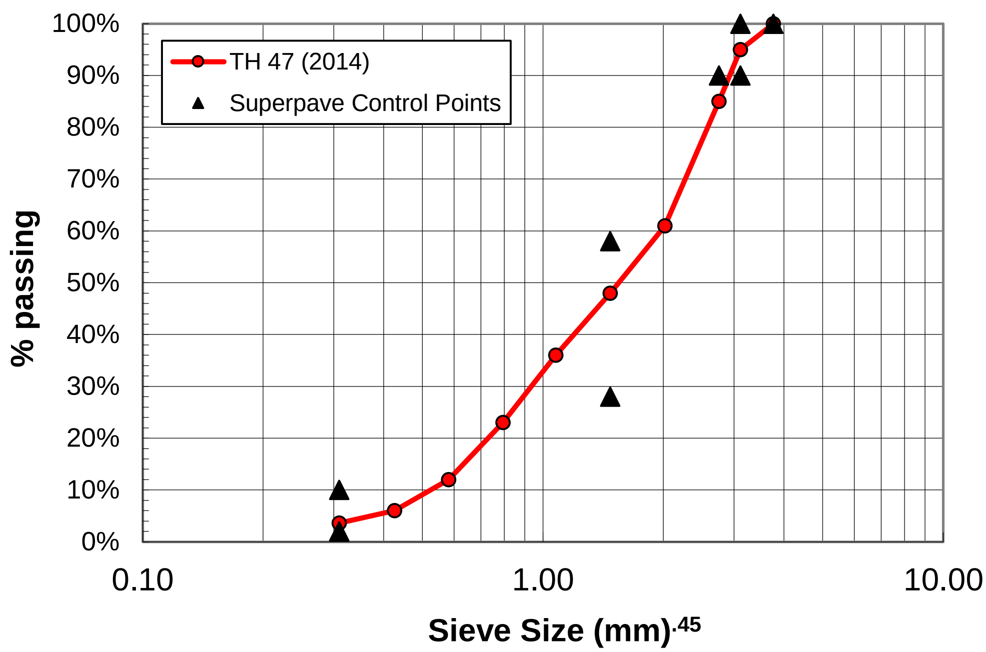

Figure 4-10 Extracted gradation; TH 47 (2014 winner)

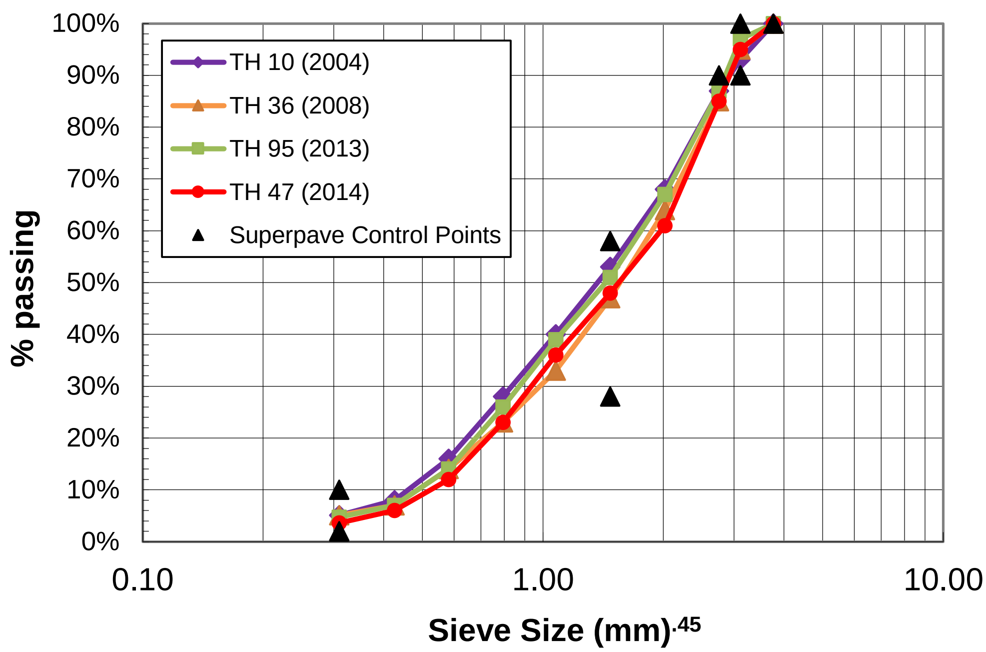

Figure 4-11 Extracted gradation; all Metro sections with Superpave control points

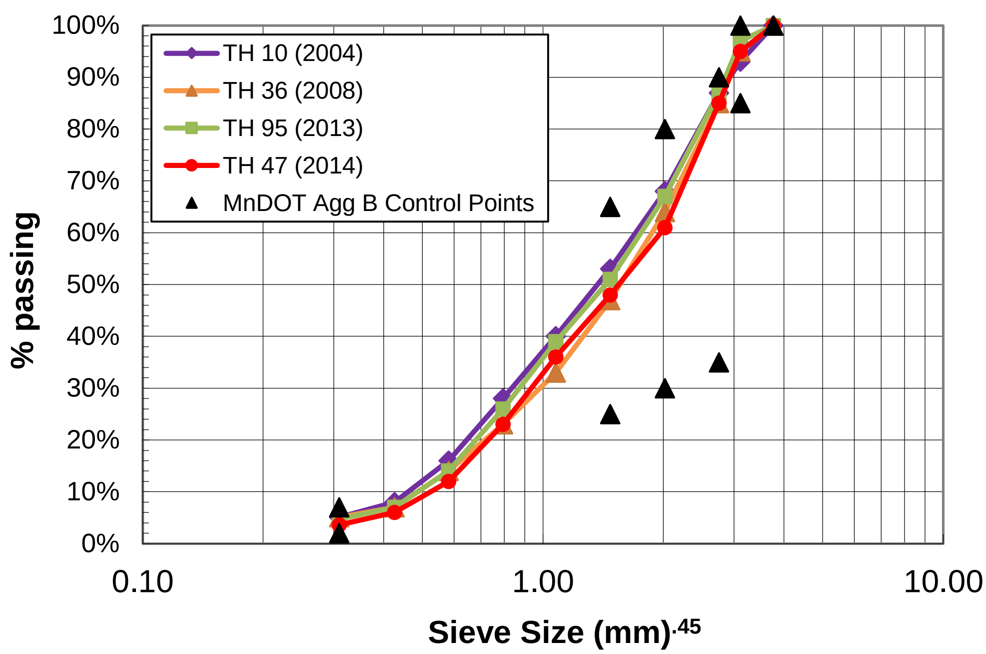

Figure 4-12 Extracted gradation; all Metro sections with MnDOT Type B control points

4.2.3 Resilient Modulus Test

Resilient Modulus (RM) tests were performed on the pucks obtained from the bottom of the un-cracked non-wheelpath cores (UNWP). These materials were in place for a long time and ideally, have been made from durable, fatigue resistance HMA as they have withstood the maximum tensile strain, which happens at the bottom of the asphalt layer, for an extended period of time. Figure 4-13 through Figure 4-16 show the side view of the UNWP cores after the bottom existing stripping were trimmed off.

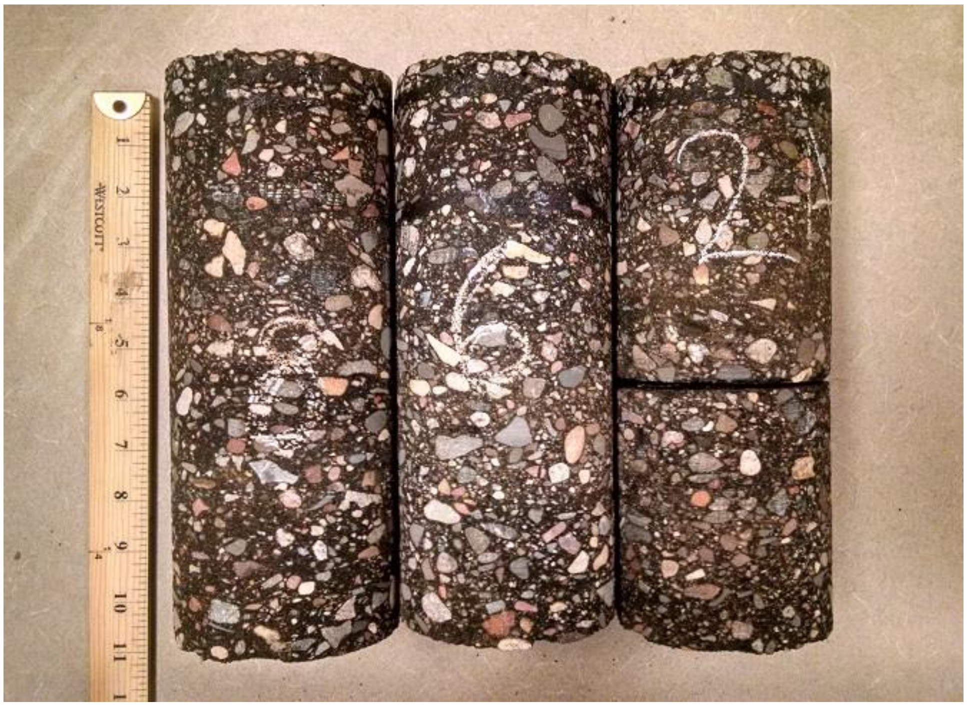

Figure 4-13 TH 10 (2004) cores used for RM (Cores 2, 6, and 8)

Figure 4-14 TH 36 (2008) cores used for RM (Cores 20, 22, and 24)

Figure 4-15 TH 95 (2013) cores used for RM (Cores 26, 29, and 32)

Figure 4-16 TH 47 (2014) cores used for RM (Cores 11, 14, and 17)

ASTM D 7369 requires the RM test be performed at 25°C, but since all these sections have survived Minnesota's long winters for an extended period of time, RM tests were also performed at a low temperature of -5°C. The spread of 30 degree Celsius could show how different the materials perform at different temperatures. Table 4.4 presents the RM testing results.

Table 4.4 Resilient Modulus testing results

Roadway	Core #	Temp. (°C)	RM (ksi)	Avg. RM at 25°C (ksi)	Avg. RM at -5°C (ksi)	RM ratio[(1)]
TH 10 (2004)	2	25	680	707	2,415	3.4
		-5	2,155			
	6	25	882			
		-5	2,532			
	8	25	558			
		-5	2,558			
TH 36 (2008)	20	25	NA[(2)]	260	2,316	8.9
		-5	NA[(2)]			
	22	25	208			
		-5	2,093			
	24	25	312			
		-5	2,539			
TH 95 (2013)	26	25	359	488	2,755	5.6
		-5	2,427			
	29	25	630			
		-5	3,423			
	32	25	476			
		-5	2,415			
TH 47 (2014)	11	25	509	362	2,490	6.9
		-5	3,098			
	14	25	292			
		-5	2,178			
	17	25	285			
		-5	2,193			

[(1)]ratio of RM at -5°C to RM at 25°C
[(2)]sample broke during testing

As Table 4.4 shows the RM value at 25°C ranges approximately between 250 and 700 ksi which suggests there are noticeable differences in the material's behavior at medium temperatures. It is interesting to note that at the low temperature of -5°C, these differences appear to be much less pronounced, as the RM value ranges approximately between 2,300 and 2,750 ksi. In other words, at low temperatures, different mixtures appear to perform similarly. This could be one reason for the similar long-life behavior of theses pavements, as they have been subjected to the low temperature condition in a substantial portion of a year (up to 5 to 6 months) in the state of Minnesota.

4.3 rePave Program

The rePave program was utilized to analyze Metro District projects. This program provides guidance for deciding where and under what conditions to use existing pavement as part of roadway renewal projects and identifies new alternatives to renewal approaches. These alternatives determine what needs to be done at the time of analysis, to keep these long-lived perpetual pavements to serve for another extended period of time, up to 50 years.

The rePave analysis was performed twice for each project: 1) in the current year (2016), and 2) in the year which the first overlay was performed.

The following assumptions were made in running the rePave program:

- The coring information was used for the total HMA thickness in 2016. Underlying layer thicknesses (base and subbase) and the HMA thickness in the year of the first overlay were obtained from the construction plans information presented in Chapter 3.
- No height restriction was assumed.
- The design period was assumed to be 30 years in all the cases.
- An existing base modulus of 50,000 psi was assumed due to high CBR values from the field DCP tests.
- Due to the subgrade corrections which were performed during the initial construction in majority of the projects, a resilient modulus of 20,000 psi (CBR of 13%) was assumed for the subgrade soils.

To evaluate the sensitivity of rePave program to the assumed base and subgrade modulus values, a sensitivity analysis was performed which is presented in Section 4.3.4 of this report.

4.3.1 Existing Pavement Conditions

The MnDOT pavement condition data was used to determine rePave inputs for the existing pavement conditions. Table 4.5 shows how the MnDOT distress types were converted to the required inputs.

Table 4.5 Existing Pavement Conditions

rePave Input	MnDOT Distress Type
Fatigue cracking (%)	Sum of the longitudinal cracking (%) and the longitudinal joint deterioration (%) and block cracking (%)
Patching (%)	Sum of patching (%) and alligator cracking (%)
Rutting (in)	Average rut depth (in)
Transverse cracking (per 100 feet)	Transverse cracking (%) was converted to the number of cracks
Stripping	Assumed to be present where raveling was reported

The measured pavement distresses (percentages) in 2015 were as follows:

TH 10 (in 2015):

- Transverse cracking (Low severity): 32%
- Longitudinal Joint Deterioration (Low severity): 25%

TH 36 (in 2015):

- Transverse cracking (Low severity): 1%
- Longitudinal Joint Deterioration (Low severity): 12%

TH 95 (in 2015):

- Transverse cracking (Low severity): 13%
- Transverse cracking (Medium severity): 5%
- Longitudinal cracking (Low severity): 8%
- Block cracking: 42%
- Rutting: 1%
- Longitudinal Joint Deterioration (Low severity): 69%

TH 47 (in 2015):

- Transverse cracking (Low severity): 24%
- Longitudinal cracking (Low severity): 2%
- Longitudinal Joint Deterioration (Low severity): 92%

The measured pavement distresses (percentages) before the first overlay was performed were as follows:

TH 10 (in 1976):

- Transverse cracking (Low severity): 97%
- Longitudinal cracking (Low severity): 24%
- Block cracking: 9%
- Alligator cracking: 1%
- Patching: 4%

TH 36 (in 1984):

- Transverse cracking (Low severity): 16%
- Transverse cracking (High severity): 22%
- Longitudinal cracking (Low severity): 21%
- Block cracking: 13%

TH 95 (in 1990):

- Transverse cracking (Low severity): 28%
- Transverse cracking (High severity): 13%
- Longitudinal cracking (Low severity): 25%
- Longitudinal cracking (High severity): 3%
- Block cracking: 12%

TH 47 (in 1990):

- Transverse cracking (Low severity): 14%
- Transverse cracking (High severity): 18%
- Longitudinal cracking (Low severity): 15%
- Longitudinal cracking (High severity): 8%
- Block cracking: 14%
- Rutting: 3%
- Raveling: 6%

4.3.2 rePave Traffic Calculation

Equivalent Single Axle Loads (ESALs) were calculated using MnDOT State Aid 10 Ton ESAL Traffic Forecast Calculator. ADT in 2016 and in the year of first overlay were calculated using the compound traffic growth function derived for each project in Chapter 3. The percentage of HCAADT and the growth rates were also calculated in Chapter 3. Table 4.6 and Table 4.7 present the calculated ESAL's (per year), for 2016 and the year in which the first overlay was performed, respectively.

Table 4.6 Estimated ESALs for Metro award winners – design in the current year (2016)

	TH 10 (2004)	**TH 36 (2008)**	**TH 95 (2013)**	**TH 47 (2014)**
ADT in 2016	73,000	31,000	14,000	39,000
Truck (%)	4.7	3.7	5.6	3.4
Growth rate (%)	0.66	0.41	0.66	0.31
20-year forecast	8,196,000	2,941,000	2,087,000	3,079,000
ESAL (per year)	**410,000**	**147,000**	**104,000**	**154,000**

Table 4.7 Estimated ESALs for Metro award winners – design in the year of the first overlay

	TH 10 (2004)	TH 36 (2008)	TH 95 (2013)	TH 47 (2014)
Year of the first overlay	1978	1987	1992	1989
ADT in the year of first overlay	57,000	27,000	12,000	36,000
Truck (%)	4.7	3.7	5.6	3.4
Growth rate (%)	0.66	0.41	0.66	0.31
20-year forecast	6,410,000	2,620,000	1,739,000	2,851,000
ESAL (per year)	**321,000**	**131,000**	**87,000**	**143,000**

4.3.3 rePave Results

rePave program renewal options is directly related to whether or not transverse cracking (thermal cracking) are present. When transverse cracking is present, the renewal options will include Full Depth Reclamation (FDR) or full depth removal (remove and replace), regardless of what the other distresses show. Transverse cracking is expected to be present in most of Minnesota's pavement since it is located in a cold region. The following three repair options are suggested by rePave for sections with transverse cracking:

1) **Full Depth Reclamation (FDR) and overlay**: HMA overlay over pulverized existing pavement: pulverize existing flexible pavement to eliminate all cracking and materials related damage and overlay with HMA.

2) **Stabilized Full Depth Reclamation (SFDR) and overlay**: HMA overlay over pulverized existing flexible pavement: pulverize existing flexible pavement to eliminate all cracking and treat pulverized material to produce treated base and overlay with HMA.

3) **Full Depth Mill and overlay**: HMA overlay after removing and replacing existing HMA where needed: remove and replace existing HMA because of stripping or other materials related distress then overlay with HMA. For stripping this may be limited for the stripped layers and for the top-down cracking it will be limited to the top 2 inches of HMA.

When transverse cracking is not present, the renewal options can also include:

1) **Patch and overlay**: Patch existing HMA where fatigue cracking or top-down cracking is less than 10%, then overlay with HMA.

2) **Mill and overlay**: Remove and replace existing HMA because of stripping or any other materials related distress then overlay with HMA. For stripping this may be limited to the stripped layers and for the top-down cracking it will be limited to the top 2 inches of HMA.

4.3.3.1 rePave recommendations in the current year (2016)

For TH 10, TH 95, and TH 47 where transverse cracking was present, the rePave repair recommendation were FDR and overlay, SFDR and overlay, and full depth mill and overlay. Figure 4-17 through Figure 4-25 present the rePave outputs for these three options for TH 10, TH 96, and TH 47.

For TH 36, most of which was reconstructed for a new bridge alignment in 2015, the transverse cracking percentage in 2015 was only 1%, so no transverse cracking was assumed for this section. For TH 36 the rePave renewal recommendation was to mill the top 2 inches and overlay with 3 inches of HMA. Figure 4-26 shows the repave output for this project.

From the rePave results, the total recommended new pavement thickness for the Metro District projects in 2016 are as follows:

- TH 10 (2004): 8.5 inches
- TH 36 (2008): 3 inches
- TH 95 (2013): 7.5 inches
- TH 47 (2014): 7.5 inches

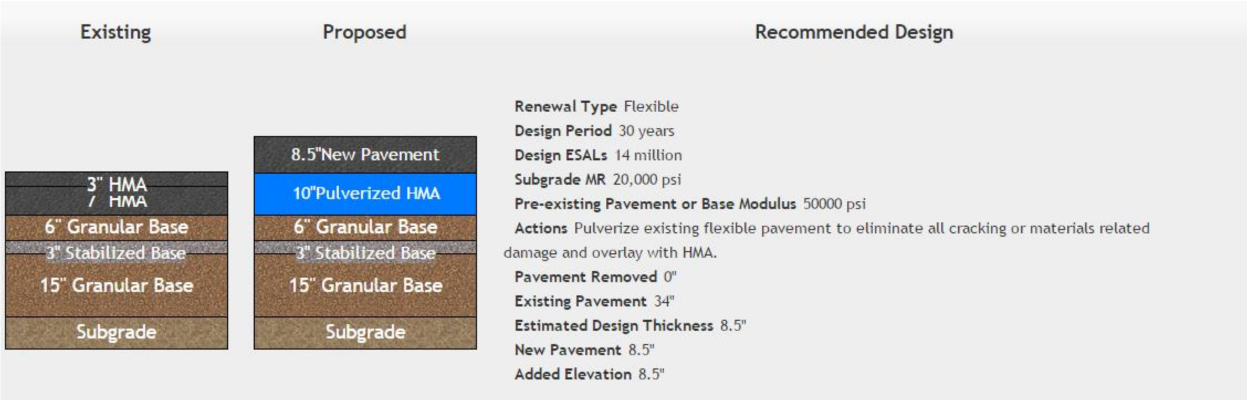

Figure 4-17 rePave output for TH 10 (2004) – FDR and overlay

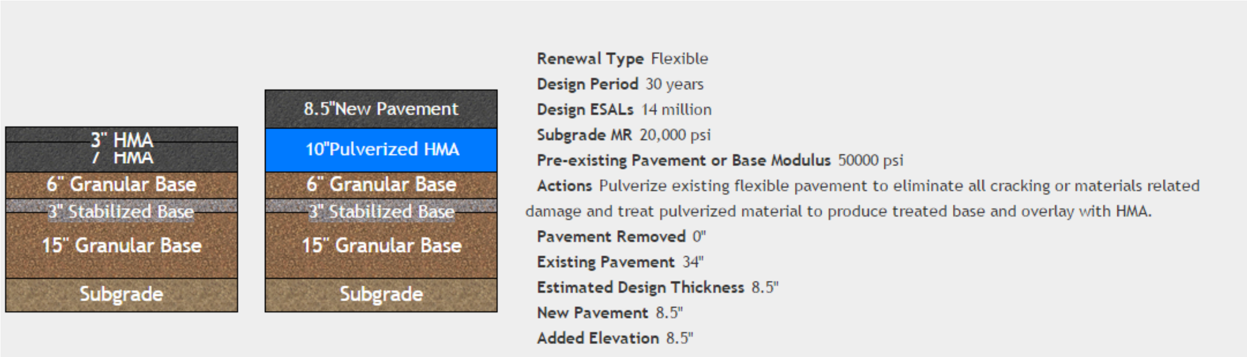

Figure 4-18 rePave output for TH 10 (2004) – SFDR and overlay

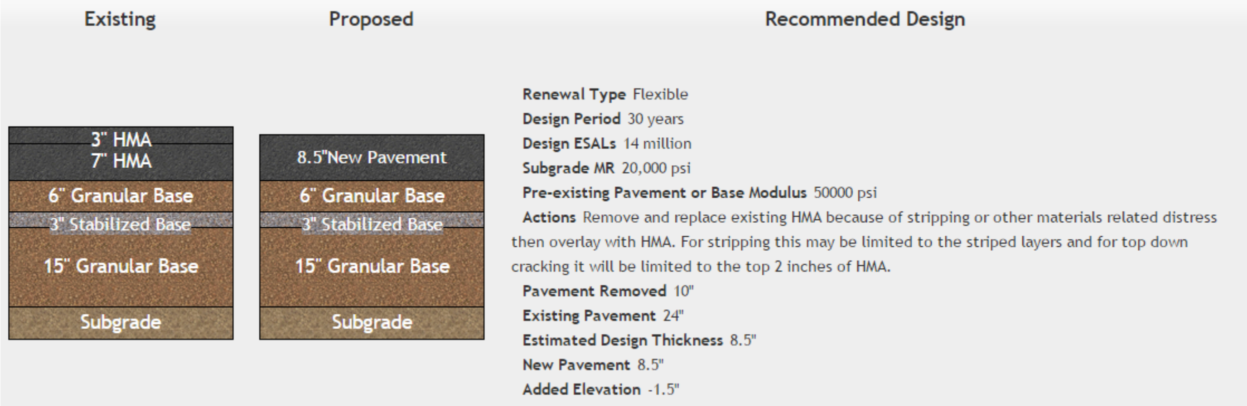

Figure 4-19 rePave output for TH 10 (2004) – Full depth mill and overlay

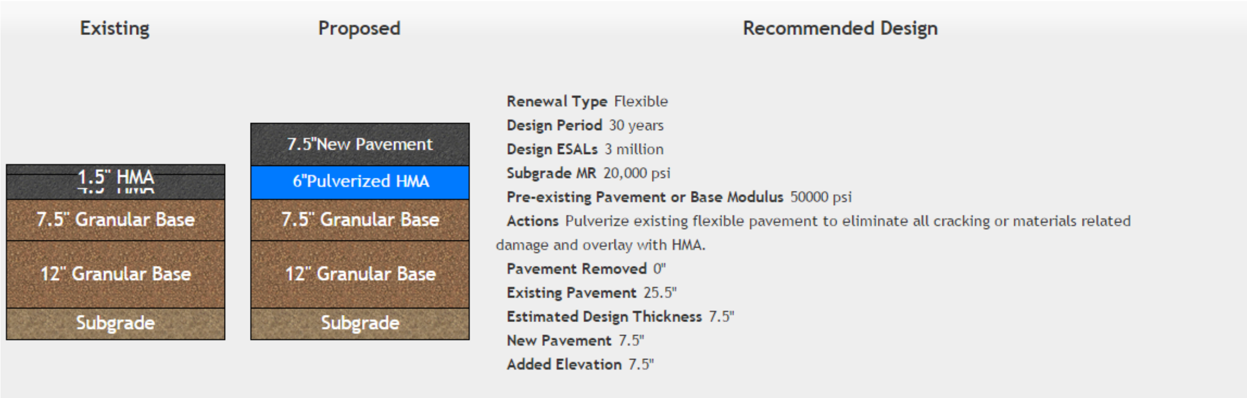

Figure 4-20 rePave output for TH 95 (2013) – FDR and overlay

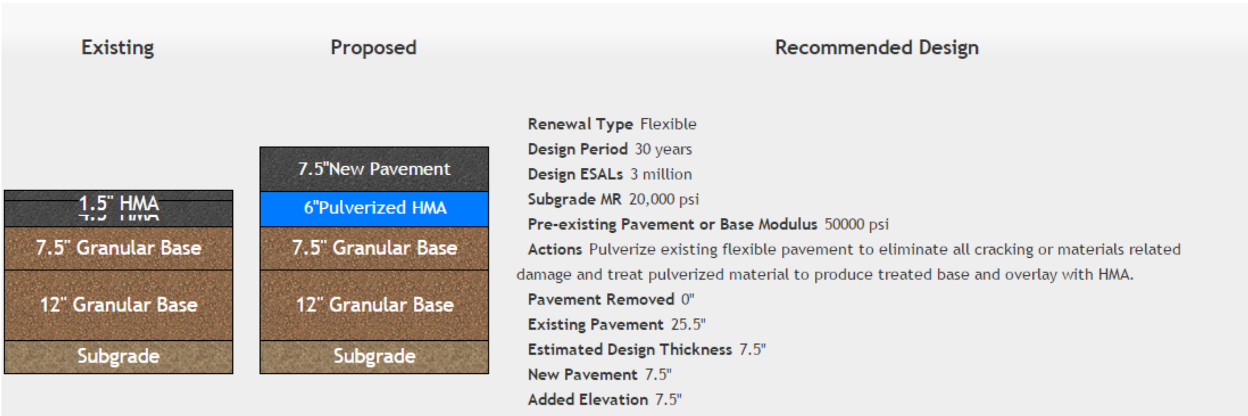

Figure 4-21 rePave output for TH 95 (2013) – SFDR and overlay

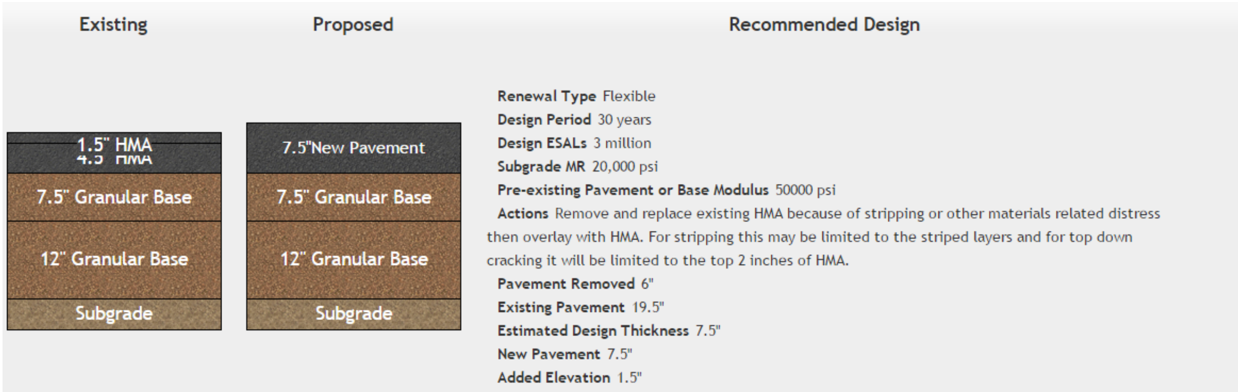

Figure 4-22 rePave output for TH 95 (2013) – Full depth mill and overlay

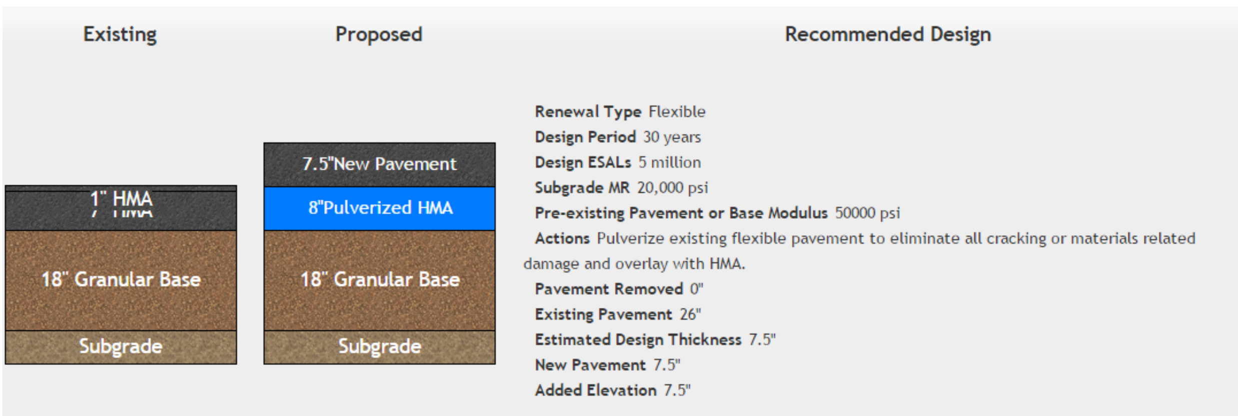

Figure 4-23 rePave output for TH 47 (2014) – FDR and overlay

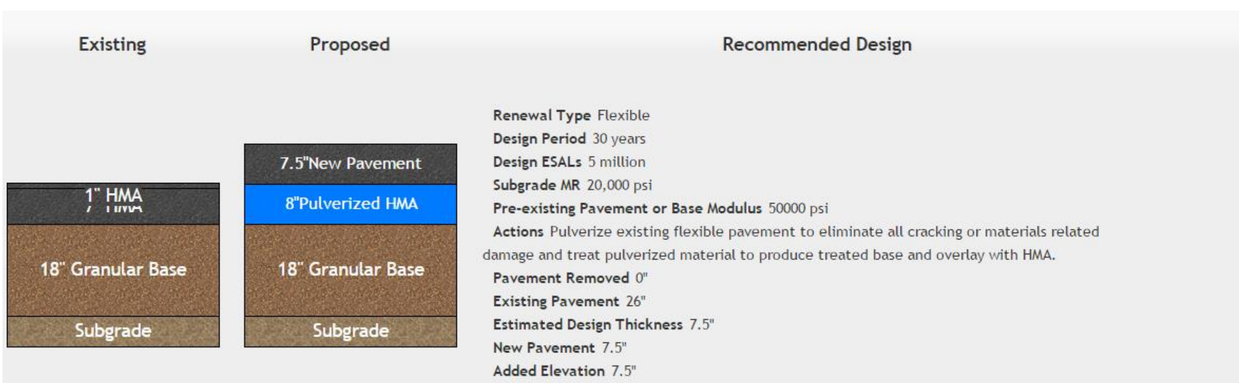

Figure 4-24 rePave output for TH 47 (2014) – SFDR and overlay

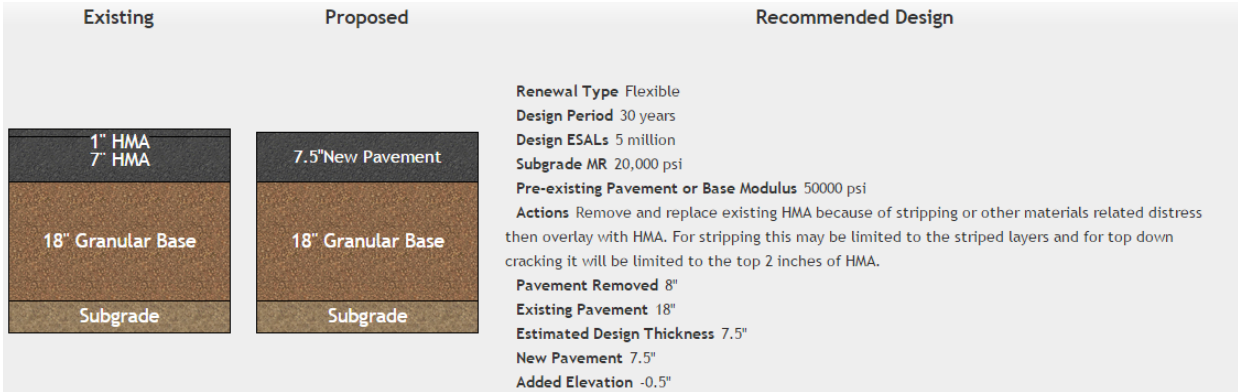

Figure 4-25 rePave output for TH 47 (2014) – Full depth mill and overlay

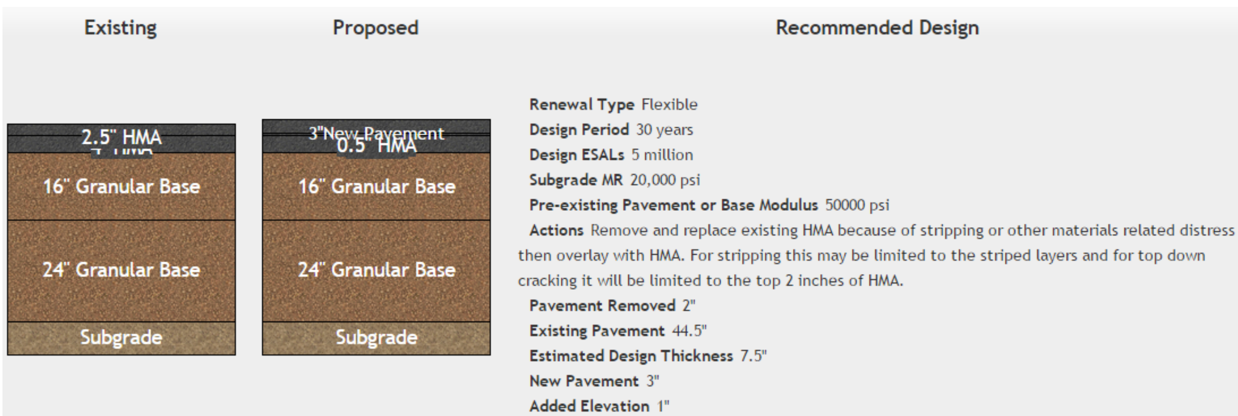

Figure 4-26 rePave output for TH 36 (2008) – Mill and overlay

4.3.3.2 rePave recommendations in the year of the first overlay

In the year in which the first overlay was performed, all the sections had transverse cracking, so rePave repair recommendation was remove and replace (FDR and overlay, SFDR and overlay, and full depth mill and overlay) for all the projects.

The required pavement thicknesses were as follows:

- TH 10 (2004): 8.5 inches
- TH 36 (2008): 7.5 inches
- TH 95 (2013): 7.5 inches
- TH 47 (2014): 7.5 inches

None of these recommendations were actually performed on these sections in the year of the first overlay; TH 10 and TH 95 received an overlay and TH 36 and TH 47 received a partial depth mill and overlay in that year.

It is interesting to note that the required pavement thicknesses from the above remove and replace rePave runs are fairly close to the actual pavement thicknesses (Table 4.1) which indicates that the perpetual pavement award winner projects in the Metro District compare to the rePave program recommendations fairly well. It should be noted that the rePave program has been calibrated for the average temperature found in US, not for the extreme Minnesota environment, so some variations would be expected. Even though the PerRoad program was not utilized in this study due to several unknown program inputs, it is expected that the PerRoad runs generally result in about one inch thinner estimates than for the rePave.

It should also be noted that rePave a in the year of the first overlay and in 2016 are the same, except for TH 36 which only required a mill and overlay in 2016. This is because the rePave program traffic intervals are defined as follows:

1) ESALs < 10 millions
2) 10 millions < ESALs < 25 millions
3) 25 millions < ESALs < 50 millions
4) 50 millions < ESALs < 100 millions
5) 100 millions < ESALs < 200 millions

TH 10 30-year ESAL falls in the second interval for both the current year and the year of the first overlay, while TH 36, TH 95, and TH 47 30-year ESALs fall in the first interval (less than 10 millions) in the both cases, and therefore, recommended thicknesses have turned out to be the same.

4.3.4 <u>rePave Sensitivity Analysis</u>

To evaluate the sensitivity of rePave program to the assumed input values for the subgrade and base modulus, multiple runs were performed for a section with 30-year ESALs of less than 10 million (to cover TH 36, TH 95, and TH 47) and for another section with ESALs between 10 to 25 million (to cover TH 10). The assumed subgrade and base modulus were as follows:

- Subgrade modulus: 5,000 psi, 10,000 psi, and 20,000 psi
- Base modulus: 30,000 psi, 50,000 psi, 75,000 psi, and 100,000 psi

Table 4.8 and Table 4.9 show the required thicknesses for different combinations of subgrade and base modulus for TH 10 and TH 36, TH 95, and TH 47, respectively.

Table 4.8 rePave sensitivity analysis on TH 10

Required Pavement Thickness (in)		**Base Modulus (psi)**			
		30,000	**50,000**	**75,000**	**100,000**
Subgrade Resilient Modulus (psi)	**5,000**	11	10	8.5	6.5
	10,000	11	9	8	6.5
	20,000	10	8.5	7	6

Table 4.9 rePave sensitivity analysis on TH 36, TH 95, and TH 47

Required Pavement Thickness (in)		**Base Modulus (psi)**			
		30,000	**50,000**	**75,000**	**100,000**
Subgrade Resilient Modulus (psi)	**5,000**	10	9	8	6
	10,000	10	8	7	6
	20,000	9.5	7.5	6.5	5.5

Figure 4-27 presents the required pavement thickness versus base modulus at different subgrade modulus levels of 5,000, 10,000, and 20,000 psi. As these graphs suggest, when the subgrade modulus is constant, the required pavement thickness decreases approximately 0.3 inches for every 5000 psi increase in the base modulus.

Figure 4-28 presents the required pavement thickness versus subgrade modulus at different base modulus levels of 30,000, 50,000, 75,000, and 100,000 psi. As these graphs suggest, when the base modulus is constant, the required pavement thickness decreases approximately between 0.2 to 0.5 inches for every 5000 psi increase in the subgrade modulus.

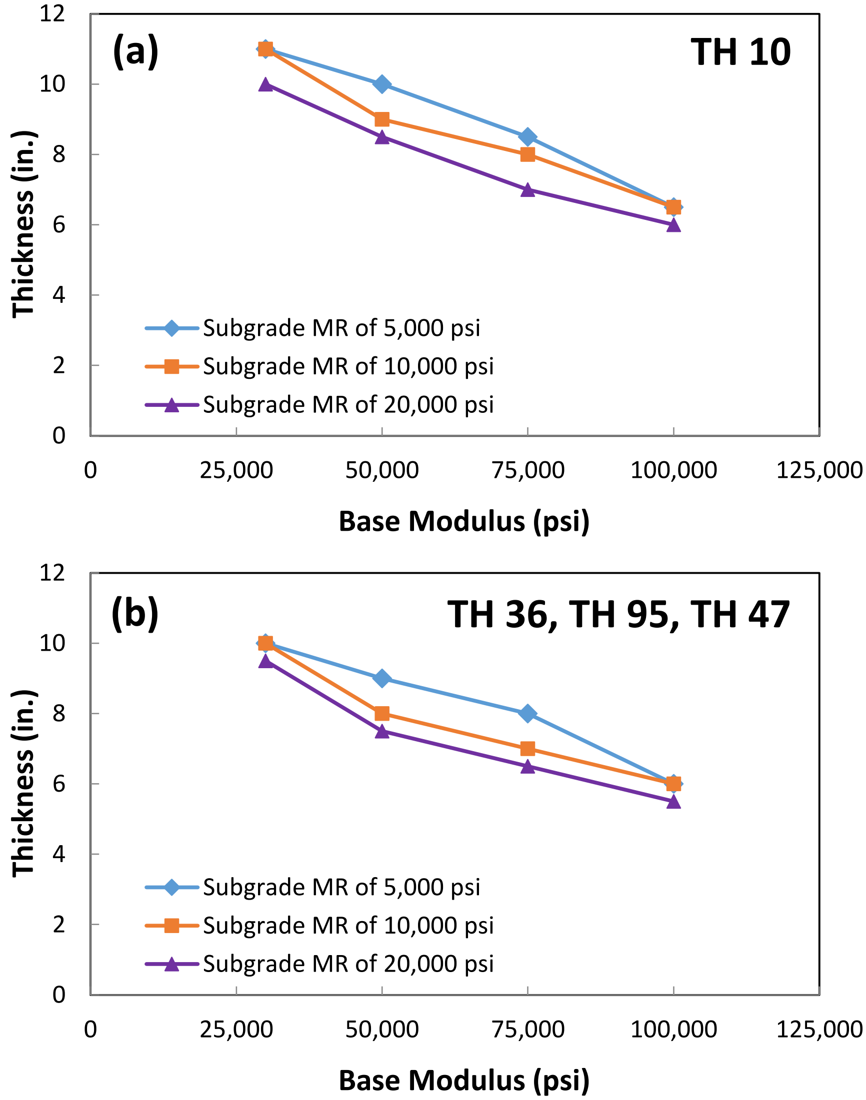

Figure 4-27 Pavement thickness vs. base modulus at different subgrade modulus values for: a) TH 10 and b) TH 36, TH 95, and TH 47

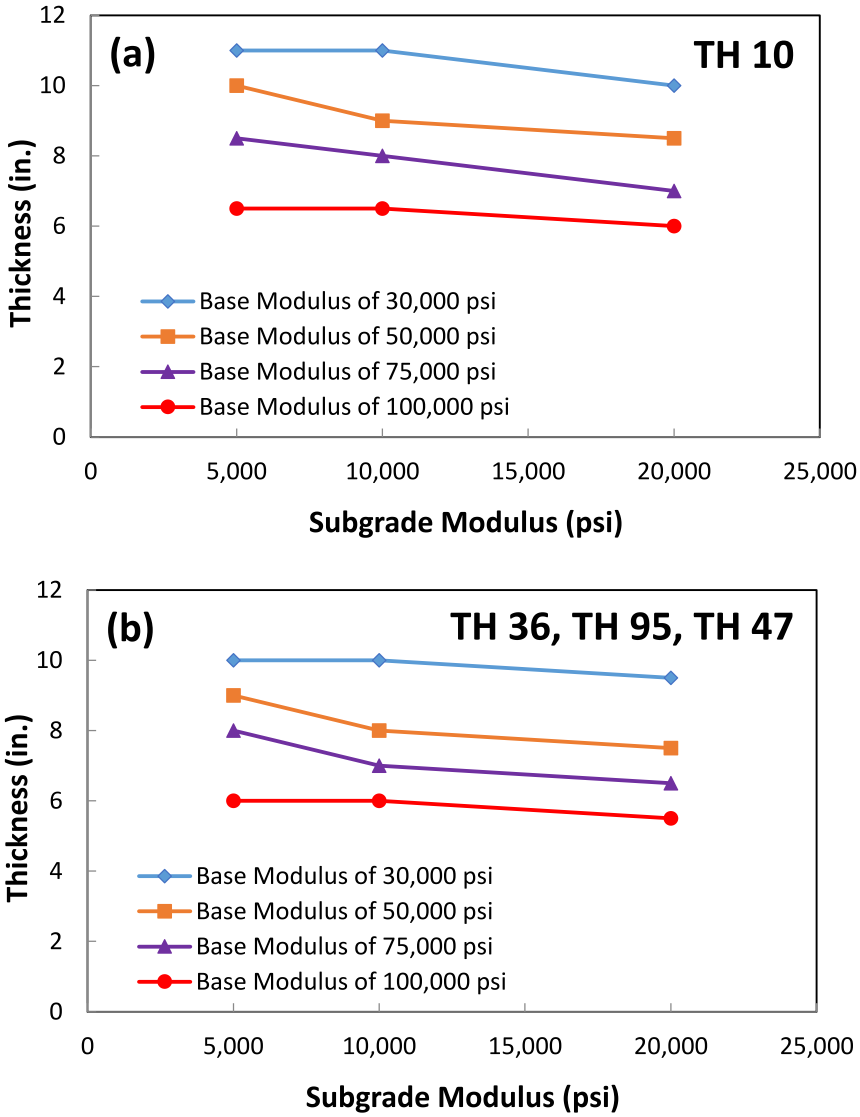

Figure 4-28 Pavement thickness vs. subgrade modulus at different base modulus values for: a) TH 10 and b) TH 36, TH 95, and TH 47

4.4 Summary and Discussion

The following conclusions can be made from the laboratory tests performed on the Metro District projects:

- Most of the test results were similar among all the projects. It could be because all the projects have shown excellent performance despite their long ages. In other words comparing the test results from these projects essentially means comparing a "good" pavement against another "good" pavement.

- Coring of the projects resulted in HMA thicknesses similar to the expected thicknesses from the construction plans and maintenance histories. Average core densities and asphalt binder contents were about the same in all the sections.

- DCP testing results indicated that the in-situ materials were strong with high CBR values in all the tested sections.

- The extracted aggregate gradations from different projects, satisfied the Superpave control points. This was while the majority of the in-place asphalt mixtures were produced before the Superpave mix design method was developed. Having appropriate aggregate gradations should have helped with the stability and durability of asphalt mixtures which eventually have extended the life of these pavements.

- Resilient Modulus testing showed that the asphalt mixtures from different Metro sections perform different at medium temperatures, but this difference is much less pronounced at low temperatures. In other words, at low temperatures, different mixtures appear to perform similarly. This could be one reason for the similar long-life behavior of theses pavements, as they have been subjected to the low temperature condition in a substantial portion of a year (up to 5 to 6 months) in the state of Minnesota.

- rePave analysis was performed twice for each project: once in the current year (2016) and the other in the year which the first overlay was performed. rePave renewal recommendations to keep these long-lived perpetual pavements to serve for another extended period of time were included Full Depth Reclamation (FDR) and overlay, Stabilized Full Depth Reclamation (SFDR) and overlay, and mill and overlay (either full depth or in the top few inches). The recommended new pavement thicknesses were found to be the same in the current year and in the year of the first overlay, since the 30-year ESALs were falling in the same pre-defined traffic intervals of the rePave program.

- The required pavement thicknesses from the remove and replace rePave runs were fairly close to the actual pavement thicknesses. This indicates that the perpetual pavement award winner projects in Metro District compare to the rePave program recommendations fairly well.

- The rePave sensitivity analysis showed that when the subgrade modulus is fixed, the required pavement thickness decreases approximately 0.3 inches for every 5000 psi increase in the base modulus. Also, when the base modulus is fixed, the required pavement thickness decreases approximately between 0.2 to 0.5 inches for every 5000 psi increase in the subgrade modulus.

CHAPTER 5: SUMMARY AND CONCLUSIONS

In this study, all the perpetual pavement award winner roadways in Minnesota were reviewed to determine the common material and design factors and considerations which have led these roadways to last for an extended period of time, often exceeding 50 years, despite the harsh Minnesota climate. In order to achieve this goal, all the available information for the 14 award winners and any pertinent supporting information were reviewed including MnDOT Highway Pavement Management Application (HPMA) data and performance histories as well as the construction histories and plans.

Moreover, an in-depth analysis was performed on the four projects located within the Metro District. To further investigate and characterize these sites, coring and hand auger borings were performed in cracked and un-cracked areas along with Dynamic Cone Penetrometer (DCP) which was performed in selected core holes. The cores were then used to measure thicknesses, densities, and asphalt contents, and to perform extracted gradations and resilient modulus testing at low and intermediate temperatures. The laboratory testing data were used to further refine the Metro award winner information to perform data analysis using rePave program. This program was developed under SHRP 2 R23 study which provides guidance for deciding where and under what conditions to use existing pavement in roadway renewal projects.

The findings from this study are as follows:

- Most of the sections were constructed in the 1960s when the rate of construction was low which might have resulted in better compaction, and therefore, performance improvements.

- In most of the cases subgrade corrections were performed which included excavation of unstable materials and correction of adverse subsoil conditions which may have increased the uniformity of the compacted materials. The excavated areas were backfilled with a select granular backfill material which created a drainable, strong construction platform to pave against and provided long-lasting foundations.

- Use of non-frost susceptible base and subbase materials in underlying layers have improved the drainage resulting in improved performance.

- In some cases the upper portion of the granular subbase or aggregate base was treated with bituminous which has strengthened the foundation. In some other cases, a layer of prime coat was placed over the aggregate base before placing the asphalt layer(s). This has increased the integrity of the granular base and has reduce dust during construction.

- In some cases the construction was extended over a year or more. This staged construction may have allowed the foundation to go through seasonal cycles and thus enhanced the overall pavement structural stability.

- Several projects had a road-mixed bituminous base material providing a flexible fatigue resistant base layer called for in the three layer perpetual pavement design. Road-mixed base could provide similar characteristics as current emulsion base stabilization materials used at MnRoad and various other projects throughout the state that have shown exceptional performance. Base stabilization not only provides a strong foundation for construction of perpetual pavements, but also creates a bound layer, thus transferring the maximum tensile strains deeper into the pavement structure which has shown to reduce the strain levels at the bottom of the upper HMA layers. Research has demonstrated that reduction of stress and strain to below a certain level at the bottom of the HMA layer increases the pavement fatigue life.

- HMA thicknesses from coring data were similar to the expected thicknesses from the construction plans and maintenance histories, except for one section. Average core densities and asphalt binder contents were about the same in all the sections. Also, field DCP testing indicated that the in-situ materials were strong with high CBR values in all the tested sections.

- Even though the majority of the in-place asphalt mixtures were produced before the Superpave mix design method was developed, they satisfied the Superpave control points. An appropriate aggregate gradation will increase the stability and durability of asphalt mixtures and eventually extends the life of these pavements.

- Resilient Modulus testing showed that the asphalt mixtures from different Metro sections perform different at medium temperatures, but this difference is much less pronounced at low temperatures. In other words, at low temperatures, different mixtures appear to perform similarly. This could be one reason for the similar long-life behavior of theses pavements, as they have been subjected to the low temperature condition in a substantial portion of a year (up to 5 to 6 months) in the state of Minnesota.

- rePave analysis was performed twice for each project: once in the current year (2016) and the other in the year which the first overlay was performed. These analyses suggested three main renewal options to keep these long-lived perpetual pavements to serve for another extended period of time: 1) Full Depth Reclamation (FDR) and overlay, 2) Stabilized Full Depth Reclamation (SFDR) and overlay, and 3) mill and overlay (either full depth or in the top few inches).

- The perpetual pavement award winner projects in Metro District compared to the rePave program recommendations fairly well, as the required pavement thicknesses from the remove and replace rePave runs (in the year of the first overlay) were fairly close to the actual pavement thicknesses.

- A sensitivity analysis was performed on rePave program to determine the effect of change of base and subgrade modulus values on the recommended overlay thicknesses. This analysis showed that when the subgrade modulus is fixed, the required pavement thickness decreases approximately 0.3 inches for every 5000 psi increase in the base modulus. Also, when the base modulus is fixed, the required pavement thickness decreases approximately between 0.2 to 0.5 inches for every 5000 psi increase in the subgrade modulus.

A combination of the above design factors and considerations in conjunction with likely good inspection and construction practices in the field at the time of placement, have enabled the award winner projects to service to the public for many years.

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APPENDIX A

CORE PHOTOS

Figure A-1 Core 1; TH 10 (2004), cracked, wheelpath

Figure A-2 Core 2, TH 10 (2004), un-cracked, non-wheelpath

Figure A-3 Core 3, TH 10 (2004), un-cracked, wheelpath

Figure A-4 Core 4, TH 10 (2004), cracked, wheelpath

Figure A-5 Core 5, TH 10 (2004), un-cracked, non-wheelpath

Figure A-6 Core 6, TH 10 (2004), un-cracked, wheelpath

Figure A-7 Core 7, TH 10 (2004), cracked, wheelpath

Figure A-8 Core 8, TH 10 (2004), un-cracked, non-wheelpath

Figure A-9 Core 9, TH 10 (2004), un-cracked, wheelpath

Figure A-10 Core 19, TH 36 (2008), un-cracked, non-wheelpath

Figure A-11 Core 20, TH 36 (2008), un-cracked, wheelpath

Figure A-12 Core 21, TH 36 (2008), un-cracked, non-wheelpath

Figure A-13 Core 22, TH 36 (2008), un-cracked, wheelpath

Figure A-14 Core 23, TH 36 (2008), un-cracked, non-wheelpath

Figure A-15 Core 24, TH 36 (2008), un-cracked, wheelpath

Figure A-16 Core 25; TH 95 (2013), cracked, wheelpath

Figure A-17 Core 26, TH 95 (2013), un-cracked, non-wheelpath

Figure A-18 Core 27, TH 95 (2013), un-cracked, wheelpath

Figure A-19 Core 28, TH 95 (2013), cracked, wheelpath

Figure A-20 Core 29, TH 95 (2013), un-cracked, non-wheelpath

Figure A-21 Core 30, TH 95 (2013), un-cracked, wheelpath

Figure A-22 Core 31, TH 95 (2013), cracked, wheelpath

Figure A-23 Core 32, TH 95 (2013), un-cracked, non-wheelpath

Figure A-24 Core 33, TH 95 (2013), un-cracked, wheelpath

Figure A-25 Core 10; TH 47 (2014), cracked, wheelpath

Figure A-26 Core 11, TH 47 (2014), un-cracked, non-wheelpath

Figure A-27 Core 12, TH 47 (2014), un-cracked, wheelpath

Figure A-28 Core 13, TH 47 (2014), cracked, wheelpath

Figure A-29 Core 14, TH 47 (2014), un-cracked, non-wheelpath

Figure A-30 Core 15, TH 47 (2014), un-cracked, wheelpath

Figure A-31 Core 16, TH 47 (2014), cracked, wheelpath

Figure A-32 Core 17, TH 47 (2014), un-cracked, non-wheelpath

Figure A-33 Core 18, TH 47 (2014), un-cracked, wheelpath