- Final Paper -

DEVELOPMENT OF A MASTER PLAN FOR THE RECONSTRUCTION AND REPLACEMENT OF THE OHIO TURNPIKE

Theme: Innovation in Infrastructure Construction and Maintenance
Sub-theme: Concrete Roads

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Paper Abstract (max 300 words)
Constructed half a century ago, the Ohio Turnpike is a toll road linking eastern industrial states to the throughways of Indiana, Illinois, and Port Toledo. In its first year of operation, the Turnpike carried an astounding 10 million vehicles, with a 5-fold increase of more than 51 million vehicles in 2006. During its 55 years of service, traffic has consisted of about 70% automobiles and 30% commercial trucks with legal weights as high as 127,500 pounds.

Built with the highest design and quality of the time at 10” of concrete pavement, the Turnpike has far exceeded its original design. The original 241.1 miles of pavement on this four-lane divided highway remain today but have been resurfaced and overlaid many times.

Rii developed a comprehensive Master Plan (MP) for the reconstruction/replacement of the original pavement. Using innovative, state-of-the-art technologies, Rii conducted a condition assessment of 982 lane miles of pavement involving:

- Review of original design, construction, traffic, performance and maintenance history.
- Review of historical pavement condition survey data such as international roughness index (IRI), pavement condition rating (PCR), structural deduct, faulting, and rutting.

- Comparison of current conditions with historical data to assess progressive effects of traffic damage.
- Non-destructive pavement evaluations to assess subgrade support, pavement thickness, layer moduli, voids and structural integrity of concrete. Included both non-traditional and innovative methods such as RT 3000, GPR, and ADCP, as well as more traditional methods.

Rii developed the sustainable MP in less than six months. Traditional approaches would have required unnecessary sampling, coring, and testing; hundreds of man hours, and traffic congestion.

The completed MP was divided into 48 five-mile sections. Each section was given a ranking of 1-48, based on degree of deterioration. It identified 15 segments for immediate replacement and provided a 10-year timeline for reconstruction of the remaining sections. The first segment is currently in construction.

DEVELOPMENT OF A MASTER PLAN FOR THE RECONSTRUCTION AND REPLACEMENT OF THE OHIO TURNPIKE

1. Background

The Ohio Turnpike, a 241.1-mile long multilane mainline roadway, has been serving Northern Ohio and neighboring states for more than half a century. Built in 1955, it currently carries more than 50 million vehicles annually. While the original pavement structure was built with the highest quality materials at the time, now, after a half-century of service, there are predominant signs of rapid deterioration and disintegration.

A recent asset management study recommended the systematic replacement of the mainline pavement in 48 five-mile sections based on priority and helped develop a timeline based on site conditions and structural and functional key performance indicators. Milepost 95.8-101.2 was ranked highest in priority, followed by six other five-mile sections designated for immediate reconstruction.

To replace the pavement, the Ohio Turnpike Commission (OTC) expressed its strong desire that the new structures be designed and constructed as "perpetual pavements and zero-maintenance," as nearly as possible. It necessitated that "Performance Based Specifications" (PBS) be incorporated into the design and construction of new structures.

The construction documents for the pavement replacement provided the contractor with numerous alternatives, all meeting the "specified performance" required for a perpetual, zero-maintenance pavement. The PB Contract specified requirements for each of the pavement components, such as a subgrade, shoulder, and the pavement. As an example, in contrast with conventional contracts, under the PB Contract the subgrade was required to be Lime Stabilized, on the entire five-mile section, with uniform 16 inches of depth of treatment and meeting specified minimum shear strength. As the first unique infrastructure design in Ohio, the Roller Compacted Concrete (RCC shoulder) was also specified as an alternate design and with the truck driving lane of 14 ft wide lane as a component of PB Contract. The design also satisfies the MEPDG and perpetual design guidelines.

This paper describes design alternatives, construction methodology and lessons learned from construction and maintenance of traffic. Additionally, it describes the asset management efforts, innovative technologies used for analysis of alternatives, and setting of the "performance requirements."

1. Historical Perspective

The Ohio Turnpike, a 241.1 mile long multilane mainline roadway with 982 lane miles of original pavement, has been serving the northern Ohio and its neighboring states connecting to the major toll roads of eastern Industrial states for more than half a century. Built in 1955, along the US Interstate Transportation Network, the Turnpike provides a link between major hubs New

York City, Pittsburgh, Cleveland, Toledo, Detroit and Chicago, and the western States Toll roads.

At the time it was completed in 1955, the Turnpike was designed to carry 10 million vehicles annually with about 30% commercial vehicles and 70% passenger vehicles. Today, while the commercial vehicle percentages have remained almost constant throughout past decades, the toll road carries more than 50 million vehicles annually with truck weights as high as 127,000 pounds. Additionally, it carries 13 classes of vehicle composition and design Single Axle loads of 50 to 80 million ESAL. See Figure 2 below.

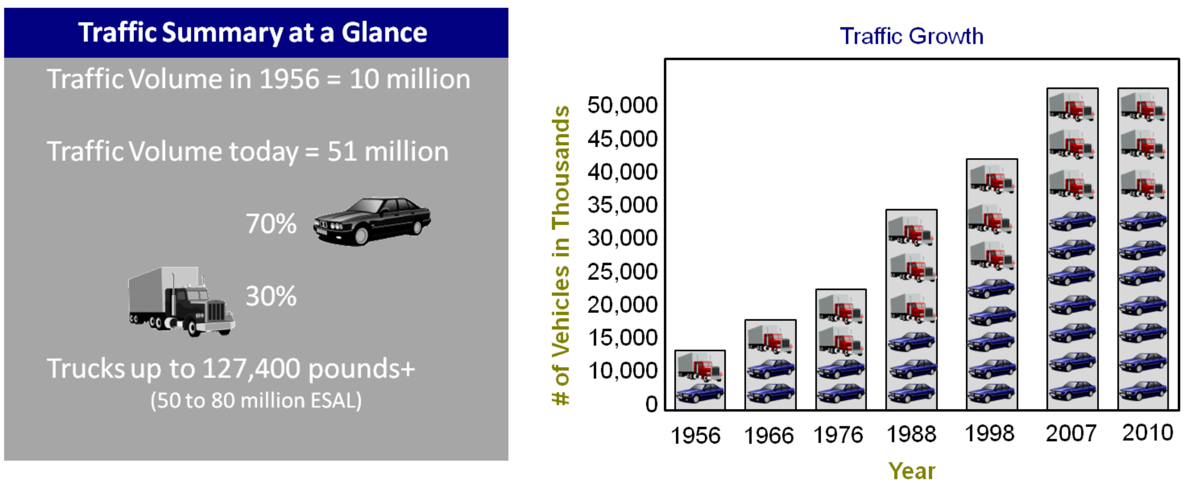


FIGURE 1. Traffic Summary at a Glance

The toll road traverses a variety of geological conditions, soil types, and climatic regions of Ohio. The original pavement design was composed of 10" reinforced concrete pavement with a 6" aggregate base course and a Design CBR of 4.0 (Mr = 4800 psi). The original pavement structure was constructed with the highest quality standards at the time, i.e. compressive strength; the quality of the workmanship has been reflected in its durability over time as measured by past Pavement Maintenance Studies (PMS). [1]

The pavement management studies performed by Rii in the past have concluded that while some sections of the original pavement still retain high enough quality and design strength to continue performing well for many more years, there are also signs of rapid deterioration in other sections. This indicates that some sections of the original pavement have far exceeded their design life, resulting in a need for immediate rehabilitation, reconstruction and replacement.

2. Need for Master Plan

The results of past pavement management studies clearly showed the need for immediate rehabilitation, reconstruction and replacement of the original 982 miles of pavement. For this reason, the Turnpike Commission requested that the Rii team develop a Master Plan for replacement and reconstruction of the original pavement and develop a priority ranking system for the reconstruction, and a timeline for its replacement. The severity of deterioration would govern the sequence and priority of reconstruction and replacement.

Utilizing innovative pavement evaluation methodologies, Rii prepared a Master Plan and timeline for the reconstruction, replacement, and rehabilitation of the Turnpike. The Project Team completed the entire plan in just nine months, which included six months of data acquisition, and three months of reporting.

2.1 Maintenance History

To complete the Master Plan, the Rii Team took a closer look at the previous maintenance history of the Turnpike. The initial review of the pavement indicated that it had been overlaid many times, starting in 1967, and by 1972, most of the sections had been overlaid with asphalt. A deeper analysis found that most of the length of the Turnpike had been resurfaced four to five times. [1]

Using the maintenance history as a preliminary indication of what was needed, Rii set forth all other important objectives to develop a decision tree. The tree (shown on the right) helped the Rii Team develop the priority for replacement, using all key performance indicators, which are described in the next section.

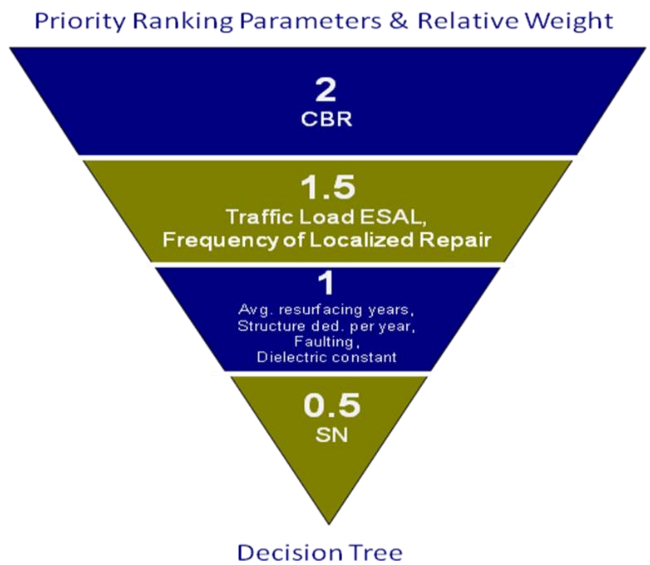


FIGURE 2. Decision Tree

3. Master Plan Objectives

The Master Plan objectives included developing a timeline and priority ranking for the rehabilitation, replacement and reconstruction of the original concrete pavement. A decision tree was created using relative weighting for various performance indicators and then summarized for individual sections.

3.1 Key Performance Indicators

To implement the priority ranking and reconstruction timeline, the project was divided into 48 five-mile sections and each of the key performance indicators was assessed. Each performance indicator was assessed in four quality levels and assembled through review of historical data, the collection of new in-situ data, and analytical projections.

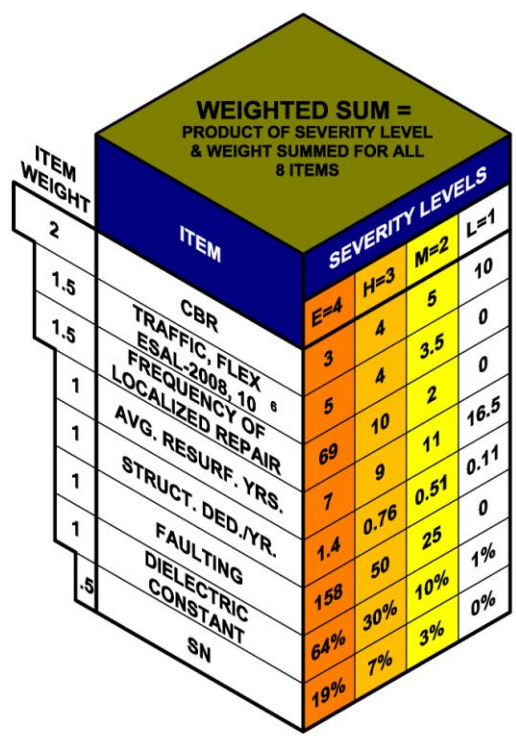


FIGURE 3. Key Performance Indicators

3.1.1 Maintenance Frequency

The maintenance frequency is one the most important performance indicators when developing the priority rankings and timeline. While the average resurfacing intervals for the original pavement ranged between 7 to 10 years, the frequency of localized repair and maintenance varied significantly throughout and was used to identify priority sections.

3.1.2 Riding Quality

The Decision Tree also recognized the pavement riding qualities such as pavement surface distresses, rate of change of structural distresses, international roughness index (IRI), and faulting as key performance indicators.

3.1.3 RT-3000

The RT-3000, a third-generation pavement survey vehicle, was utilized for collecting asset inventory data and surveying the existing pavement condition. The vehicle simultaneously collected data on longitudinal profile, crossfall, roughness, surface distress, rut depths, digital video, and pavement images. The innovative and new RT-3000 technology was used in place of traditional visual survey of Pavement Condition Rating (PCR), thus providing more efficient and accurate results.

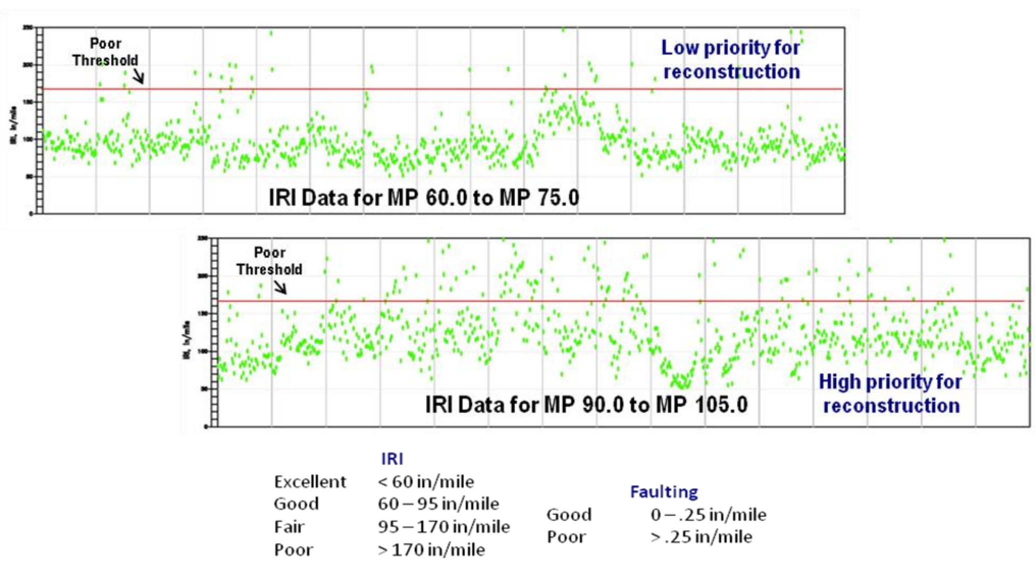


FIGURE 4. Pavement Riding Quality

3.2 Subgrade Soil Strength

Past subgrade soil strength evaluations covered various innovations and evaluation methodologies. Rii conducted a comprehensive review of historical in-situ soil strength data from 1988-2009 by use the conventional soil explorations, Non-Destructive Testing equipment (Dynaflect), and 3rd and 4th generation technologies. The Falling Weight Deflectometer (FWD) and Automated Dynamic Cone Penetrometer (ADCP) equipment were used as innovative techniques, which ultimately saved both time and resources. The severity of pavement deterioration was influenced by poor soil strength and traffic load and by its frequency of maintenance required.

3.2.1 Falling Weight Deflectometer (FWD) Method

The Subgrade Soil Strength was evaluated indirectly from back calculation of deflection, often known as the FWD method. FWD is a nondestructive testing method which simulates the effect of a moving vehicle wheel load. The system applies a load as low as 1,000 pounds up to 26,000 pounds for a pulse duration of approximately 25 to 30 msec. The pavement properties are "back-calculated" from the response to impulse load.

3.2.2 Automated Dynamic Cone Penetrometer (ADCP) Method

Subgrade Soil Strength was also evaluated directly by an innovative ADCP method. The ADCP system is equipped with an automatic lift/drop mechanism and Windows-based data acquisition system, providing direct and accurate shear strength results in less than five minutes without the need for extensive laboratory testing. ADCP testing is less intrusive and requires drilling a 1.5" diameter hole, unlike traditional coring and boring methods, which include thousands of soil samples.

The data collected from FWD and ADCP testing is presented in the graph above. In the high priority segment, many CBR data points fall below the Turnpike's original design threshold.

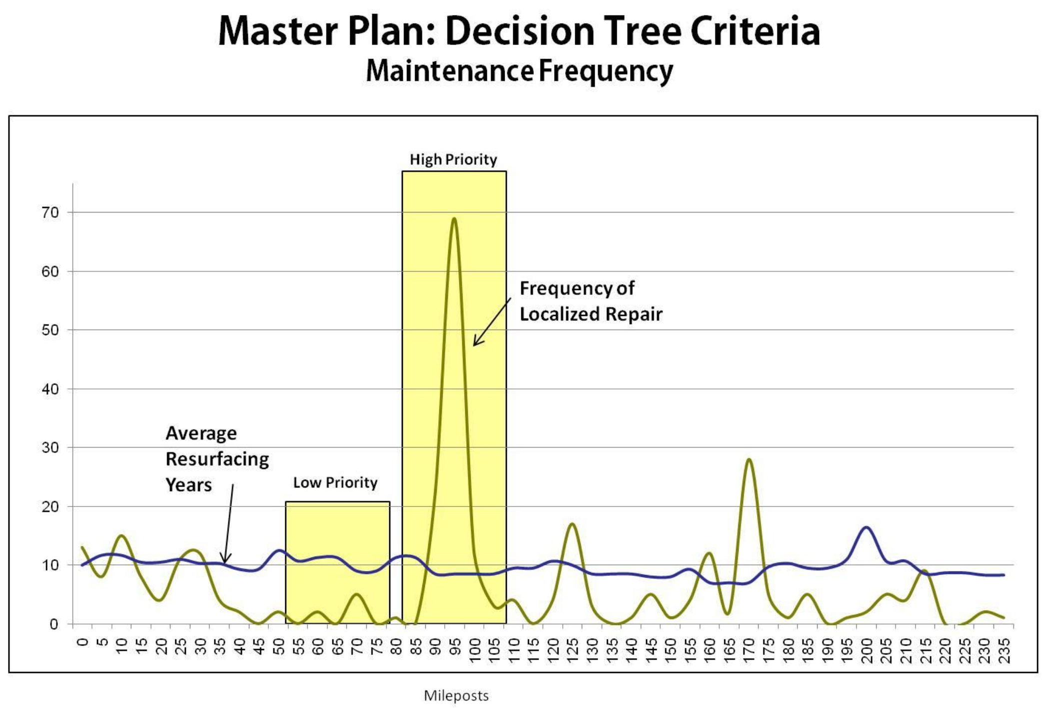
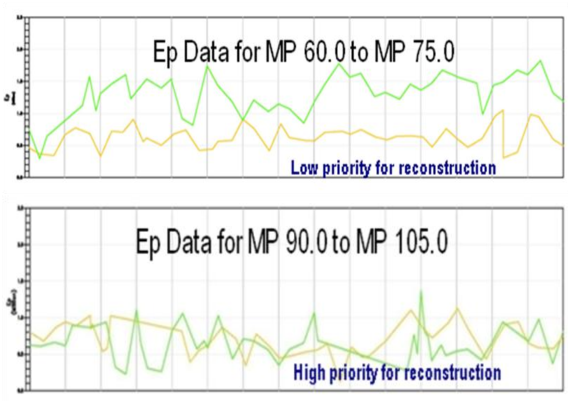


FIGURE 5. Maintenance Frequency

3.3 Pavement Structural Strength

Another thing considered in our Master Plan decision tree was the structural response of pavement to traffic load. The Effective Modulus (Ep) and Structural Number (SN) of the original 982 miles of concrete pavement was evaluated by a FWD, simulating the effect of a moving vehicle wheel load.

Pavement Effective Modulus (Ep) is calculated from:



Pavement Effective Modulus (Ep) is calculated from:

$$d_o = 1.5\, p\, a \left[1 / M_R \left\{1 + \left(D/a \left(Ep/ M_R\right)^{1/3} \right)^2 \right\}^{1/2} \right] + 1.5\, p\, a \left[\left\{ 1 - 1 / \left(1 + \left(D/a\right)^2 \right)^{1/2} \right\} / Ep\right]$$

d_o=deflection measured at the center of the load plate (and adjusted to a standard temperature of 68° F) (inches),
p=FWD Load Plate pressure (psi),
a=FWD Load Plate radius (inches),
D=total thickness of pavement layers above the subgrade (inches)

FIGURE 6. Pavement Effective Modulus (Ep)

Pavement AASHTO Structural Number (Sneff) is calculated from:

Pavement AASHTO Structural Number (Sneff) is calculated from:

$$SNeff = 0.0045\, D\, (Ep)^{1/3}$$

D= total thickness of pavement layers above the subgrade (inches)

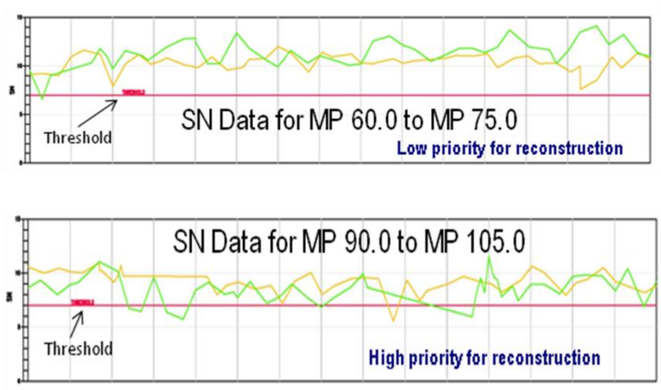


FIGURE 7. Pavement AASHTO Structural Number (Sneff)

In the figure above, the estimated SN parameter is compared with a threshold SN value estimated from pavement thickness and pavement core results.

3.4 Pavement Layer Thickness Analysis

Innovative radar technology, Ground Penetrating Radar (GPR), was used to determine continuous pavement layer thicknesses of the Ohio Turnpike, at highway speed. GPR replaces the need for more than 2,000 cores that are typically sampled by destructive methods, and hundreds of hours of lane closures and traffic control. [2] [3]

3.5 GPR Detection of Weakened Concrete
Rii utilized 2D and 3D GPR tomography to visualize pavement substructure, layer thicknesses, voids and evidence of pavement abnormalities. This task was carried out at highway speed, an application of innovative technology to pavement management, and also within the framework of sustainability to save time and resources.

3.5.1 Analysis of Dielectric Constant of Weakened Concrete
The most unique and innovative application of GPR that Rii utilized in this process was the detection of concrete pavement deterioration not visible with traditional pavement distress survey techniques.

Rii used GPR technology to detect the variations in concrete dielectric constants and relate them to concrete integrity and quality. The dielectric constants of construction material are an indicator of the amount of deterioration that has occurred. [2] [3]

4. Sustainable Solutions

The pavement design was performed as a Perpetual Pavement Design strategy with a longer life cycle, and minimum maintenance and quality management. The design of the first section (MP 95.8-101.2) also followed the Master Plan guidelines to meet the Greenroads' Sustainability standards. In this connection, the proposed design included the following features: [4] [5]

- The options to use recycled concrete and roller compacted concrete in the shoulder, thus lowering energy consumption during construction
- Minimization of noise and air pollution by selecting a composite pavement structure
- Presentation of a MOT (Maintenance of Traffic) plan, assuring free flow of traffic during construction and reduce traffic congestion

4.1 Performance Based Contract Specifications
The construction documents for the replacement of the pavement provided the contractor with several alternatives, all meeting the “specified performance” required for a perpetual, minimum-maintenance pavement. The PB Contract specified requirements for each of the pavement components, such as a subgrade, shoulder, and the pavement. As an example, in contrast with conventional contracts, under the PB Contract, the subgrade was required to be Globally Stabilized using Lime Stabilization on the entire five-mile section, with uniform 16 inches of depth of treatment and meeting specified minimum shear strength. As the first unique infrastructure design in Ohio, the Roller Compacted Concrete (RCC) was also specified for shoulders as an alternate design. This design also satisfied the design criterion used by MEPDG (Mechanistic-Empirical Pavement Design Guide) and perpetual pavement design guidelines.

5. Summary and Conclusions

5.1 Priority Ranking and Timeline for Construction
As discussed by the Master Plan, the 241.1 miles of multilane Turnpike was evaluated by its key performance indicators, at four quality levels. Each of the 48 five-mile sections was ranked for the priority for replacement and reconstruction. A total of 15 five-mile sections have been

identified for replacement in the next five years. Milepost 95.8-101.2 was ranked highest in priority, followed by six other five-mile sections designated and selected for immediate reconstruction and replacement. The first section (Section 1) is already under construction at this time and the Turnpike Authorities are considering construction of Section 7 soon. [4] [5]

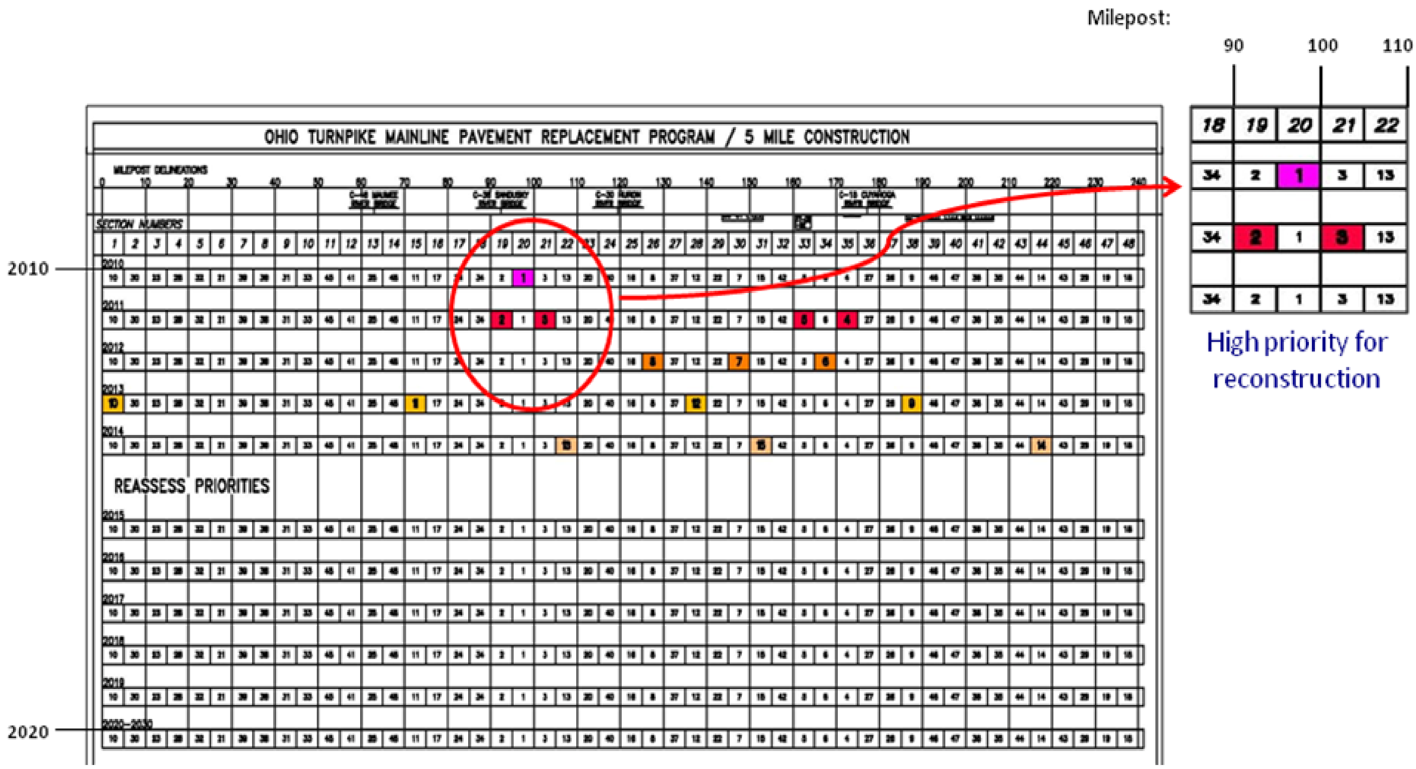


FIGURE 8. Timeline for Construction

5.2 Conclusion

This paper describes the details of a case study to develop a master plan for the reconstruction of a major highway in Ohio. The use of innovative technologies such as testing equipment, design tools and technologies, and proper considerations for the environment, were some of the items that were incorporated in this project. A successful completion of the first and subsequent construction sections and their future performances will reveal the values and applications of these innovative technologies and tools for many other future projects.

Publications:

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5. Khorshidi, S., Majidzadeh, K. and Saraf, C. (June 2010), Phase 2 Feasibility Study - Mainline Pavement Reconstruction, Prepared for the Ohio Turnpike Commission. Report prepared by Resource International, Inc., Cleveland, Ohio