BENEFITS OF RESEARCH FOR SOCIETY IN THE STATE OF MAINE

An Interactive Qualifying Project Report

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by

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ABSTRACT

This study evaluated the beneficial effect of research on pavement materials in the state of Maine. Using Full Depth Reclamation asphalt mixes researched by WPI, the evaluation of the benefits of research showed that research is beneficial for the society in the state of Maine. The recommendation is that pavement research should be encouraged and supported by public and private agencies.

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INTRODUCTION

Research is the detailed investigation and/or experimentation aimed at the discovery and interpretation of facts, (as defined by Merriam-Webster's Collegiate Dictionary). The purpose of research is to learn and apply what has been learned. Research clarifies current standings, review options available, and helps to determine which is the best option based on scientific data. However, research needs funding and time.

WPI conducted a research and developed a new mix design system using recycled materials. This new system provides good structural strength at low cost compared to the traditional methods of rehabilitation. After the implementation of the new system, an evaluation of the benefits must be made.

The impact of any research can be evaluated by a variety of factors, including the improved quality of life, the added value to society, and the savings that can be realized through the implementation of the results of the research. The State Department of Transportation (DOT) in Maine invested a total of $110,000 for WPI to conduct research on pavements. The results of this research, when implemented properly, are not only beneficial to the DOT in Maine, but also to other states' DOT's, as well as the general population, who are affected by pavement conditions. Therefore, the impact of research should be evaluated by considering the funds invested by state DOT's and the benefits realized by the society in the state of Maine.

OBJECTIVE

The objective of this study is to evaluate the beneficial effect of research on pavement materials in the state of Maine.

SCOPE

The scope of work consisted of a review of the 21,000 miles of road systems in Maine, a survey conducted in the state of Maine, a review of the budgets for rehabilitation of pavements, evaluations of savings in rehabilitation cost through the implementation of research results, and a comparison of research expense and probable savings.

A research study conducted by Worcester Polytechnic Institute (WPI) researchers lead by Dr. Rajib B. Mallick was performed for the state of Maine. This study was considered for the evaluation of the benefits of research for the Department of Transportation as well as for the traveling public, industries and health care professionals. A comparison of cost and probable benefits of research was then made. Figure 1 shows the plan of study for this IQP project.

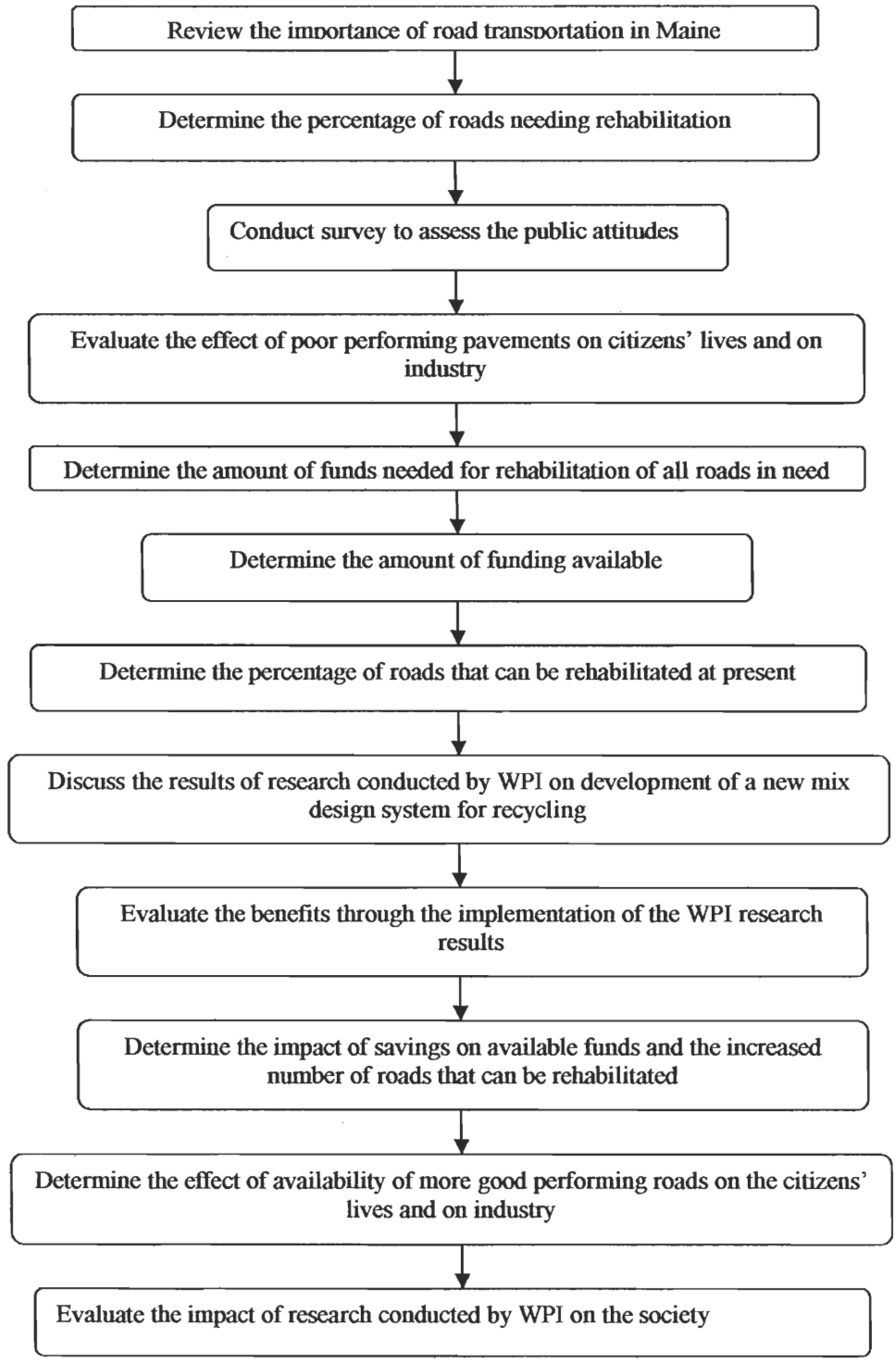

Figure 1. Plan of Study

The flowchart in Figure 1 illustrates the course of action taken for this study. The first step is to state in a clear way the present conditions of the subject of study, in this case, to review the importance of road transportation in the state of Maine, and to determine the percentage of roads needing rehabilitation.

A survey was conducted to assess the attitudes that people have toward the present day road conditions. This was followed by the evaluation of the effects of poor performing pavements on citizens' lives and on the industry.

Under the fixed Maine budget, the rehabilitation of all the roads could not be completed, so the next step was to find the amount needed to repair all roads in poor condition. Next, this amount was compared with the amount of funding available; the percentage of roads that could have been rehabilitated at the present with that amount was then calculated.

Next, the benefits of implementation of the WPI new mix design system for recycling on citizens and industry was determined, and the impact determined. The last step was to determine the value of research through an evaluation of the impact of the research conducted by WPI.

LITERATURE REVIEW

Importance of Transportation

Transportation is an essential part of the economic development of a society. Without good transportation, a nation cannot fully use its natural resources or reach the maximum productivity of its people. People travel for a variety of reasons, including locating food, to go to work, to travel, for trade or commerce, to explore new areas and for personal fulfillment. People and goods travel from one location to another; farmers ship produce to markets, and millions of workers travel to their jobs each day. Government services, including mail delivery and defense, depend on good transportation.

The Secretary of Transportation Rodney Slater, in a report at the 80th Annual Transportation Research Board in Washington, D.C, .was quoted in the January12, 2000, edition of Roads and Bridges as stating, "Transportation is essential to strengthening America for the untold challenges and limitless opportunities of the 21st Century. America will need an integrated transportation system that moves people, goods, information, and services safely and efficiently as a means for spurring the economy, enhancing the human and natural environment, and ensuring national security."

The speed, cost, and capacity of available transportation impact the economic vitality of an area and the use of natural resources. In a broad view, countries that have advanced transportation systems are more developed than other nations. Good transportation helps in achieving economic success and the lack of it contributes to failure. When the system

flows smoothly, it allows for specialization of industry and commerce, reduces costs for both raw materials and manufactured goods, and increases competition between areas, which benefits the consumer through greater choices and lower costs.

Use of Roads

One major method to transport freight is on highways. According to statistics on U.S. transportation, trucking has increased steadily, rising from 16% in 1950 to 28% in 1996, (See Figure 2.), [F]. Intercity bus transportation usage has declined while the use of personal cars has increased. The automobile is responsible for 80% of all domestic intercity passenger miles. An increase in population correlates to an increase in traffic on roadways each year.

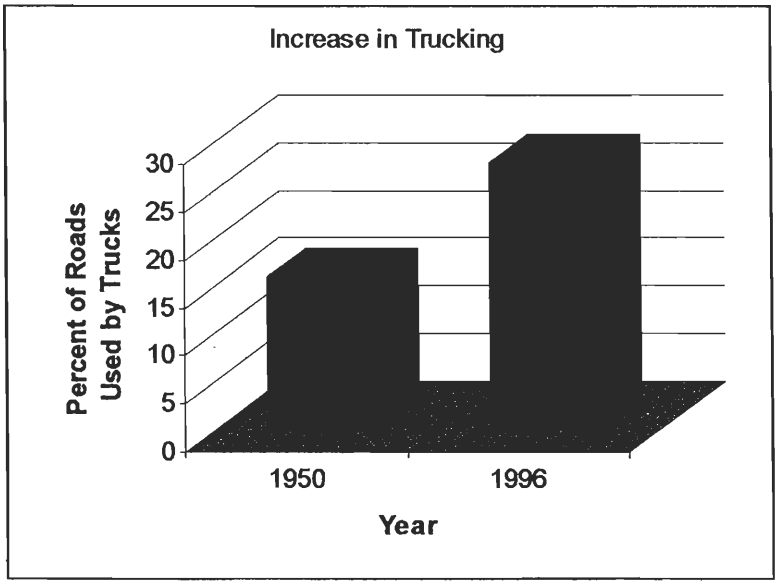

Figure 2. Increase in Trucking

Road deterioration

Of the approximately 2.2 million miles of roads in the U.S., more than 94% are paved with Hot Mix Asphalt (HMA). These roads, when performing well, provide a relatively safe and efficient mode of transportation. However, gradual deterioration of these roads occurs over time, due to traffic and the effects of the environment. As pavements age, their conditions deteriorate and their performances fall.

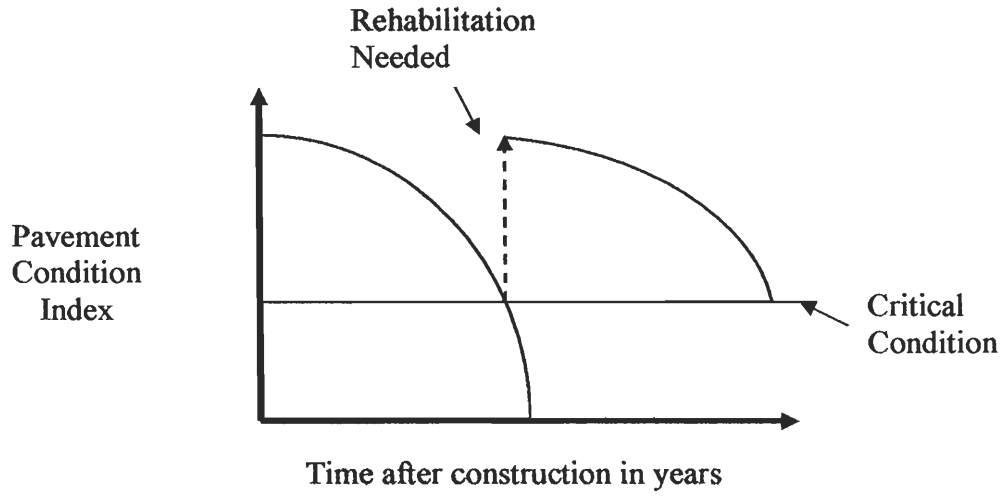

Figure 3. Plot of Time versus Pavement Condition

Figure 3 shows the condition of a typical pavement over time. As noted in the figure, beyond a certain pavement condition (quantified by critical pavement condition index), a pavement does not remain functional, for example, rutting and cracking can occur over time. See Figures 4 and 5.

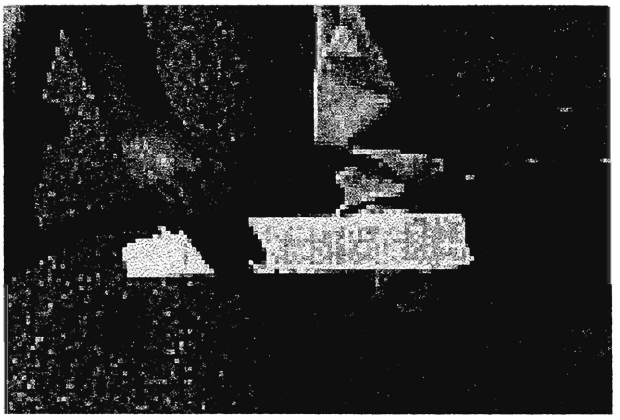

Figure 4. Rutting

Figure 5. Cracking

Hence, once constructed, every pavement must be maintained regularly and rehabilitated before its condition reaches the critical pavement index. Rehabilitation improves performance of a pavement, extends its service life, and brings its condition up to a point above the critical pavement condition index (Figure 3).

Rehabilitation Options

The major rehabilitation options are milling and overlay, total reconstruction, and recycling. Milling is a process in which a milling machine containing a rotating drum with carbide bits strikes the HMA surface and removes the material to a prescribed cutting depth. Overlay is a thin layer of HMA used to increase the life of the pavement, provide a smooth ride to the motoring public and improve pavement surface skid resistance. Total reconstruction or Full Reconstruction (FR) consists of milling all the material (which may include the base and subbase), disposal of the materials, and bringing new materials for the construction of the pavement. Recycling consists of milling and reclaiming the materials used previously on the road and using them in the rehabilitation of the pavement.

All pavements are composed of different layers that serve different purposes. Figure 6 shows a cross section of a typical asphalt pavement.

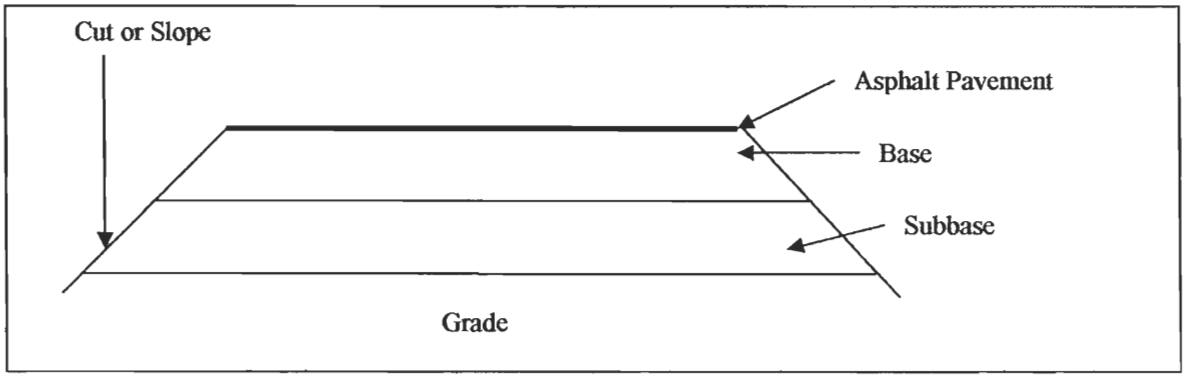

Figure 6. Pavement Section

If a pavement has good base and subbase, normally the most affected layer in a pavement is the top layer. The reason for this deterioration is that this layer is the one on the surface of the pavement, and it is in direct contact with the environment and traffic. If most of the problems in the existing roadway are confined to top layers, milling and overlaying are commonly selected as rehabilitation options. In many cases, when the distresses are mostly due to problems in the underlying layers such as base or subbase courses, milling and overlaying are not sufficient and total reconstruction is the only choice. However, recent advances in design and construction technology make recycling an attractive option. The benefits of pavement recycling include:

- Construction costs are reduced
- Aggregate and binders are conserved
- Pavement geometrics and thickness can be maintained
- Energy is conserved
- Disposal of existing material is avoided.

In addition, the use of some recycling procedures results in less traffic disruption, and therefore less user delay.

Need for Research on Recycling

Quite often the annual funds available to a state are not sufficient for adequately addressing all pavement rehabilitation needs. The state of Maine has an annual budget of

55 million dollars for road construction and maintenance. This budget is not enough to cover all of the deteriorated miles of road. With the 55 million dollars, a total of 701 lane miles can be repaired out of 3,992 lane miles that require rehabilitation. This leaves 3,291 lane miles that still need reparations. Hence, there is a need to optimize existing design and construction methods to obtain better results and rehabilitate more pavements with the available funds. Although Full Depth Reclamation (FDR), a recycling technique, has been shown to be very cost effective in rehabilitation of pavements, currently the mix design system is based on experience or outdated techniques. Available design methods are not able to produce recycled mixes that are comparable to virgin mixes. To utilize its potential fully, there is a need to develop a mix design system, using newly developed techniques such as the Superpave gyratory compaction method. This IQP project involves the evaluation of the results of a research study that was conducted by WPI for the Maine Department of Transportation, for the development of a rational and practical mix design system for producing recycled mixes that are comparable to virgin pavement mixes. The WPI study, A Laboratory Study of Full Depth Reclamation (FDR) Mixes, focused on the use of recycled materials on the rehabilitation of the pavements. Reusing materials can decrease the total cost of rehabilitation by increasing the amount of rehabilitation done for the same cost.

The WPI Study: Developing a Mix Design System

The first phase of the work consisted of selection of test sections, and testing of existing materials. The second phase consisted of designing the mixture for FDR material, and development of specification for construction of test sections. The third phase consisted

of construction of test sections and testing of in-place materials. The fourth phase consisted of refinement of laboratory mix design method, based on the results of the tests on in-place materials. The results from the study were used to provide recommendation for designing durable and stable recycled mixes. The mix design system and mixes recommended by WPI researchers can provide recycled pavements with as much strength and durability as in the case of a fully reconstructed pavement. [C]

Research

The impact of research on society has increased accordingly to the progress in research. The scientific method is used to develop the study. This is an organized system that establishes the steps to follow. First, a phenomenon is observed and described. Second, a hypothesis is formulated to explain the phenomena. Third, the hypothesis is used to predict the existence of other phenomena, or to predict quantitatively the results of new observations. Lastly, experimental tests of the predictions are performed by several independent experimenters in properly performed experiments.

Research conducted by NASA has had a drastic effect on today's society; the spin off products range from technology in health care, consumer products, and computer technology. The list of previous products is long, and includes such well known items as athletic shoes, scratch-resistant sunglasses, the global tracking system, x-ray machines, and CAT scanners.

Thermoplastic is a recent innovation which provides protection from ultraviolet radiation, and can be used to protect art, outdoor statues, and as a possible additive in cosmetics and outdoor paint. A process that improves bar code technology and image-correction software that is used in law enforcement are two 2001 innovations that are in the Space Technology Hall of Fame. Many of the new insights will work their way into the daily lives of citizens everywhere. The impact of the research is enormous.

Maine

Maine is located at the northeast end of the continental United States. It became the 23 rd state on March 15, 1820. It is known as the pine tree state and as vacationland. The largest city is Portland and the state capitol is Augusta. Maine has summer temperatures averaging 70°F and winter temperatures averaging 20°F. Maine possesses some 3500 miles of ocean coastline and over 2500 lakes and ponds. It is about 320 miles long and 210 miles wide, and has a total area of 33,215 square miles. The state is comprised of 16 counties with 22 cities, 424 towns, 51 plantations and 416 unorganized townships. Maine can be considered a rural area with a population density of 41.3 persons per square mile; the total population is approximately 1.2 millions. Maine has an extensive area of forests, approximately 17 million acres, which means that 90 percent of the state is forested. Maine forests support the state's oldest industry, papermaking.

Maine's industries are agricultural, marine and tourism. Maine's agriculture products range from blueberries, potatoes and apples to milk, eggs, livestock and maple syrup. The marine industry products range from lobster as the most famous, to finfish, shellfish

and salmon. Maine's four seasons offer an invigorating environment for the traveler. The state has a comfortable summer climates; winter snowfall amounts average between 60 and 90 inches. This makes the state popular with skiers and other winter sports enthusiasts. A map of Maine is shown in Figure 7.

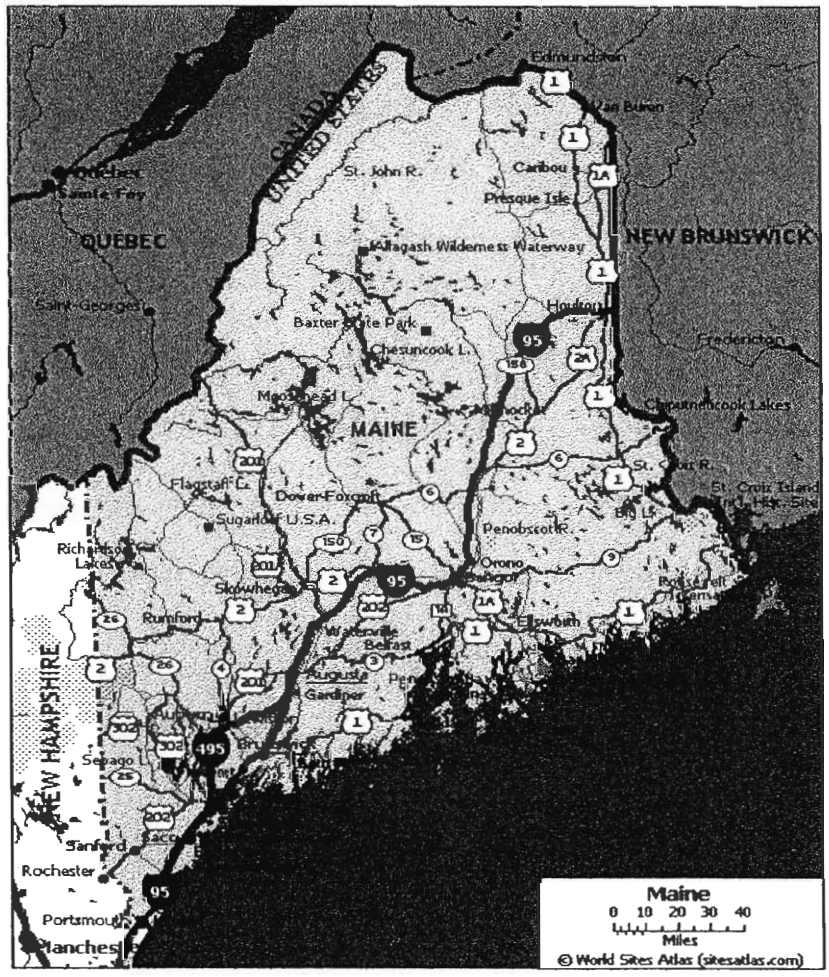

Figure 7. Map of Maine

In the south shore, the Atlantic Ocean is a tourist attraction because of the quality of the beaches and the fresh seafood of the area. The higher mountains are located in the western section of the state, but the mountains extend towards the east, covering the mid

section of the state. This is the area preferred for snow sports which are an attraction for tourists that come every year, and are a source of income to the state. The southeast section of the state, with I-95 and 495 has the highest population density. The area shared by these two highways is where the highest traffic flow would be found in the state. These two highways serve the cities of Portland and Augusta which are the biggest city and the capitol of the state respectively, and also two urban and industrial centers. Every industry needs to receive raw materials and ship products out. This leads to the necessity of having a transportation system. Also, the workers need to be able to commute every day, which requires effective transportation. Roads are used extensively as they are accessible to everybody and provide a low cost mode of transportation for people and industries. Maine possesses over 21,000 miles of public highways, which are designed, constructed and maintained mostly by Maine Department of Transportation and Maine Turnpike Authority.

Asphalt Roads

The basic materials from which asphalt roads are made are mineral aggregate and asphalt binder that is a by product of the petroleum industry. Each of these materials varies in properties and characteristics. For example, the aggregate varies in the gradation, shape, toughness, specific gravity, absorption and durability. Different combinations of these properties can be used to fulfill different requirements. Asphalt, on the other hand, is the cementing part of the mix that can vary in composition. It is important to know the characteristics of the asphalt before designing a mix. Asphalt can be identified for a specific mineral content and/or its range of resistance to temperature. Temperature is an

important factor because it can affect the viscosity of the asphalt: if too fluid, it will lower the resistance of the mix and lead to rutting, and if too stiff, it can lead to crackling problems [A].

The basic structure of a road in many of the cases consists of: subbase as the lowest layer (closest to the soil), base (intermediate layer), and Hot Mix Asphalt (HMA) which is the layer on top [A]. In this study, full depth reclamation (FDR) and full reconstruction were compared. The basic difference between these two methods is that in full depth reclamation, all in-place material is recycled and there is no need for excavation, while in full reconstruction a large portion of the existing road structure is excavated and removed and new materials are needed for different layers.

Information on Roads in Maine

According to Dale Peabody, the state transportation research engineer [E], Maine has a two-year program for new construction and rehabilitation of roads. Currently, $253 million are allocated for highway alterations, including improvements and resurfacing. An additional $247 million is presently budgeted for bridges. The existent two-year program to rehabilitate passenger and freight transportation programs plans for a total of $613 million.

According to the Six Year Plan dated February, 2001, close to fifty percent of the roads in Maine require rehabilitation: 3,992 miles out of a total of 8,269 miles need reconstruction or other capital improvements. Dale indicated four main causes of road

deterioration: severe climate, inadequate drainage, truck loads (particularly during the spring thaw), and inadequate financial resources to maintain the 8,269 miles of highways.

Full reconstruction (FR) of asphalt pavements involves excavating the existing material which has a cost of $29,647 per lane-mile. A new aggregate subbase of coarse gravel (depth of 2.13 ft) is then placed which has a cost of $48,765 per lane-mile. This yields a total cost of $78,412 per lane-mile.

A comparison of cost involved in full reconstruction ($78,412 per lane mile) and the mileage of roads needing rehabilitation shows that only a minor percentage of the roads can be rehabilitated every year with the currently available budget, if no option other than full reconstruction is available.

The two year program plans for specific road rehabilitation (Table 1). Fifty six miles of reconstruction will occur along arterial highways: fifty two - miles along the rural arterial highways and four miles along urban arterial highways. One hundred sixty one miles along connectors will be rehabilitated: one hundred eleven miles along major collectors and fifty miles of improvements along minor collectors. The plan also calls for four hundred miles of pavement preservation along arterial and collectors, and 1,450 miles of maintenance mulch, which is a 5/8 sand mix with a high asphalt content.

Table 1. Distribution of the Rehabilitation of Roads in Maine

Amount of miles for rehabilitation	Use
52 miles	rural arterial highways
4 miles	urban arterial highways
161 miles	connectors
111 miles	major collectors
50 miles	minor collectors
400 miles	pavement preservation
1450 miles	maintenance mulch

Available Recycling Method

The structural number represents the strength of a pavement. It can be determined from different tests that can be conducted in the field (falling with deflectometer) or in the laboratory (with the resilient modulus test). Higher structural numbers indicate greater strength within the pavement. Based on assumed data from the Maine DOT Technical Report 02-2 dated February, 2002, the average structural number for FDR pavement prior to the use of the newly developed mix design system, was considered to be 81 and that for FR as 100 (Figure 7). There is an expected twenty year service life for FR highways, and a 12-15 year service life for FDR highways. Therefore, recycling can not be economically advantageous since recycled pavements were considered to be weaker compared to fully reconstructed pavements. However, if a mix design system is developed that produces pavement mixes with same strength and durability as virgin mixes, the full savings from recycling can be realized.

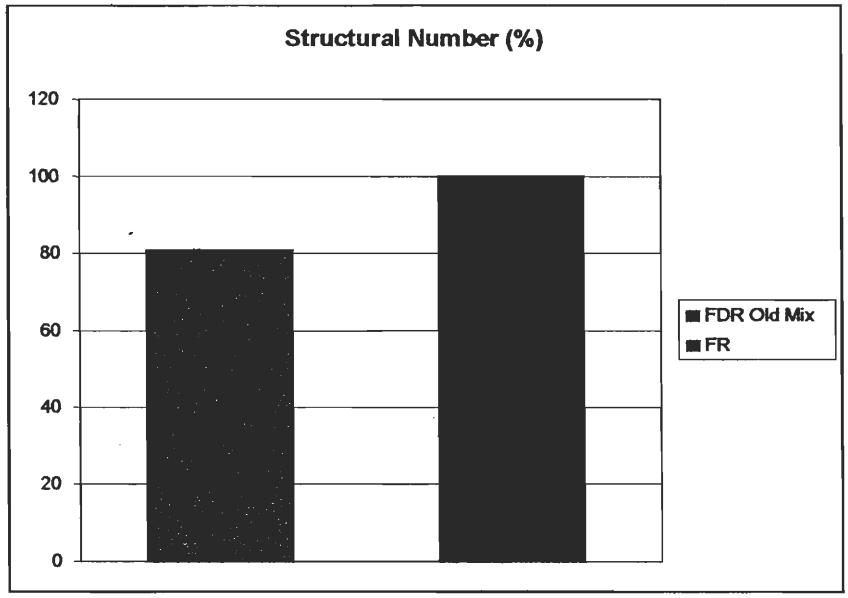

Figure 8. Structural Number for FR and FDR Old Mix Design

Importance of Roads

Good roads are important. Road usage has increased along with an increase in population. A well maintained system leads to a safe and efficient method of transportation. A combination of traffic and environmental factors combines to deteriorate the pavement to the point where it is no longer functional (in critical condition). Poor roads cause car damage, increase risk of accidents, increase travel time, and decrease comfort levels. Road repairs cause traffic disruption and delays.

Importance of Research

Research has played an important role in realizing improved materials. Through intense study under varying conditions, data is gathered that support certain methods and materials. The improvement can be in terms of strength, durability, cost, maintenance

required, etc. Incorporating this information into practice will yield positive results. Research is the means to obtain improved methods and procedures.

Importance of Pavement Research

Research leads to better pavements. A survey was conducted with the purpose of collecting information from a sample of the people and industries affected by the pavement conditions in the state of Maine. Almost all respondents considered time spent in traffic due to road repair, and time spent traveling poor roads, an irritation. Road improvements would lessen the amount of dissatisfaction and lead to an improvement in the quality of life. Research has a value in society and an important role to play.

SURVEY

Views of Public Citizens, Industries and Health Care Professionals on the Importance and Condition of Roads in the State of Maine

A survey is a method of collecting information directly from people. The most common means are interviews and questionnaires. Interviews are arranged between the two parts, the respondent and the interviewer. The interview can go into depth in the answers and opinions of the respondent and can be done in person, over the phone, through electronic mail. The questionnaire is self - administered and self - explanatory. Questionnaires can be administered in a specific time and place.

Before the actual survey is administered to the people, it must be formulated. A decision must be made in terms of the type of questions (fixed choice item or open ended item).

The questions must be designed to ask exactly what is needed to be known. Once a representative sample is chosen, the type of survey is determined: a cross-sectional (once) or longitudinal (overtime) design. Once the design of the survey is complete, the design of the data processing and analysis takes place. This may include percentages, averages, comparison of groups, relationships, and changes over time. [B]

Purpose of survey

A survey was conducted to measure public opinion from a sample of the people and industries affected by the pavement conditions in the state of Maine. Several communities throughout the state of Maine were involved. The focus was to target citizens, industry, health care, insurance, and tourism throughout the state to obtain information on the impact of road conditions on these segments of society. The objective of this survey was to gain information regarding Maine's pavements and to survey the community responses toward the existing road conditions and future improvements. A survey using five different survey instruments targeted the different professions described above.

Method of Survey

Two methods were used to obtain information. The first method was through electronic mail. Web addresses were obtained through Superpages.com and 411.com. Approximately 60 surveys went out to insurance agents, 60 to citizens, 20 to health care, 20 to tourism, and 20 to industry. Many of the surveys were sent along the southwestern section of the state, and along Interstate 95. A total of 5 responses were received from health care, 48 from citizens, 14 from industry, 37 from insurance, and none from

tourism. Each survey was written on Microsoft Excel, this is one of many programs that could be used as tools for an easier tabulation process. To simplify the results, the majority of questions required ranking from 1-10, with 1 as the lowest value, and 10 as the highest. Some queries involved generating percentages, from 1% to 100%. Other questions involved education level, job position held, nature of business, and comments. Each survey was intended to target specific areas pertaining to each topic.

A brief message was sent to each recipient, (shown in Appendix A) and the matching survey (Appendix B) was attached. The intent was to have each recipient complete the survey and reply to the questioner at WPI. Various portions of the state were targeted; the concentrations of the survey were in or near heavily populated areas such as Portland, Augusta, and the southern quarter of the state.

Sample citizen and health questions asked for responses to the following: well-maintained roads are important for improved quality of life, poor road conditions are a safety concern, present day road conditions are adequate, a reduction in road repair frequency will help to improve traffic, when maintenance is necessary, the system of leaving one lane free for traffic will cause less disruption, a maintenance system that reduces the amount of time to make repairs will improve your quality of life, poor roads increase car repair bills, auto insurance prices are affected by local conditions, well-maintained roads decrease travel time, level of education, and additional comments.

Insurance questions were similar, slightly different questions included: well maintained roads are important for emergency response, approximately what percentage of accidents on the roads are caused by poor road conditions, approximately what percentage of road accidents occur during maintenance repairs, what is the nature of your business, and what is your job title.

Questions specific to industry included: well maintained roads can lead to faster and cheaper deliveries, do you have a fleet of vehicles (if yes, what percentage of your budget is spent on road related wear and tear (tires, breaks, shocks, etc.), what type of transportation do you use for shipping and receiving? (Rank those that apply and number according to importance).

Results of survey

See Appendix D for comparison graph that shows how different respondents answered same questions.

Insurance

A total of 37 insurance responses were submitted. The majority of the responses considered poorly maintained roads a safety concern; over 88% ranked the importance as above five; 41% ranked the answer a ten. The results are shown in Figure 9.

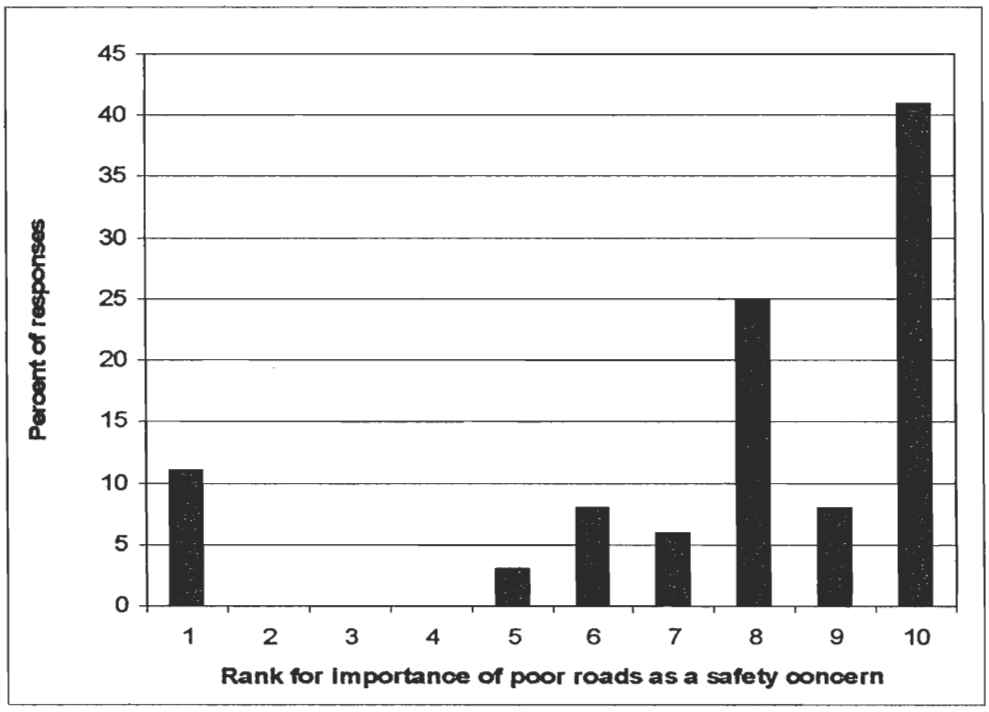

Figure 9. Insurance Response: The Importance of Poorly Maintained Roads as a Safety Concern

The results were evenly split, however, on whether the road quality affects either auto insurance or medical insurance prices. They do agree, however, that well maintained roads affect the quality of life and are important for emergency response times.

Ratings were heavily balanced towards the higher numbers; with most agreeing that the system of leaving one lane free for traffic will cause less disruption by allowing traffic to flow in one lane while reparations are made in the other lane. Most also agreed that a maintenance system that reduces the amount of time to make repairs will help the insurance business.

Figure 10 shows that accidents caused by poor road conditions fall generally between 10% - 60%, with the majority of responses from 10% – 30%. Of those accidents, most ranked the percentage that occurs during maintenance repairs from between 10% to 80%, with the majority falling below 50%.

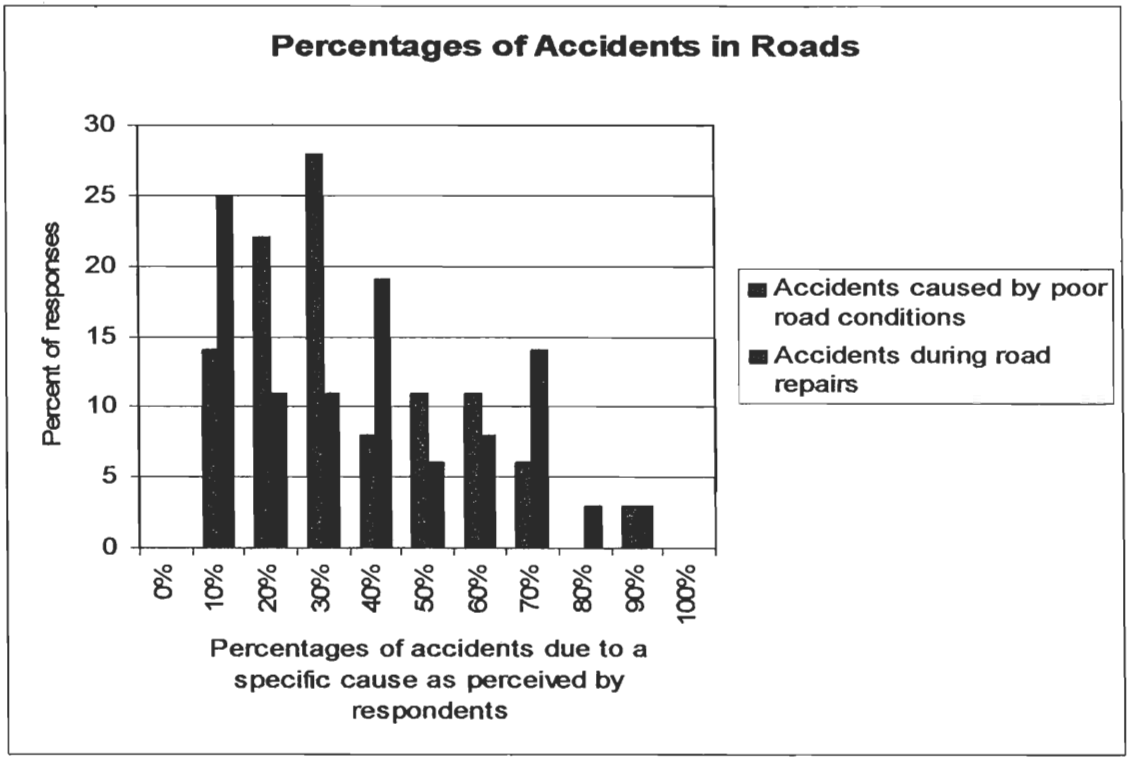

Figure 10. Insurance Response: Percentages of Accidents in Roads According to the Survey.

Accidents caused by poor road conditions and road repairs together contribute to a major percentage of the total number of accidents. This information is helpful in assessing the importance of road repair. Most of the insurance respondents were well educated: twenty-five percent attended high school, seventeen percent had some college, and forty-seven percent graduated from college.

There were a range of job titles: three listed the nature of their business as law (a legal assistant, a legal secretary, and a litigation manager). Several job titles were given under insurance: 14 claims representatives, 2 claims handlers, 1 auto insurance agent, 4 adjustors, 2 clerical insurance, 8 managers (these ranged from team leaders to litigation managers, managing general adjuster, and a district manager), 1 appraiser, and 2 processors.

Comments included:

- "overall the road conditions are not good – too many road repairs that go on forever,"
- "Contractors are not held accountable for cost increases due to slow performance by its employees - no incentive to complete job quickly."
- Roads are outdated and cannot handle the amount of traffic using interstate highways.

Citizens

Forty-eight citizens replied to the survey. Ninety percent felt that well maintained roads are important for an improved quality of life and rated the question a seven or higher, 48% ranked it a 9 or 10. Citizens also gave high marks to poor road conditions as a safety concern: 86% rated it from 8 – 10, 60% rated a ten. At the same time, the majority rated current road conditions at 5 or lower (60%); most of the scores fell around 4 or 5.

Maintenance questions provoked similar responses –see Figures 11,12. The majority agreed that less road repair would improve traffic (63% rated an 8 or better), and that

leaving one lane free for traffic would cause less disruption (58% rated 8 or higher). No one responded less than a 6 to the question that asked that if maintenance time were decreased that their way of life would improve.

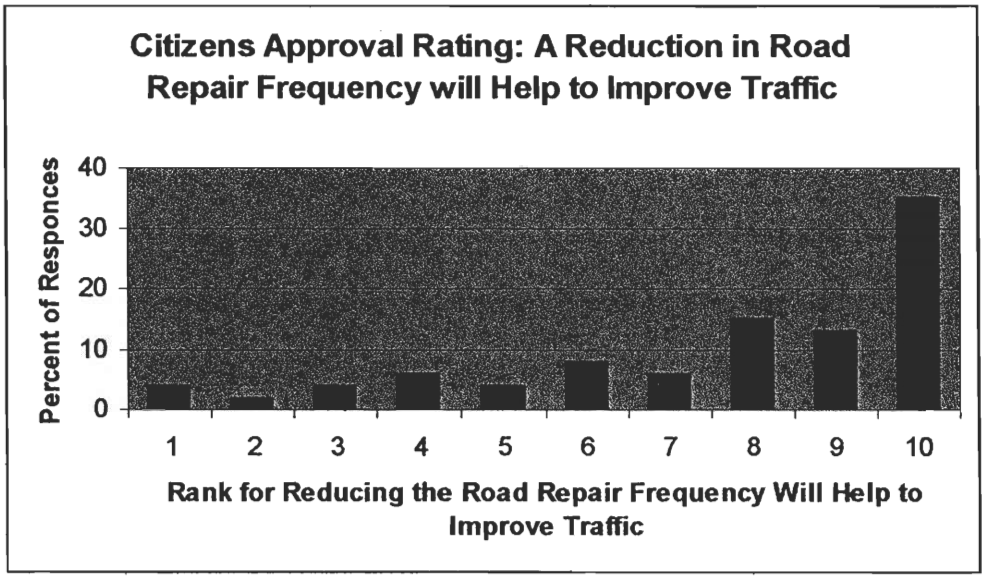

Figure 11. Citizens approval for reducing repair frequency

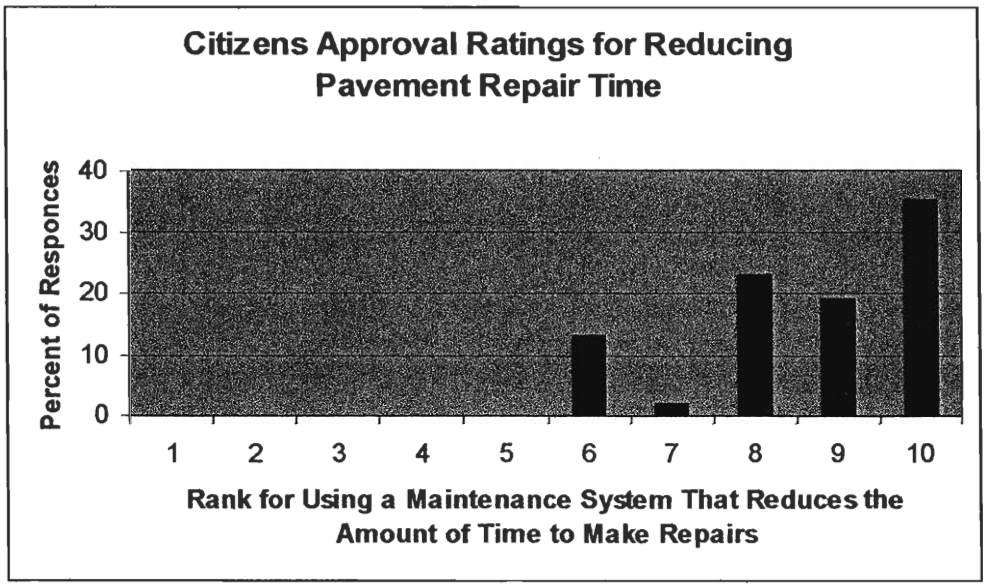

Figure 12. Citizens approval for reducing repair time

Most people found a correlation between poor roads and car repair bills; ninety percent rated the question a 7 or higher. They were in agreement that local road conditions affect auto insurance prices (86% rated a 5 or higher), and that well maintained roads decrease travel time.

The education level was reported as follows: twenty three attended high school, seven had some college, nine attended college, and seven had some graduate level work. Many citizens made comments about the poor road conditions and traffic. One stated, "The frequency of potholes on state and municipal roads often is excessive and the time lapse between notification and repair may take many months." Another thought, "Contractors don't see urgency to work quickly and efficiently. The longer the job takes the more money he makes." A final thought was, "Road conditions are horrible. When doing road work, it should not be during rush hour."

Tourism and Health Care

No responses were received from tourism, and only five health care email messages were answered. Due to the low response the results are not included.

Industry

Industry sent fourteen replies out of the twenty that were sent. Of those, 93% stated that well-maintained roads are important to business success and rated the question above six.

Similar ratings correlated improved road conditions and business success. At the same time, seventy -one percent stated that present day road conditions are not adequate and rated the query a three or lower.

Sixty- four percent ranked 8 or higher in response to the idea of leaving one lane free for traffic during maintenance repairs. The lowest number was a five in response to the question that asks if a maintenance system that reduces the amount of time to make repairs will help the business. Sixty-three percent chose an eight or higher.

Thirty-six percent had a fleet of vehicles. Of those, respondents determined that from 10% to 30% of the budget was spent on road related wear and tear, which included items such as tires, breaks, and shocks. The majority used cars and trucks for shipping and receiving (81%); 10% used trains and 9% used planes.

Of the 14 respondents, one had a high school education, 3 attended college, 6 had college degrees, and 4 had completed some graduate level work. Three were attorneys, one a litigation consultant, one operations manager for payroll processing, one warehouse distribution manager, one pre press manager, one gas station owner, and one landscaper. The only comment from an operations manager was, "Most product is picked up and delivered by our courier fleet. Road conditions affect client satisfaction."

Conclusions of Survey

People in all areas appear to be concerned about road conditions and roadway repair. The overwhelming majority feel the need for roads to be well- maintained, for improved

business success, safety, and quality of life. They also feel that well-maintained roads decrease travel times, which lead to faster and cheaper business deliveries. They rate current road conditions as needing improvement.

Citizens view poor road conditions as a safety concern that increases car repair bills and insurance rates. Insurers feel that well maintained roads are important for emergency response, and they attribute about 30% of the accidents on the roads to be caused by poor road conditions.

All groups agree that a reduction in road repair frequency will help traffic, and a system that reduces road repair frequency will be beneficial. They also come to a consensus that leaving one lane free for traffic during repairs will cause less disruption.

Cost/Benefit of Recycled Mixes with New Mix Design System Developed by WPI Researchers.

Research reports [C], [D], show that mixes designed by the new system can provide pavements with the same strength and durability as from fully reconstructed pavements. From cost figures provided by the Maine DOT [C], [D], it is noted that pavements reconstructed with mixes designed by the new system are significantly lower in cost compared to fully reconstructed pavements. The cost, strengths (as compared to fully reconstructed pavements) and other benefits of three options –full reconstruction, recycling by old design method and recycling by new design system, is shown in Table 2.

Table 2. Options for Rehabilitation

Option / Method	Cost/ square meters	Cost / lane mi	Strength	Reconstruction Rate (Lane-Miles per Year)*	Additional Benefits
FR	13.33	$78,412	100%	701	NA
FDR with Old Design	2	$11,773	80%	Not Available	Reuse of materials. Avoid excavation and dumping. Lane free for traffic flow.
FDR with New Mix Design	3.8	$22,353	100%	2461	Lane free for traffic flow. Reuse of materials. Avoid excavation and dumping.

* Based on a budget of $55 Million.

As shown in Table 2, the cost difference between the two FDR mixes is 1.8 more per square meter for the New Mix Design. In addition to initial reconstruction cost, another factor to consider is the strength acquired. With FDR New Mix Design, the strength increased 20 % of the strength obtained with the FDR Old Mix Design. The strength reached 100 % of the strength that can be obtained with the FR method.

There are substantial savings involved in the use of the FDR new method. At a cost of $22,353 per lane mile, the 2,461 miles that require rehabilitation would cost $55 million. The same 2,461 miles, repaired with the FR method, would cost $193 million. The difference in price between the two methods is $138 million. If this difference in cost were used with both methods, the FR system would pave an additional 1,759.7 lane miles, while the FDR new system would pave an additional 6,173.7 lane miles.

At any point in time, there are approximately 50% of the roads, or 3,992 miles in Maine, in need of repair. With the FR method, 17.5% of the roads needing repair can be fixed per year; while with the FDR new method, 61.6% of the roads needing repair can be fixed each year. Another way to view this is that 82% of the roads (that need repair) are in

disrepair annually using the FR method, compared to 38% of the roads that are in poor condition with FDR new method.

Full depth reclamation (FDR) involves recycling the existing material; full reconstruction (FR) involves excavating the material and replacing the subbase. For hot mix asphalt including emulsion and lime, no excavation is required and the subbase aggregate is reused, the cost of recycling using FDR is $22,353 per lane-mile; the cost for FR is $78,412. Full depth reclamation yields a savings of $56,059 per lane-mile over the full reconstruction method.

The cost of the FR method allows for a maximum reconstruction rate of 701 lane-miles per year while the FDR new method allows for 2,461 lane-miles per year on a budget of 55 million dollars. The difference in the former method is 1,760 lane-miles annually, more than three times the FR method, if the budget were the only limiting factor.

The use of a cheaper and long lasting pavement will actually increase the benefits of recycling as shown in Figure 13. Full depth reclamation can be done in one lane, keeping the other lanes free for traffic. This cannot be done in full reconstruction, where the entire pavement has to be closed to traffic.

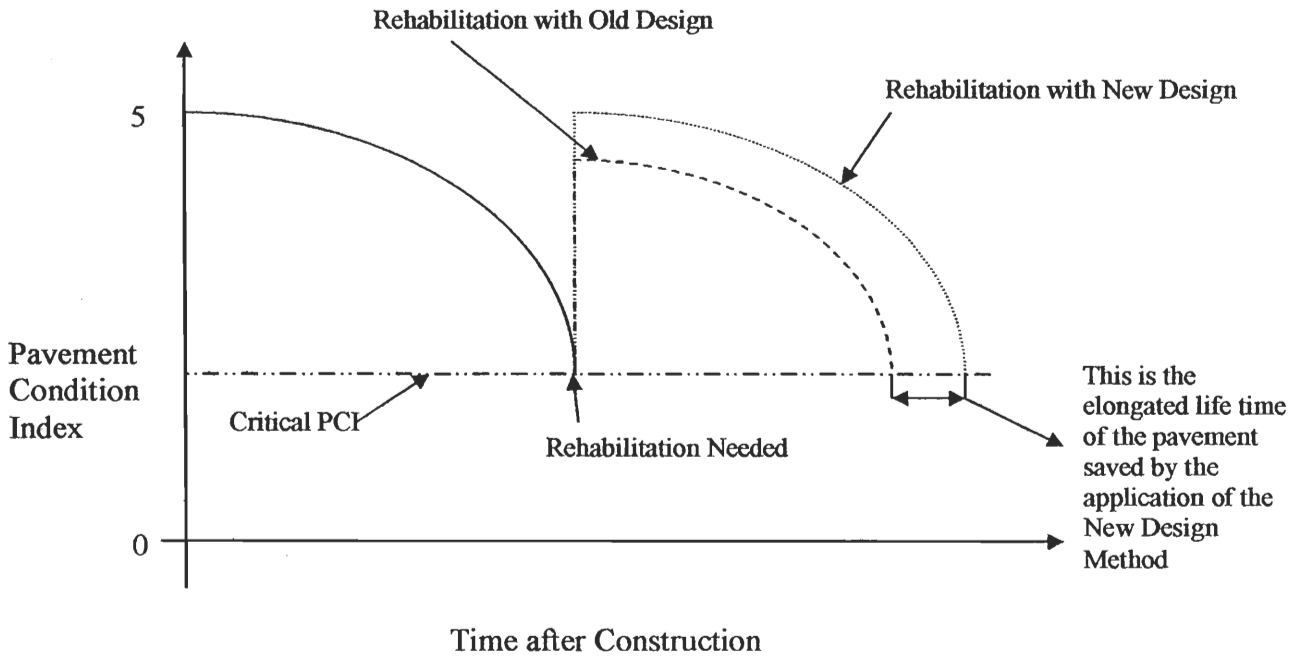

Figure 13. Comparison of the FDR Method: Before and After the Use of the New Design Developed by Research

Benefits of Research for the Society

As shown in the last section, the results on research on pavements, when implemented on a regular basis will lead to faster rehabilitation of roads and hence result in significant percentage of good performing roads in the state of Maine.

As indicated by the citizens, industries and health care professionals who were surveyed, the existence of good roads will benefit the society by

- Reducing accidents
- Reducing vehicle maintenance cost
- Reducing travel time
- Providing a more comfortable ride

However, the research that has lead to these benefits also required funding, and it should be taken into consideration when comparing the cost/benefit factor for research.
The WPI research study cost approximately $110,000. Theoretically, if all 3,992 miles can be rehabilitated, using the FR method it would cost $313,020,704, using the new FDR method it would cost $89,233,176. However, a probable saving of $223,787,528 is achieved by implementing the results of a research project that cost $110,000. This means, only 0.07% of the savings was needed for investment in the research. The amount spent for research is minuscule in comparison to the possible savings if the FDR new design of recycling pavement is adopted on a regular basis in the state of Maine.

Conclusions and Recommendations

From this IQP study, the following conclusions and recommendations are made.

1. Roads have a fundamental part in the development of our society.
2. With continuous use, roads deteriorate and need rehabilitation.
3. There is not enough money available to rehabilitate all roads in need of rehabilitation.

4. Considering this lack of money for rehabilitation and the increase in the deterioration of roads, there is a need to develop new techniques with good strength and durability that are also cost effective.
5. Citizens consider poor road conditions to be a factor in accidents.
6. The public considers the reparation of roads to be a necessary but a significant factor in causing traffic delays. Drivers prefer construction methods that keep one lane free for traffic.
7. The FDR new design is a product of research that can save approximately $56,000/lane mile with the available budget.
8. The use of the FDR new design allows the rehabilitation of 62% of the roads in need of rehabilitation in the state of Maine in any one year.
9. The use of FDR new saves money, conserves natural resources, and prevents landfills from filling up with materials that can be reused.
10. FDR new can be constructed by keeping one lane free for traffic.

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APPENDICES

Appendix A: Introduction to the Survey sent to the Public

WPI is conduction a survey on the importance of road conditions and their effects on a variety of businesses and the community. As prices continue to rise, government agencies continue to cut budgets reducing the available funds for maintenance and repairs of our roadways. Data indicates there is insufficient funding for the growing amount of roadwork required. Asphalt pavements have a long duration period if kept maintained. However, with the lack of funding a great amount of asphalt pavements are left to deteriorate beyond rehabilitation. This survey is part of a study to develop longer lasting asphalts that require less maintenance hence reducing the amount of funding required for safe roadways.

Results will be tabulated and included in a report of recommendations for a statewide maintenance system. We are grateful for your questions. Any additional input that you have would be helpful. Data is needed as soon as possible. We appreciate your prompt response.

Appendix B: Survey Results

CITIZENS

1. Well-maintained roads are important for improved quality of life.

1	2	3	4	5	6	7	8	9	10
			2	4	4	15	27	21	27

2. Poor road conditions are a safety concern.

1	2	3	4	5	6	7	8	9	10
				2	6	6	13	13	60

3. Present day road conditions are adequate.

1	2	3	4	5	6	7	8	9	10
10	8	8	17	17	6	15	6	6	4

4. A reduction in road repair frequency will help to improve traffic.

1	2	3	4	5	6	7	8	9	10
4	2	4	6	4	8	6	15	13	35

5. When maintenance is necessary, the system of leaving one lane free for traffic will cause less disruption.

1	2	3	4	5	6	7	8	9	10
	6		4	8	17	6	27	15	17

6. A maintenance system that reduces the amount of time to make repairs will improve your way of life.

1	2	3	4	5	6	7	8	9	10
					13	2	23	19	35

7. Poor roads increase car repair bills.

1	2	3	4	5	6	7	8	9	10
			2	2	6	19	15	19	35

8. Auto insurance prices are affected by local road conditions.

1	2	3	4	5	6	7	8	9	10
4	4		6	19	8	13	15	15	13

9. Well-maintained roads decrease travel time.

1	2	3	4	5	6	7	8	9	10
4			2		10	8	19	31	25

10. What is the level of your education?

	High School	Some College	College Degree	Graduate	Ph. D
Certificate:	15	19	48	15	0

11. Please note any comments that you have that relate to road conditions and maintenance.

INSURANCE

1. Poorly maintained roads are a safety concern.

1	2	3	4	5	6	7	8	9	10
11				3	8	6	25	8	41

2. Auto insurance prices are affected by the quality of local road conditions.

1	2	3	4	5	6	7	8	9	10
6	8	8	8	11	11	19	11	8	8

3. Well maintained roads improve the quality of life.

1	2	3	4	5	6	7	8	9	10
6	3		3	8	14	19	19	22	11

4. Well maintained roads are important for emergency response (fire, police, medical).

1	2	3	4	5	6	7	8	9	10
					3		22	31	42

5. Present day road conditions are adequate.

1	2	3	4	5	6	7	8	9	10
11	14	8	17	8	3	22	17		

6. A reduction in road repair frequency will help my business.

1	2	3	4	5	6	7	8	9	10
11	11	3	3	19	14	8	8	6	8

7. When maintenance is necessary, the system of leaving one lane free for traffic will cause less disruption.

1	2	3	4	5	6	7	8	9	10
3	3	3	11	14	8	11	14	14	11

8. A maintenance system that reduces the amount of time to make repairs will help my business.

1	2	3	4	5	6	7	8	9	10
3		3	3	6	19	19	17	8	19

9. Medical insurance is affected by poor road conditions.

1	2	3	4	5	6	7	8	9	10
19	6	14		8	14	14	14	3	8

10. Approximately what percentage of accidents on the roads is caused by poor road conditions?

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
	14%	22%	28%	8%	11%	11%	6%		3%	

11. Approximately what percentage of road accidents occurs during maintenance repairs?

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
	25%	11%	11%	19%	6%	8%	14%	3%	3%	

12. What is the nature of your business? _____

13. What is your job title? _____

14. What is the level of your education?

	High School	Some College	College Degree	Graduate	Ph. D
Certificate:	25	17	47	8	3

15. Please note any comments that you have that relate to road conditions and maintenance.

INDUSTRY

1. Well-maintained roads are important for my business success.

1	2	3	4	5	6	7	8	9	10
			7		14	14	21	7	36

2. An improvement in road conditions will help my business.

1	2	3	4	5	6	7	8	9	10
			7		7	21	21	7	36

3. Present day road conditions are adequate.

1	2	3	4	5	6	7	8	9	10
50	14	7		7		7	7	7	

4. A reduction in road repair frequency will help my business

1	2	3	4	5	6	7	8	9	10
7		7	7	21		7		21	29

5. When maintenance is necessary, the system of leaving one lane free for traffic will cause less disruption.

1	2	3	4	5	6	7	8	9	10
	7		14	7		7	29	14	21

6. A maintenance system that reduces the amount of time to make repairs will help my business.

1	2	3	4	5	6	7	8	9	10
				7	7	7	21	21	29

7. Well maintained roads can lead to faster and cheaper deliveries.

1	2	3	4	5	6	7	8	9	10
	14				14	21	14	7	29

8. What is the nature of your business? _____

9. What is your job title? _____

10. Do you have a fleet of vehicles?

Yes	No
36	57

11. If yes, what percentage of your budget is spent on road related wear and tear (tires, brakes, shocks, etc.)?

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	10
	20%	20%	40%							

12. What type of transportation do you use for shipping and receiving?

Please indicate those that apply and number according to importance.

	Cars/Trucks	Trains	Ships	Planes	Other (please specify)
Rank:	81	10	_____	9	_____

13. What is the level of your education?

	High School	Some College	College Degree	Graduate	Ph. D
Certificate:	14	50	21	7 0	

14. Please note any comments that you have that relate to road conditions and maintenance.

HEALTH CARE

1. Well-maintained roads are important for improved response time for medical emergencies.

1	2	3	4	5	6	7	8	9	10
								40	60

2. Faster response times are important in health care.

1	2	3	4	5	6	7	8	9	10
							20	20	60

3. Present day road conditions are adequate.

1	2	3	4	5	6	7	8	9	10
20		20		40		20			

4. A reduction in road repair frequency will help the delivery of health care.

1	2	3	4	5	6	7	8	9	10
20		20						40	20

5. When maintenance is necessary, the system of leaving one lane free for traffic will cause less disruption.

1	2	3	4	5	6	7	8	9	10
	20	20		20			20		20

6. A maintenance system that reduces the amount of time to make repairs will help the health care services.

1	2	3	4	5	6	7	8	9	10
						20	20	20	40

7. Insurance costs will decrease due to well maintained roads.

1	2	3	4	5	6	7	8	9	10
				20		40	20	20	

8. What is the nature of your business? _____

9. What is your job title? _____

10. Poorly maintained roads are a safety concern.

1	2	3	4	5	6	7	8	9	10
							20		80

11. What is the level of your education?

	High School	Some College	College Degree	Graduate	Ph. D
Certificate:	20	40	20	0	20

12. Please note any comments that you have that relate to road conditions and maintenance.

Additional Comments from the Survey

Insurance:

- "overall the road conditions are not good – too many road repairs that go on forever,"

- "Contractors are not held accountable for cost increases due to slow performance by its employees - no incentive to complete job quickly."

- "Roads are outdated and cannot handle the amount of traffic using interstate highways."

Citizens:

-"Road conditions are poor."

-"Roads need improvement."

-'Pot holes need fixing."

-"Rush hour traffic is terrible."

-"Too much traffic!"

-"The frequency of potholes on state and municipal roads often is excessive and the time lapse between notification and repair may take many months."

-"Contractors don't see urgency to work quickly and efficiently. The longer the job takes the more money he makes."

-"Road conditions are horrible. When doing road work, it should not be during rush hour."

Industry

"Most product is picked up and delivered by our courier fleet. Road conditions affect client satisfaction."

Appendix C: Questions for Dale Peabody

1. **Do you have any information on a project that involves asphalt rehabilitation?** YES, we have experimental construction projects involving highway rehabilitation techniques.
2. **In the state of Maine, what is the budget for highway and pavements for new construction or r rehabilitation?** In the current two year program, there is $253 million budgeted for highway improvements & resurfacing. The total two year program for highway & bridges is $490 million. The total two year program including passenger & freight transportation programs is $613 million.
3. **What percent of the state of Maine's budget is for pavements?** For actual hot mix asphalt pavement it's estimated at $50 to $60 million per year.
4. **How much does rehabilitation save?** To totally reconstruct a highway costs around $1 million per mile, the highway improvement program results in about $500,000 per mile. This is initial cost and does not represent life cycle cost. However, a 20 year service life is expected for new or reconstructed highways, while a 12 to 15 year service life is expected from highway improvement projects.
5. **What do you think are the main factors leading to road deterioration (trucking, lack of maintenance, etc.)?** In Maine, a combination of the severe climate, inadequate subsurface drainage, and truck loads especially during spring thaw periods. We also maintain over 8000 miles (8269) of highways and have inadequate financial resources to properly do so.

6. **Do you have any evidence that links poor roads to accidents or vehicle damage?** No.
7. **What percent of roads need rehabilitation?** Of the 8269 miles, 3992 have been identified as being in need of reconstruction or other capital improvements. (This is from our Six Year Plan dated Feb. 2001).
8. **What percent of roads can be rehabilitated at present?** The current two year program has: 52 miles of reconstruction along the rural arterial highways, 4 miles of reconstruction along urban arterial highways, 111 miles of improvements along major collectors, 50 miles of improvements along minor collectors, 400 miles of pavement preservation along arterials and collectors, and 1450 miles of maintenance mulch (a 5/8" sand mix with high asphalt).

Appendix D: Graphs

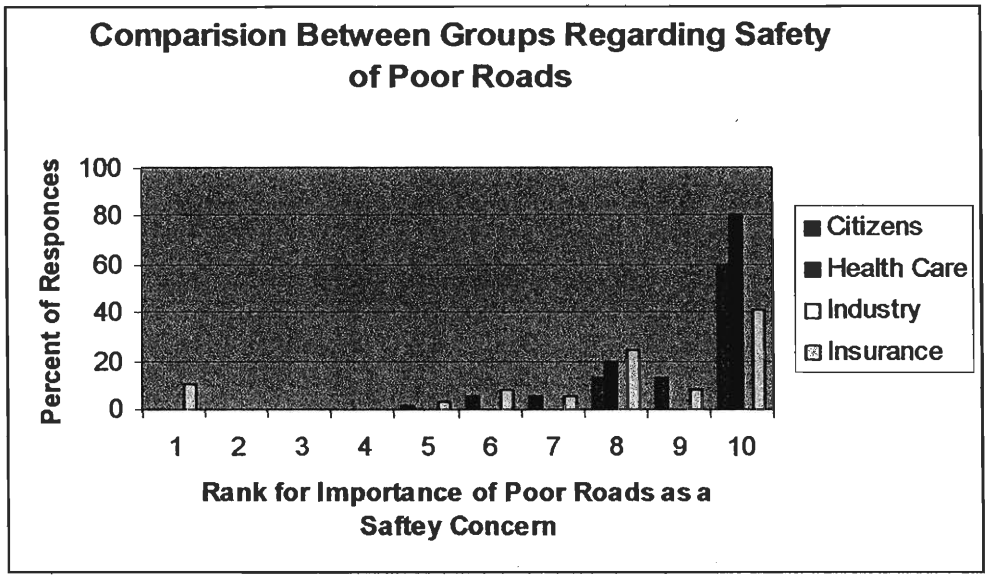

Figure 11. Comparison between groups regarding safety of poor roads

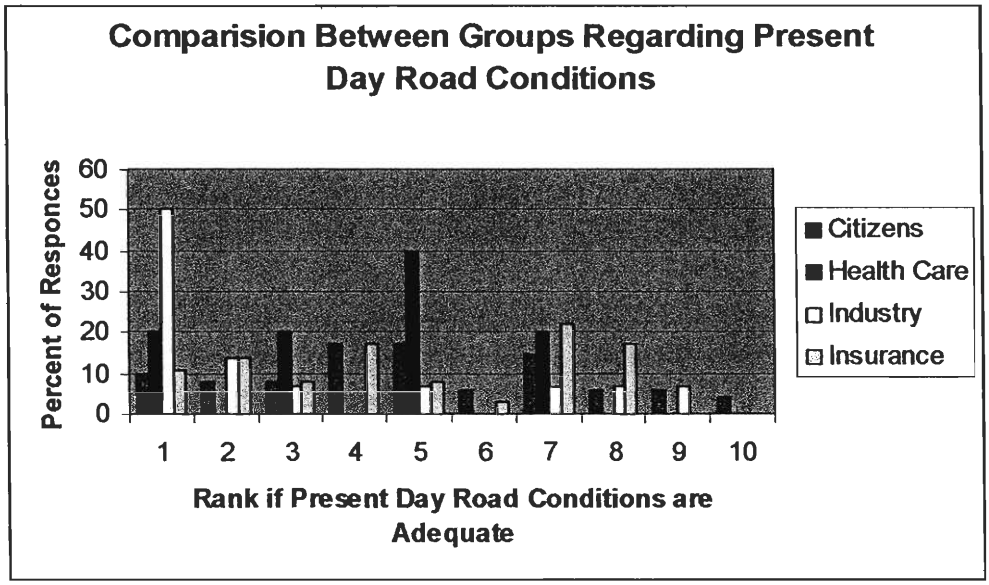

Figure 12. Comparison between groups regarding present dry road conditions

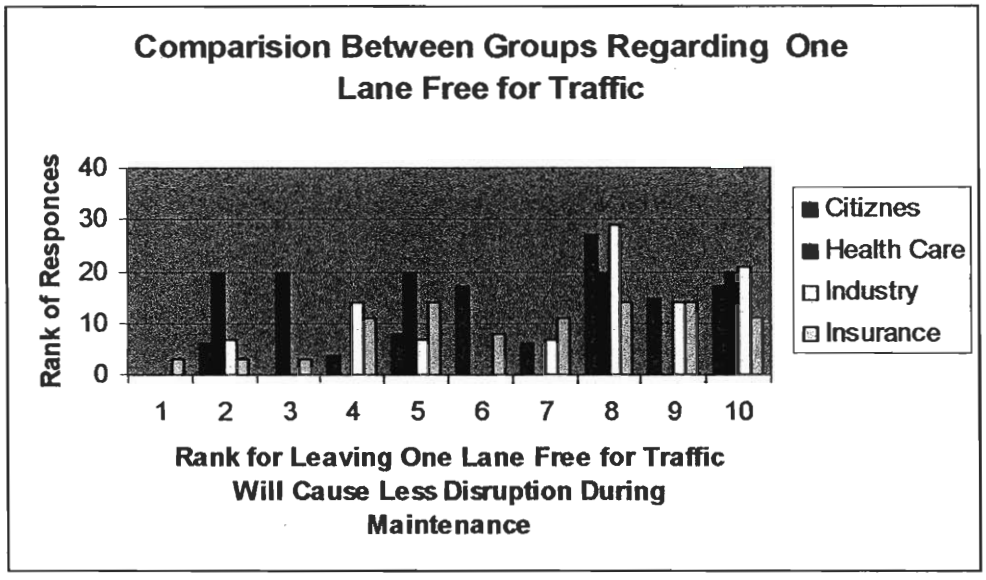

Figure 13. Comparison between groups regarding one lane free for traffic