

Economic Benefits Resulting from Road Research Performed at MnROAD

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ABSTRACT

The Minnesota Road Research Project (MnROAD) was built in the early 1990s and has led to positive economic benefits during its initial research phase. As MnROAD enters Phase II of its existence several research projects have been initiated to help both Minnesota and its research partners to better understand how to build and maintain our roadway network.

Phase-I road research has benefited Minnesota by providing insight into policies resulting in increased pavement life. Some of these areas include seasonal load policies (winter and spring), mechanistic-empirical design (asphalt and concrete), asphalt binder grading, low temperature cracking reduction, and improved pavement maintenance operations. The benefits gained at MnROAD have led to an annual savings for Mn/DOT of at least \$33 Million.

Phase-II road research has been designed around continuing the effort to provide transportation research to help provide the safe, efficient and cost-effective movement of people, goods, and services that is the backbone of our economy. Priority research and implementation activities include the development and calibration of a mechanistic-empirical design guide; implementation of innovative construction technology; improved preventive maintenance techniques; effective use of recycled materials; development and refinement of techniques for cost-effective pavement rehabilitation; understanding of pavement surface characteristics; and continued support of many non-pavement research areas.

This paper documents Minnesota's economic benefits resulting from MnROAD's initial phase and estimates of the potential future savings for its phase-II efforts currently being constructed. This paper will show how small increases in performance and pavement life can result in large savings for society.

INTRODUCTION

Accelerated Pavement Testing research is needed more now than ever with the continuous development of both new pavement materials and design methods. This comes along with the fact each agency is being asked to maintain and expand its existing infrastructure while working with funding that cannot keep up with the demands of rising costs. Every agency is facing a grim future as noted in a January 2006 TRB Critical Issues in Transportation, which makes the following observations related to the United States (1):

- It will take fifty years to reconstruct the federal highway system at current funding levels.
- Total highway vehicle miles traveled will increase fifty percent by the year 2020 from the year 2000 based on current trends.
- Total tonnage of freight transferred over the highway system will double by the year 2020 from the year 2000 based on current trends.
- A large part of current highway funding is used for repair and maintenance resulting in limited new construction and increasing congestion.

Minnesota has also struggled with the demands related to the upkeep and expansion of its pavement infrastructure system. In 2005 the state of Minnesota reported the following statistics related to roadways in Minnesota.

- \$1.5 Billion construction budget (State, County, City Costs)
- Population of nearly 5 million people
- 131,937 total miles of maintained roads
 - Minnesota Interstate & State = 13,836 miles
 - County = 45,194 miles
 - City/Township = 72,907 miles
 - This total does not include pavements and parking lots that are privately owned but benefit from the use of Mn/DOT specifications and research findings to correctly build and maintain those pavement systems.

Minnesota with its research partners has continued to be proactive with its current leadership to understand the beneficial role research can play in understanding that a small improvement in pavement performance has the potential to save a large amount of money. This report is designed to show the benefits related to past phase-I (1994-2006) and current phase-II (2007-2017) research efforts at the Minnesota Road Research Project, otherwise known as MnROAD. This second phase is a credit to MnROAD's qualified staff and its research partners including TERRA (2), which continues to be actively looking for research opportunities and additional research partners throughout the world.

MnROAD was constructed by the Minnesota Department of Transportation (Mn/DOT) in 1990-1993 as a full-scale accelerated pavement testing facility, with traffic opening in 1994. Located near Albertville, Minnesota (40 miles northwest of Minneapolis-St. Paul), MnROAD is one of the most sophisticated, independently operated pavement test facilities of its type in the world. Its design incorporates thousands of electronic in-ground sensors and an extensive data collection system that provide opportunities to study how traffic loadings and environmental conditions affect pavement materials and performance over time. All this information is fed into the MnROAD database for researchers use worldwide. MnROAD consists of two unique road segments located parallel to Interstate 94:

- 3.5-mile Mainline interstate roadway carrying "live" traffic averaging 28,500 vehicles per day with 12.7 % trucks – See Figure 1 for the test cell layout.
- 2.5-mile closed-loop Low Volume Road carrying a MnROAD-operated 18-wheel, 5-axle, 80,000-lb tractor-semi-trailer to simulate the conditions of rural roads – See Figure 2 for the test cell layout.



PHASE-I COSTS AND BENEFITS

Phase-I Initial Objectives

During Phase-I fourteen initial research objectives were developed in the early 1990's to help guide the future research efforts for MnROAD and are covered in detail in reference (3) along with a number of other technical papers located on the MnROAD web page.

Phase-I Initial Costs

The MnROAD project was originally developed in the early 1990's at a cost of \$25 million. These costs covered the initial design, construction, environmental impact study, initial pilot projects, pavement sensors and data collection equipment, land along I-94, buildings, and equipment. This consisted of 60% Federal Highway Administration funding and 40% Mn/DOT funding.

The majority of MnROAD annual operating costs is funded through a partnership between Minnesota Department of Transportation (Mn/DOT) and the Minnesota Local Road Research Board (LRRB). The LRRB funding comes from legislation stating .05% of the construction costs relating to roadways for Minnesota Cities and Counties go into a fund for the LRRB research board to distribute towards city and county research needs. Annual operating costs have averaged around \$950,000 to date. This consists of \$450,000 Mn/DOT and \$500,000 of LRRB funding and has stayed consistent over the first 12 years. Annual research contracted projects related to MnROAD is estimated to be about \$500,000 per year.

Reconstruction of a number of test cells were also completed in MnROAD's phase-I when other test cells failed or already served their research needs and could be replaced. These efforts were funded through a number of different partnerships and are shown in Table 1 as actual dollars from the year of construction.

MnROAD Phase-I Benefits

Conservative annual savings/potential benefits based on implemented MnROAD Phase-I research results in over 33 million dollars a year based on its first 12 years of operations only for Minnesota. This analysis uses cost and quantities estimates from Minnesota state and local industries and are described below. These benefits do not include all of the other research products developed at MnROAD, since they are more difficult and subjective to define. The lessons learned papers (3-5) cover some of the other beneficial projects of MnROAD along with Table 2.

Spring Load Restrictions

Properly applying spring load restrictions was a major source of pavement deterioration in Minnesota before models could be developed and verified at MnROAD. The problem existed that many of the roads in the state are not structurally strong enough (10-ton rating) to withstand the spring thaw during its weakest time of the year for about an 8-week period. Most of these "weaker" roads are located on lower volume city and county roadway system. These restrictions also impacts many local businesses in the way they operate during this time period so there is pressure to reduce or eliminate load restriction. MnROAD provided the data that city/county engineers and legislators could use to back up their decisions.

The following is taken from a seasonal load report written in 2000 (6). In Minnesota there are about 39,000 miles of paved roads that do not meet the 10-ton spring load design standard and therefore should be restricted to lower loads during the spring. Included in these 39,000 miles are about 1,600 miles of state trunk highways, 23,600 miles of county state aid highways, 2,400 miles of municipal state aid city roads, and roughly 11,000 miles of other local roads constructed and maintained through local funding. The vast majority of these roads are paved with asphalt concrete, which has an annual construction and overlay cost of about \$12,000 per mile per year. This cost is based on a present value construction cost of

\$210,000 per mile, which includes two overlays, a discount rate of 4.5 percent, and a total life of 35 years. Unfortunately the time before the first overlay, between overlays, and the total life are reduced if unanticipated damage occurs in the spring. The results in this chapter show that a delay in the start of SLR may result in more than one year of life lost before the first overlay and that complete reconstruction may be required after 32 years rather than the projected 35 years. Given these shortened period the actual annual cost would be about \$12,500 per mile per year rather than \$12,000 per mile per year. Multiplying this \$500 per mile per year by the number of miles of restricted roads (most likely to sustain spring damage - about 75 percent of the 39,000) or 29,000 miles.

- Benefit = \$14,000,000 a year (2000 dollars)

Winter Load Increase Policy

Properly applying the start and end of winter load increases were also issues before models were implemented and data was collected at MnROAD. Without the winter load increase models we commonly would allow 10% overloads (88,000 5 axle semi tractor trailers) on roadways up till the spring load restrictions were placed (which sometimes were 7-10 days late). Now you have more loading on the weaker roads during its most critical period. The same rehabilitation criteria was used to determine the benefits of this work but only half of the 29,000 miles were expected to be impacted.

- Benefit = \$7 million a year (2000 dollars)

Asphalt Binder Grading Benefits

Use of PG 64-34 wear surface and PG 58-28 non-wear base materials were verified acceptable based on temperature profiles collected at MnROAD. It has been shown the lower layers do not receive the extreme high/low temperatures as the surface layers and a savings of asphalt grade type can be recognized. This saves money on the non-wear HMA layers using a less costly PG asphalt binder. Calculations include the use of 2005 Mn/DOT paving quantities and MAPA 2005 reported HMA costs. There was 374,000 tons of Non-Wear HMA mix placed in 2005 and the 2005 asphalt costs for a PG 64-34 was \$18.15/ton and a PG 58-28 was \$12.65 ton. This represents a \$5.50 ton savings between mixes using these PG binders.

- Benefit = 374,000 tons*\$5.50 savings = \$2,057,000 (2005 dollars)

Mechanistic-Empirical Design (asphalt)

MnROAD developed MnPAVE as its mechanistic-empirical design tool for flexible pavements. MnPAVE was created from the information collected at MnROAD and has shown our current designs are structurally over designed. Observations at MnROAD support this program. MnROAD's mainline test cells show the "thinner 6" HMA" 5-year cells are performing as well as the "thicker 8" HMA" 10-year test cells. The environment is the main cause of the initial cracking and then the traffic deteriorates the cracks. MnPAVE is based on mechanistic principals of a layered structure and is a research result from instrumented sections at MnROAD. The advantages of MnPAVE over the current MnDOT designs are:

- Ability to adapt to different distress modes
- Better materials tests and characterization
- Ability to adapt to changing load limits and configurations
- Ability to achieve agreement between structural and material design.

Comparing MnPAVE and the current MnDOT design, the current MnPAVE has potential to design a flexible pavement with a thinner HMA layer (approximately 1-1.5" thinner). It is estimated that MnPAVE can save approximately 394 tons of HMA per 12 foot lane and \$41/ton HMA (2007 Data) and the average mileage of new construction on the state highway is reported to be 134 lane/miles/year (average/year since 1997) for the state of Minnesota only.

- Benefits = Potential saving 134miles*394tons/mile * \$41/ton = 2,164,636 (state roads)

Mechanistic-Empirical Design (concrete)

MnROAD has found that concrete designs used on our roadways are structurally over designed. This is evident related to MnROAD's 5 and 10-year mainline interstate test cells and also on its LVR where cell-32 has performed well over 7 years of traffic with only 5" of concrete. Using 2005 Mn/DOT concrete costs square yard quantities and by reducing the thickness by 1" over the entire system based on our MnROAD observations, which are also being supported by national design guide recommendations for concrete pavement designs.

- Potential benefit per inch of PCC = \$24,000 per inch per SY per mile * 50 miles placed = \$1.2 million (2005 dollars)

Sealing Pavement/Shoulder Joints

In 2005 Mn/DOT installed 400,000 lineal feet (76 miles) of 4" perforated pipe edge drain at an average cost of \$4 per foot (\$21,500 per mile); the total cost of edge drains was \$1.6 million. Research at MnROAD has shown that sealing the edge joints of a concrete pavement reduces the water outflow through the edge drains by 90%, thereby eliminating the need for edge drains. Joint sealing costs approximately 25 cents per foot, or \$1320 per mile. Using only the pavements placed in 2005, if Mn/DOT sealed the edge joint four times over the life of the pavement instead of installing edge drains, the total cost would be \$400,000. It's also worthy to note that drained test cells at MnROAD have performed the same as non-drained test cells (no difference in performance).

- This would amount to a cost savings of \$1.2 million per year.

Low Temperature Cracking Reduction

Asphalt Binder Recommendations related to cold weather states. MnROAD cells 33-35 have demonstrated that PG58-28, PG58-34, PG58-40 does not perform the same. We recommend a PG58-34 even though a PG58-40 is suppose to perform the best, but has cracked the most. This is the basis for the low temperature cracking pooled fund effort and our questioning the performance of modified binders. The cost savings related to this recommendation can be calculated using data from 2005 Koch Materials and 2005 MAPA average mix prices. These include PG 58-34 costs at \$17.60/ton and PG 58-40 costs at \$19.80/ton. In 2005 Mn/DOT reported that 2.6 million tons of HMA was used in the state.

- Benefits = \$2.20/ton* 2.6 million = 5.7 million

Phase-I Cost / Benefit Analysis

MnROAD Phase-I (1994-2006) costs were estimated to total \$44,304,562 for a 12-year analysis period. Its benefits were shown to be \$33 million per year or \$396,000,000. Table 3 contains the summary of the costs and benefits using a non-time value of money since the costs and benefits are all estimates anyway. The authors did not see the benefit to further manipulate the data for this analysis. This represents a 8.9/1 benefit/cost ratio if you consider all the costs (construction, staffing, research projects) over the first 12 years of MnROAD and assume the research benefits started at year 6 (2000) and will run at least another 6 years after Phase-I is complete (2012) for this analysis. This time frame is random and neglects additional future benefits that exist past the selected analysis period.

PHASE-II COSTS AND BENEFITS

Phase-II Core Research Areas

MnROAD Phase-II was designed around the following core research needs through TERRA and other MnROAD research partners.

- **Design Guide** - Development and calibration for both new and rehabilitated pavements that may lead to reduction in pavement thickness and improved low temperature cracking prediction.
- **Innovative Construction** – Implement technology and methods for bound and unbound materials. Reduced construction costs + faster and more consistent = longer life
- **Preventive Maintenance** – Improve techniques to maintain our current pavement investments. 11.2/1 ratio to dollars spent vs. future construction costs.
- **Recycled Materials** – Effective use throughout the pavement structure including taconite aggregates. 90% of Mn/DOT Asphalt mixes uses recycled materials at a lower cost but at what cost to pavement performance?
- **Rehabilitation** – Develop and refine techniques for cost effective pavement rehabilitation. Majority of the states future construction needs/costs
- **Surface Characteristics** – Develop techniques for smooth, quiet, durable, and skid-resistant pavements. Reduction of noise at the tire/pavement source instead of funding costly noise walls which cannot be done everywhere – increased safety.
- **Non-Pavement Research** – Continued support of research in intelligent transportation systems through the University of Minnesota and other private sector partnership agreements

Phase-II Research Test Cells

The test cells being built were designed around the core research needs above and the research developed. The designs are shown in detail in Figures 1 and 2 of this report and represent both HMA and PCC pavements including composite pavement designs. Here is a quick summary of the future test cells at MnROAD.

- 32 test cells will be replaced (~500ft each)
- 23 HMA test cells are being built
 - 18 different mix designs will be available for research
 - Many will built with typical structural designs to look at material behavior's impact on performance.
- 9 PCC test cells are being built
 - 8 surface textures will be available for research
 - Both traditional mixes and pervious mixes will be used.
- 6 Composite Pavement test cells are being built.
- Intelligent compaction will be used on the unbound and HMA layers.

Phase-II Initial Costs

MnROAD current funding for its 2007-2008 construction related efforts come from a number of funding sources including \$5.1 million Mn/DOT SPR, \$600,000 LRRB, \$2.1 million of Other States/Fed. Research, \$800,000 Industry Cash & In-Kind, and \$1.4 million Mn/DOT State Funds. The total funding is \$10 million. The current costs can be broken down to the following 2007 funding levels.

- Construction = \$3.3 million
- Instrumentation/Sensors/Operations Support = \$2.9 million
- Research (5 years) = \$3.8 million

Phase-II Research Projects

MnROAD has moved into a number of both national pooled fund research efforts and more state research efforts that will benefit both Minnesota and the nation. In this paper we will predict possible benefits related to the research, but only time will tell what benefits are possible and can be implemented. We estimate the following benefits will potentially save a similar amounts related to the successful phase-I efforts. These benefits are defined from the following phase-II research efforts.

Pooled Fund Related Research Projects

All of these pooled fund research projects can be reviewed on www.pooledfund.org for the most up-to-date information updated quarterly. Pooled fund projects collect funding from a number of partners to research common issues. Mn/DOT is leading seven of these studies. Each one listed contains the partners and possible future benefits.

- **TPF-5(129) Recycled Unbound Pavement Materials**
 - Partners - CA, MI, MN, OH, TX, WI
 - What are the best combinations or designs for the use of recycled base materials from PCC and HMA pavements for base materials?
 - Benefits will include developing seasonal material properties and determining the proper designs using these materials.
- **TPF-5(132) – Investigation of Low Temperature Cracking in Asphalt Pavements – Phase II**
 - CT, IA, ID, MN, ND, NY, WI, LRRB
 - Develop a test specification for the acceptance of HMA mixtures based on the finding from the first phase of this project.
 - Benefits include a reduction of cracking – longer life – less maintenance costs related to crack sealant and other costly rehabilitation if a test specification is developed for states to use to screen out poor mix designs and build ones that will optimize life.
- **TPF-5(134) PCC Surface Characteristics – Rehabilitation**
 - Partners - MN, TX, IGGA, ACPA, FHWA, Diamond Services Inc.
 - What is the grinding configuration needed to produce the least tire-pavement noise, greatest surface texture, optimal durability and friction?
 - Benefits include a reduction of noise (less noise walls), quick rehabilitation (less driver delays), alternatives to other rehabilitation, and safer pavements for the public use.
- **TPF-5(148) Effects of Implements of Husbandry "Farm Equipment" on Pavement Performance**
 - Partners - MN, LRRB, IL, IA, PNAAW (Industry Consortium)
 - What effect does large modern farm equipment have on our low volume roads?
 - Benefits will be realized by either finding the equipment does very little damage or that the equipment needs to be improved to reduce the impact on our low volume roadways.
- **TPF-5(149) Design & Construction Guidelines for Thermally Insulated Concrete Pavements**
 - **Partners** - CA, MN, WA, FHWA, LRRB
 - Can material advantages of both HMA and PCC be optimized when they are originally built together in the same construction season?
 - Benefits may include initial construction cost savings in the amount of base materials required, quality of the concrete ride and materials, joint spacing, and easier rehabilitation in the future.
- **TPF-5(153) Optimal Timing of Preventive Maintenance for Addressing Environmental Aging in HMA Pavements**
 - MD, MN, OH, TX, LRRB
 - What factors affect HMA aging and when is the optimal time for preventative maintenance?

- Benefits could represent both the maintenance C/B ratio and 10% increased life when the timing is better understood.
- **TPF-5(165) Whitetopping Design**
 - Partners - MS, MN, MO, NY, PA
 - Develop a rational design for concrete overlays of HMA pavements.
 - Benefits may give us another rehabilitation method for cracked HMA pavements.

Partner Research Studies

Additional research projects were also developed with partners with common pavement research interests. Again these projects will be updated quarterly and the information gained will be available to share with everyone through reports and the MnROAD database. Mn/DOT has currently entered into thirteen of these studies. Each one listed contains the partners and possible future benefits.

- **Use of Taconite Aggregates in Pavement Applications**
 - Partners - NRRI, Mn/DOT
 - How well do taconite mine byproducts or waste rock/aggregates perform in both HMA and PCC pavement systems?
 - Benefits include a possible source of high quality aggregates for locations where aggregate materials are becoming scarcer. This high quality material may also outperform other typical aggregates commonly used.
- **Unbonded Concrete Overlay**
 - Partners - CPAM, ACPA, Mn/DOT
 - Commonly used rehabilitation technique, but detailed studies and data collection have not been done. What improvement can be made to this pavement system?
 - Benefits include a better understanding in this design and possible improvements in this rehabilitation.
- **Permeable (HMA) Pavement Performance in Cold Regions**
- **Permeable (PCC) Pavement Performance in Cold Regions**
 - Partners - LRRB, Mn/DOT
 - Will these designs work in cold regions and hold up to traffic?
 - Benefits include developing durable mix design and design systems that work both for HMA and PCC pervious designs for cold regions like Minnesota. These systems do reduce vehicle spray, reduce noise, and allows water to naturally return to the underlying soils and not need to be treated or handled in storm sewers, lakes and rivers.
- **Pervious Concrete “Overlay” Mix Design for Wearing Course Applications**
 - Partners - CTRE, Mn/DOT
 - Will these designs work in cold regions and hold up to traffic?
 - Benefits include developing durable mix design and design systems that work both for PCC pervious overlays in cold regions like Minnesota. These systems do reduce vehicle spray and reduce noise.
- **Full-Depth Reclamation Stabilized with Engineered Emulsion**
 - Partners – SemMaterials, Mn/DOT
 - SemMaterials providing construction & Mn/DOT providing instrumentation. Both will work together on the research projects related to these three test cells.
 - What design alternatives do local agencies have related to older cracked pavements especially related to rehabilitation of full-depth HMA?
 - Benefits include developing better methods related to the emulsion treatment of full depth reclamation of heavily cracked HMA pavements and the seasonal design inputs for M-E designs. Currently many of these pavements are only considered a reconstruction, which is more expensive than rehabilitation. We will also be demonstrating alternative construction administration.

- **HMA Surface Characteristics related to Ride, Texture, Friction, Noise, Durability**
 - Partners - LRRB, Mn/DOT, FHWA
 - What surfaces give us the longest life and optimal surface characteristics?
 - Benefits include putting values to surface characteristics related to safety, noise, texture, and friction and pavement life. Very similar to the concrete studies related to surfaces.
- **Concrete Tie Bar-Subgrade Drag Design**
 - Partners - CTRE, Mn/DOT
 - What is the optimal design of the number and size of tie bars required to keep multiple lanes/shoulders in a roadway together?
 - Benefits include a better understanding of these designs especially when roadways increase the number lanes / number of tied concrete panels.
- **Trapezoidal Concrete Pavement**
 - Partners - CTRE, MnDOT
 - Study the effects of trapezoidal concrete pavements.
 - Benefits include the reduction of concrete materials and thinner pavement designs.
- **Recycled Asphalt Pavements (RAP)**
 - Partners - LRRB, Mn/DOT
 - How does the amount of RAP and the quality effect performance?
 - Benefits include demonstrating fractionated and non-fractionated use of RAP at higher levels that are currently commonly accepted. Study will also be a very interesting tie to low temperature cracking and aging studies.
- **Field Investigation of Highway Base Material Stabilized With High Carbon Fly Ash**
 - Partners - Bloom Consultants (DOE Grant), U of WI, MPCA, Innophos, MTE)
 - What effect on design and the environment does fly ash have in our roadways?
 - Benefits could show this material should not be or should be used more in our pavement systems. Fly ash may also provide construction insurance when using poorer quality bases or when rain is complicating the placement of the surface materials.
- **Field Investigation of Polyphosphoric Acid Modified Asphalt**
 - Partners - Innophos, Marathon, Paragon, ICL, MTE, WRI, FHWA, Mn/DOT)
 - Should acid be used to modify or asphalts used in HMA pavements?
 - Benefits include a better understanding of acid, SBS, acid/Elvaloy, and acid/SBS modification and how it affects pavement performance and construction. Minnesota tends to require modified asphalts to meet its large range of temperatures from its hot summers (100 F) to cold winters (-40 F). The savings related to modifying asphalt binders with acid compared to typical SBS modifiers could potentially yield large benefits.
- **SHRP-II Composite Pavement Study**
 - Partners - ERES, University of Minnesota, Mn/DOT
 - How can HMA and PCC pavements be constructed in current non-traditional ways to achieve the best from each material?
 - Benefits include design and construction guidelines for composite pavements, which are anticipated to provide long-life, minimal maintenance pavement systems.

Minnesota Single State Research Studies

For some studies Mn/DOT had its own reasons to pursue the research when no other partners were available to team with. The information gained will be available to share with everyone through reports and the MnROAD database. Mn/DOT has currently entered into three of these studies. Each one listed contains the goal and possible future benefits.

- **Investigation of High Performance Concrete Pavement (60-year Concrete)**

- Do you get long life pavements related to pavement sensor response with the current concrete pavements designed for 60-years?
- Benefits include being able to do detailed monitoring at MnROAD to determine the possible benefits and difference with traditional and thin concrete designs.
- **PCC Surface Characteristics – New Construction**
 - What surfaces give the quietest pavements and the surface texture and friction needed for safety of the users?
 - Benefits are similar to the other surface characteristics projects for rehabilitation of PCC and HMA surfaces.
- **Concrete Pavement Optimization – Determining the Lower Threshold of Slab Thickness for High Volume Roads**
 - How thin can we realistically build concrete pavements and still expect them to perform well over time?
 - Benefits include better distress and life prediction models for more optimized (thinner) concrete pavements.

Possible Examples of Phase-II Benefits

These are a couple of example of calculated savings that are expected for the next phase of MnROAD. Again it's too early to count these as benefits, but they are included to show the possibilities.

Extended Pavement Life Savings

The combination of tools developed related to MnROAD for Phase-II should create at least a 10% increase in life and reductions in initial construction costs. The average pavement life according to Mn/DOT Pavement Management (7) is 16 years for HMA and 19 years for PCC but would be 17.6 for HMA and 20.9 for PCC after a 10% increase. Assuming 50% goes towards pavement structures \$750,000,000 spent which 25% PCC pavements and 75% HMA. So future savings can be calculated as PCC: $\$187,500,000/16 \text{ years} - \$187,500,000/17.6 \text{ years} = \$1,065,340$ future savings; HMA $\$562,500,000/19 \text{ years} - \$562,500,000/20.9 \text{ years} = \$2,691,287$ future savings.

- Minnesota Possible Benefit ~ 3.7 million

Preventive Maintenance

Determining the cause of HMA aging, when treatments are required and the effectiveness of each treatment MnROAD expects to increase the current accepted cost/Benefit ratios stated by Michigan of 11 to 1. In 2005 Mn/DOT spent \$17.2 million on preventative maintenance (7), which this research may help to increase.

Pavement Noise Reduction

Many cities are developing tall noise walls to reduce noise and keep nearby citizens happy. Currently Minnesota construction costs are averaging \$15 per square foot for noise walls. This translates into a 20-foot high wall costing approximately \$1.58 million per mile and as of December 2000, Mn/DOT has constructed approximately 85 miles of noise walls and berms located throughout the state. Future research at MnROAD will investigate quiet pavement technology. Innovations like astro-turf drag of concrete pavements, open graded/stone matrix asphalt/4.75 mm/rubber-modified asphalt pavements, and composite pavements are capable of significantly reducing tire-pavement noise, thereby reducing or eliminating the need for noise walls. For each foot that we lower the noise wall using quiet pavement technology, we would save \$79,000.

- If Mn/DOT did not need these 85 miles of noise walls Mn/DOT would save \$119 million and all the future maintenance issues with them.

SUMMARY

Transportation research is needed now more than ever to help provide the safe, efficient and cost-effective movement of people, goods, and services that is the backbone of our economy. Small increases in performance and pavement life result in a reduction in costs for maintenance, repairs, user delays, and congestion. These pavement research activities improve our national productivity and quality of life.

This paper presents a summary of the costs and benefits of the research and construction activities undertaken at MnROAD for both its original Phase-I (1994-2006) and made an attempt to predict future benefits for Phase-II (2007-2017) of MnROAD. Phase-I was shown to conservatively save the State of Minnesota 33 million dollars a year related to six projects examined in this report. This is not to say that these were the only benefits because they are many more as pointed out in past lessons learned reports. These other benefits are important but are harder to put a dollar value to may have benefits outside of the State of Minnesota. Neither national (rest of the states) nor local privately owned pavements were included in the cost savings even though they also gain a benefit through the research findings and updated construction specifications. If these other benefits were included it would only improve the cost benefit ratio even more.

MnROAD Phase-I (1994-2006) costs were estimated at \$44,304,562. Its benefits were conservative estimated at \$33 million per year for six research findings over a 12-year period (2006-2012) valued at \$396,000,000. This represents an 8.9 benefit/cost ratio. This takes into account money is invested during the project (1994-2006) and the return on that investment starts in the middle of MnROAD's phase-I efforts and continue for a finite period (2012) for this analysis. This time frame is random and neglects additional future benefits that exist past the selected analysis period.

MnROAD Phase-II (2007-2017) was also described in this report including the research core values, research partners, research studies, study focus, and possible future benefits. A couple examples of calculated benefits were reviewed, but it is too early to predict the real benefits future research will bring. It is expected similar positive outcomes will be realized for MnROAD's second phase of research.

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TABLE 1 Estimate of Phase-I Construction Costs

Year	Phase-I Construction Activities	Cells	Partners	(C)onstruction & (I)nstrumentation Costs
1997	Whitotopping (PCC over HMA)	92-97	FHWA & Mn/DOT	\$116,000 (C) \$140,000 (I)
1997	Superpave Inlay	50-51	Mn/DOT	\$58,000 (C)
1999	Superpave and Large Stone Base	27-28, 33-35	Mn/DOT	\$328,000 (C) 240,000 (I)
1999	MicroSurfacing	20, 23	LRRB	\$5,000 (C)
2000	Oil Gravel	26, 27	Mn/DOT	\$40,000 (C) \$4,000 (I)
2000	Thin PCC and Doweled PCC	32, 52-53		\$226,562 (C)
2000	60" Culvert Design	54	FHWA MnDOT Bridge	\$100,000 (C) \$55,000 (I)
2003	MicroSurfacing	Mainline HMA Cells	MnDOT OPERA Funds	\$15,000 (C)
2004	Whitotopping (PCC over HMA)	60-63	FHWA	\$161,000 (C) 31,000 (I)
2004	Mesabi Hard Rock HMA & PCC	31, 54	NRRI, MnDNR	75,000 (C+I)
2004	Flexible Slurry	24-25, 30-31	LRRB	\$25,000 (C)
2004	SuperPave	26	Mn/DOT	\$60,000 (C) \$20,000 (I)
2006	GeoComposite Barrier Drain	27-28	Idea Study & Pooled Fund	130,000 (C) \$75,000 (I)

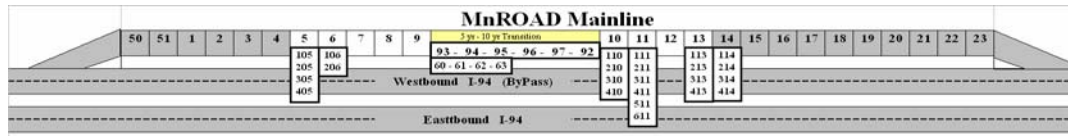
TABLE 2 Other Benefits of MnROAD's Phase-I

Impacts Related to MnROAD	
MnROAD Data used for Development of the 2002 Design Guide	Test Facility and Data Source for Several NCHRP National and Regional Studies
Environment plays key role in initial deterioration of Hot Mix Asphalt (Thermal Cracking)	Development and Validation of Pavement Monitoring/Testing Tools - DCP Implementation
Performance of Asphalt PG Binders (PG 64-22, 58-28) and (PG 58-28,58-34,58-40)	Demonstration and Monitoring of Mine Waste "Taconite" Aggregates
Driving/Passing and 80K/102K Lane Ride "IRI" Comparisons	Observations/Findings from Thermocouples throughout the Pavement Structure
Calibration of Profilers (Construction Incentives)	Pavement Performance Database
Documentation of Dowel Bar Performance	Performance of Aggregate and Chip Seal Sections
Demonstration of Oil Gravel Technology	National/International Experts at MnROAD
Effect of PCC Curling and Warping on Design	Performance of Base Materials
Moisture Evaluation using TDR Sensors	Research Impacts Pavement Education
Environmental/Response Sensor Expertise	Resilient Modulus Testing Development
Evaluation of AASHTO 93 Design Guide	Rutting Forensic Findings
Frost Depth Model Verification	Traffic Impacts on Performance (Measured vs. Design)
Impact on Policy Making related to Load Limits	Truck Safety Development (GuideStar, GPS, HUDs)
Implementation of GPR Technology	Whitetopping Guidelines

TABLE 3 MnROAD Summary of Costs and Benefits

Cost	Years	Annual Cost	Fixed Cost	Total Costs	Benefits	Total Benefits
Annual MnROAD Operations	1994-2006	950,000		11,400,000		
Annual Research Projects	1994-2006	500,000		6,000,000		
Initial Construction	1994		25,000,000	25,000,000		
Whitotopping (PCC over HMA)	1997		256,000	256,000		
Superpave Inlay	1997		58,000	58,000		
Superpave and Large Stone Base	1999		568,000	568,000		
MicroSurfacing	1999		5,000	5,000		
Oil Gravel	2000		44,000	44,000		
Thin PCC and Doweled PCC	2000		226,562	226,562		
60" Culvert Design	2000		155,000	155,000		
MicroSurfacing	2003		15,000	15,000		
Whitotopping (PCC over HMA)	2004		192,000	192,000		
Mesabi Hard Rock HMA & PCC	2004		75,000	75,000		
Flexible Slurry	2004		25,000	25,000		
SuperPave	2004		80,000	80,000		
GeoComposite Barrier Drain	2007		205,000	205,000		
Annual Benefits (10 years)	2000 - 2012				33,000,000	396,000,000
				44,304,562		396,000,000

BC Ratio = 8.9



Original Hot Mix Asphalt										SuperPave Inlay		Micro Surfacing				
5 year designs					10 year designs					50	51	1999				
1	2	3	4	14	15	16	17	18	19	20	21	22	50	51	2003	
6" 58-28 75 blow	6.1" 58-28 35 blow	6.3" 58-28 50 blow	9.1" 58-28 gyratory	10.9" 58-28 75 blow	11.1" 62-22 75 blow	8" 62-22 gyratory	7.9" 62-22 75 blow	7.9" 62-22 50 blow	7.8" 62-22 35 blow	7.8" 58-28 35 blow	7.9" 58-28 50 blow	7.9" 58-28 50 blow	3" 58-28	3" 58-28	1999	
33" Cl3sp	4" cl4sp	4" cl4sp	gyratory	75 blow	75 blow	28" Cl3sp	28" Cl3sp	12" Cl3sp Drain	28" Cl3sp	28" Cl3sp	23" Cl3sp	18" Cl3sp	4" PSAB	6" 58-28	6" 58-28	2003
Driving Lane 1.5" HMA inlay 2006	28" Cl3sp	33" Cl3sp	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	HMA Restrict Zone	HMA Coarse	2004	
Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Original Asphalt Binder Note
Sep 92 Current	Sep 92 Current	Sep 92 Current	Sep 92 Current	Jul 93 Current	Jul 93 Current	Jul 93 Current	Jul 93 Current	Jul 93 Current	Jul 93 Current	Jul 93 Current	Jul 93 Current	Sep 93 Current	Jul 97 Current	Jul 97 Current	58-28 = (120/150)	64-22 = (AC-20)

Original Concrete										1997 & 2004 Whitotopping																			
5 year designs					10 year designs					93		94		95		96		97		92		60		61		62		63	
5	6	7	8	9	10	11	12	13	93	94	93	94	93	94	93	94	93	94	93	94	93	94	93	94	93	94	93	94	
7.1" Trans Tined	7.1" Trans Tined	7.1" Trans Tined	7.1" Trans Tined	7.1" Trans Tined	9.9" Trans Tined	9.9" Trans Tined	9.9" Trans Tined	9.9" Trans Tined	3.9" 9" 58-28 1993 HMA	2.8" 10" 58-28 1993 HMA	3" 10" 58-28 1993 HMA	5.9" 7" 58-28 93HMA	5.9" 7" 58-28 93HMA	5.9" 7" 58-28 93HMA	5" 7" 58-28 93HMA	5" 7" 58-28 93HMA	5" 7" 58-28 93HMA	5" 7" 58-28 93HMA	5" 7" 58-28 93HMA	5" 7" 58-28 93HMA	5" 7" 58-28 93HMA	5" 7" 58-28 93HMA	5" 7" 58-28 93HMA	5" 7" 58-28 93HMA	5" 7" 58-28 93HMA	5" 7" 58-28 93HMA	5" 7" 58-28 93HMA	5" 7" 58-28 93HMA	
3" cl4sp	6" Cl4sp	4" PSAB	3" cl4sp	4" PSAB	4" PSAB	5" Cl3sp	5" Cl3sp	5" Cl3sp	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay
20x14 HMA Should 1" dowel	15x14 HMA Should 1" dowel	20x14 HMA Should 1" dowel	15x14 HMA Should 1" dowel	15x14 HMA Should 1" dowel	20x12 HMA Should 1.25" dowel	24x12 HMA Should 1.25" dowel	15x12 HMA Should 1.25" dowel	20x12 HMA Should 1.5" dowel	Trans Tined 4x4 Polypro	Trans Tined 4x4 Polypro	Trans Tined 6x5 Polypro	Trans Tined 12x10 Polypro	Trans Tined 12x10 Polypro	Turf 6x5	Turf 6x5	Turf 6x5	Turf 6x5	Turf 6x5	Turf 6x5	Turf 6x5	Turf 6x5	Turf 6x5	Turf 6x5	Turf 6x5	Turf 6x5	Turf 6x5	Turf 6x5	Turf 6x5	
Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay
Sep 92 Current	Sep 92 Current	Sep 92 Current	Sep 92 Current	Sep 92 Current	Sep 92 Current	Sep 92 Current	Sep 92 Current	Sep 92 Current	Oct 97 Current	Oct 97 Current	Oct 97 Current	Oct 97 Current	Oct 97 Current	Oct 97 Current	Oct 97 Current	Oct 97 Current	Oct 97 Current	Oct 97 Current	Oct 97 Current	Oct 97 Current	Oct 97 Current	Oct 97 Current	Oct 97 Current	Oct 97 Current	Oct 97 Current	Oct 97 Current	Oct 97 Current	Oct 97 Current	Oct 97 Current

Full Depth Reclamation			LTC Overlay	Unbound Recycled Base	Low Temp Cracking	Mesabi Stone Base	Unbonded PCC Overlay	Composite								
2	3	4	15	16	17	18	19	20	21	22	105	205	305	405	106	206
3" 58-34	3" 58-34	3" 58-34	3" WM	5" WM 58-34	5" WM 58-34	5" WM 58-34	5" WM 58-34	5" WM 58-28	5" WM 58-28	5" WM 58-34	4" 7.1" cracked 93 PCC	4" 7.1" cracked 93 PCC	5" 7.1" cracked 93 PCC	5" 7.1" cracked 93 PCC	2" 64-34	2" 64-34
6" FDR treated	6" FDR treated	6" FDR treated	11.1" 64-22 1993 HMA	12" 100% recycle PCC	12" 50% RePCC 50% Class 5	12" 100% RAP	12" Cl-5	12" Cl-5	12" Cl-5	12" Cl-5	3" cl4sp	3" cl4sp	3" cl4sp	3" cl4sp	6" Cl-5	6" Cl-5
2" FDR	2" FDR	4" FDR	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	27" Cl3sp	27" Cl3sp	27" Cl3sp	27" Cl3sp	Clay	Clay
26" Cl4sp	33" Cl3sp	Clay	58-34 Surface Binder	7" Select Gran	7" Select Gran	7" Select Gran	7" Select Gran	7" Select Gran	7" Select Gran	7" Select Gran	Orig 20x14 HMA Should 1" dowel	Orig 20x14 HMA Should 1" dowel	Orig 20x14 HMA Should 1" dowel	Orig 20x14 HMA Should 1" dowel	Mesabi 4.75 SuperP	Mesabi 4.75 SuperP
Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	15'x12' no dowels	15'x12' no dowels
2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008

Trapezoidal Concrete Design				Subgrade Drag Tie Bar Design				Thin Concrete				2008 Whitotopping					
110	210	310	410	111	211	311	411	511	611	113	213	313	413	114	214	314	414
6" 8" drive 6" pass	6" 8" drive 6" pass	7"	7"	7"	7"	7"	7"	7"	7"	5"	5.5"	6"	6.5"	6"	6"	6"	6"
6" Cl-5	6" Cl-5	6" Cl-5	6" Cl-5	3" Cl-5	3" Cl-5	3" ATB	3" Cl-5	3" Cl-5	3" Cl-5	5" Cl-5	5" Cl-5	5" Cl-5	5" Cl-5	5" 58-28 93 HMA	6" 58-28 93 HMA	6" 58-28 93 HMA	6" 58-28 93 HMA
Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay	Clay
heavy burlap	heavy burlap	heavy burlap	heavy burlap	15'x12' 10' PCC should 1" dowel	15'x12' 10' PCC should 1" dowel	15'x12' 10' PCC should 1" dowel	15'x12' 10' PCC should 1" dowel	15'x12' 10' PCC should 1" dowel	15'x12' 10' PCC should 1" dowel	heavy turf	heavy turf	heavy turf	heavy turf	6'x6' 1" dowels driving	6'x6' 1" dowels driving	6'x6' 1" dowels driving	6'x6' 1" dowels driving
15'x12' 1" dowel 3#5 tie	15'x13' 1" dowel 3#5 tie	15'x12' 1" dowel 3#5 tie	15'x13' 1" dowel 3#5 tie	15'x12' 1" dowel No tie	15'x12' 1" dowel 3#13 ties	15'x12' 1" dowel 3#13 ties	15'x12' 1" dowel 5#13 ties	15'x12' 1" dowel 3#19 ties	15'x12' 1" dowel 5#19 ties	15'x12'	15'x12'	15'x12'	15'x12'	no dowels passing	no dowels passing	no dowels passing	no dowels passing
2008 or 2009	2008 or 2009	2008 or 2009	2008 or 2009	2008 or 2009	2008 or 2009	2008 or 2009	2008 or 2009	2008 or 2009	2008 or 2009	2008	2008	2008	2008	2008	2008	2008	2008

FIGURE 1 MnROAD "Mainline" Test Cell Layout.

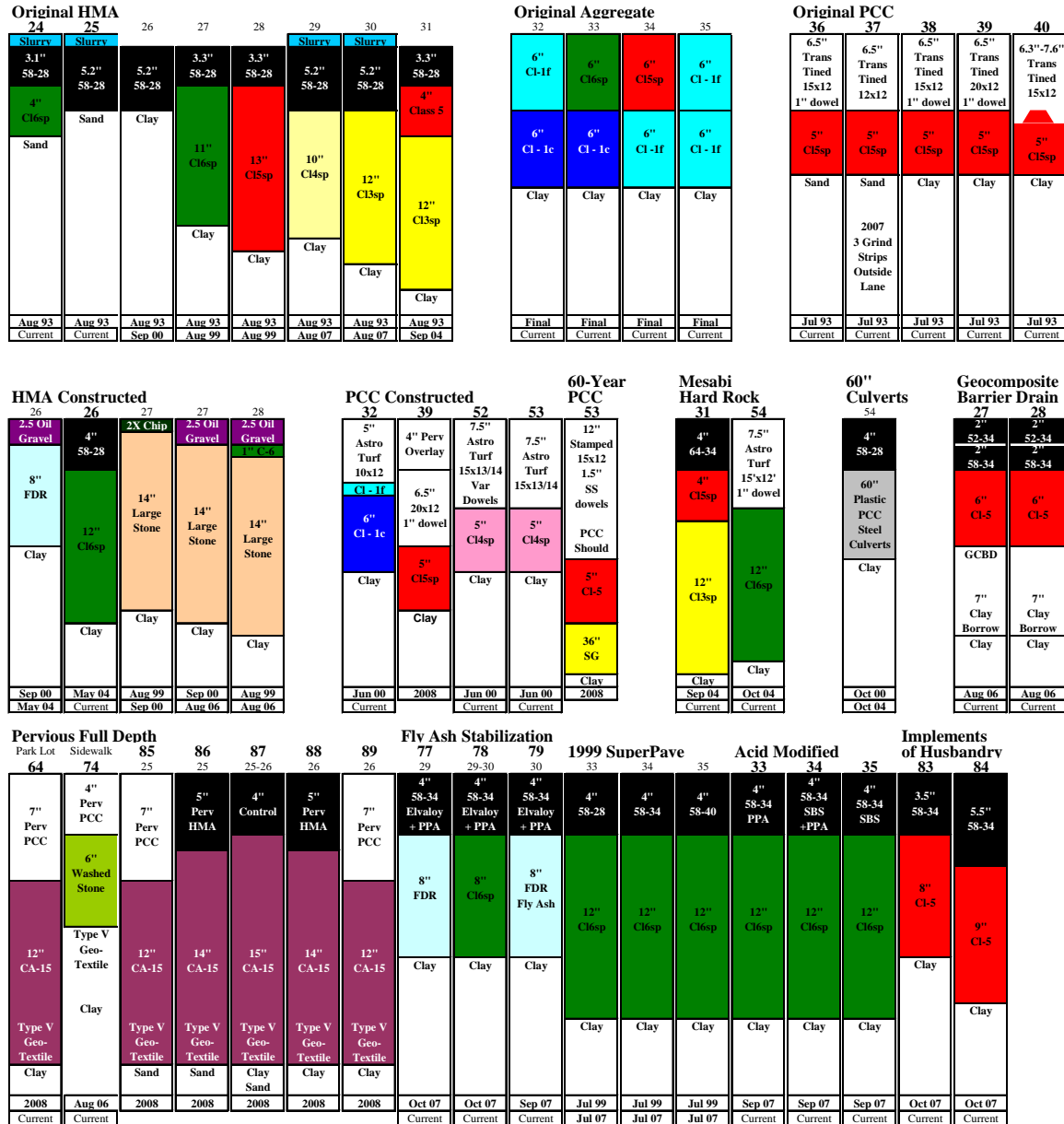
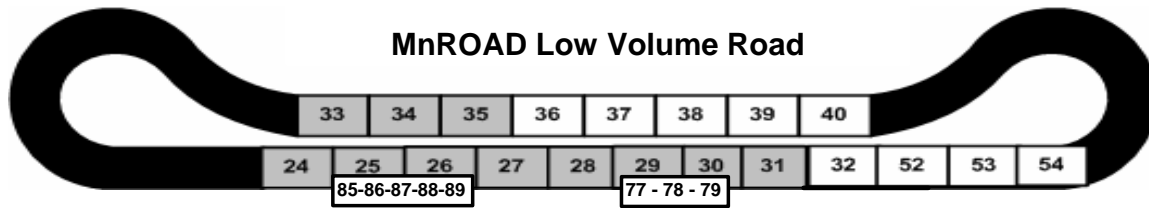


FIGURE 2 MnROAD "Low Volume Road" Test Cell Layout.