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16. Abstract

This report summarizes the results of a literature search conducted to determine engineering applications of various waste and recycled materials (WRMs). The results of a material availability and location survey conducted to determine the availability of WRMs within the Texas Department of Transportation (TxDOT) are also presented. Information of interest included the location, type, and quantity of WRMs present.

Technical laboratory studies that have been used in the past to evaluate WRMs fail to take into account the socio-economic and environmental benefits of using these materials. To overcome this problem, a WRM evaluation method was developed that considers the socio-economic and environmental benefits in addition to the technical and economic aspects when evaluating WRMs for various engineering applications. An initial screening method was also incorporated to screen out materials having low or no utilization potential. Only those materials showing high potential will be subjected to extensive technical studies.

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LOCATION AND AVAILABILITY OF WASTE AND RECYCLED MATERIALS IN TEXAS AND EVALUATION OF THEIR UTILIZATION POTENTIAL IN ROADBASE

by

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Research Report 1348-1

Project 0-1348

Recycled Materials in Roadbase, Except Glass

conducted for the

Texas Department of Transportation

in cooperation with the

U.S. Department of Transportation
Federal highway Administration

by the

CENTER FOR TRANSPORTATION RESEARCH
Bureau of Engineering Research
THE UNIVERSITY OF TEXAS AT AUSTIN

October 1995

IMPLEMENTATION STATEMENT

The waste and recycled material location and availability survey was conducted to determine the quantities of potential roadbase material available in Texas Department of Transportation (TxDOT) districts, and to classify them by quantity, location, and type. This survey provides, first, a clearer understanding of the problem of waste materials available and, second, a listing of candidate materials having potential for utilization in roadbase.

The waste and recycled material evaluation method described will enable TxDOT to determine the potential for using a particular material in roadbase — *before* that material is subjected to expensive and time-consuming laboratory studies. Because this method can identify those materials having low utilization potential, TxDOT should realize savings of both human and financial resources.

Prepared in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration

DISCLAIMERS

W. R. Hudson, P.E. (Texas No. 16821)
Research Supervisor

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SUMMARY

This report summarizes the results of a literature search conducted to determine engineering applications of various waste and recycled materials (WRMs). The results of a material availability and location survey conducted to determine the availability of WRMs within the Texas Department of Transportation (TxDOT) are also presented. Information of interest included the location, type, and quantity of WRMs present.

Technical laboratory studies that have been used in the past to evaluate WRMs fail to take into account the socio-economic and environmental benefits of using these materials. To overcome this problem, a WRM evaluation method was developed that considers the socio-economic and environmental benefits in addition to the technical and economic aspects when evaluating WRMs for various engineering applications. An initial screening method was also incorporated to screen out materials having low or no utilization potential. Only those materials showing high potential will be subjected to extensive technical studies.

CHAPTER 1. INTRODUCTION

1.1 BACKGROUND

Enormous quantities of waste materials are generated every year in the U.S. For many, the recycling of these waste materials has become a personal responsibility, one that can assist in preserving the country's natural resources. Much research has shown that recycling can reduce both the consumption of virgin materials and the cost of extracting and processing new raw materials. Recycling and using waste materials effectively can address public concerns expressed about the vast quantities of useful materials being discarded and wasted [Mauro 93].

Waste and recycled materials (WRMs) are currently attracting the attention of officials at federal and state departments of transportation. What they and others see in such material is a viable substitute for the decreasing quantities of quality virgin aggregate materials used in road and highway construction. There has been considerable emphasis on recycling certain materials, particularly old concrete pavements and old asphaltic concrete pavements [Ahmad 91, AASHTO 94]. However, in some cases these materials have not been utilized to the highest extent possible. The Texas Department of Transportation has a strong interest in the efficient use of waste materials and recycled materials. Accordingly, it has cooperated with the Texas Natural Resource Conservation Commission (TNRCC) to fund a series of studies to determine practical uses of WRMs in various highway construction projects. This particular project is concerned with the use of base materials as a possible substitute for crushed stone bases or other stabilized natural aggregate bases.

The customary approach to using these materials has been to evaluate them in the laboratory, comparing the findings with standard specifications for virgin materials. This is not an appropriate method because the materials may have extremely high value even though they do not have quality equal to virgin materials (TRB 76). These laboratory studies consider only material properties in most cases; that is, they consider neither the benefits of reusing existing materials, the environmental benefits resulting from savings in extraction and processing costs for new materials, nor the disposal cost savings realized through using recycled materials. Thus, there is an important need to consider all aspects of WRM use in highway construction; this project undertakes to examine those issues in a systematic way.

The feasibility of using a specific WRM depends on a large number of interrelated factors. To make meaningful recommendations, these factors need to be evaluated objectively. What is needed is a simple and quick methodology useful in evaluating these WRMs for potential use in construction projects. Based on this evaluation, the overall potential of a particular WRM may be assessed, with only those having high potential designated for detailed and expensive technical studies that will determine final specifications.

1.2 RESEARCH OBJECTIVES

The objective of this research effort is to develop an evaluation method for waste and recycled materials (WRMs) for potential use in roadbase construction projects. Subobjectives of the project include determining the extent of WRMs available in Texas, and identifying the rate at which they are generated. The source of these materials — whether commercial or governmental — was also considered important.

While the initial objective was to evaluate the technical feasibility of using WRMs, it became clear during the study that a total systems' methodology for evaluating WRMs for use in roadbase construction should be developed, one that considers economic, technical, social, environmental, and other factors relating to the problem. A final objective of the project will be to develop trial specifications that can be used by districts in constructing roadbases of recycled materials.

1.3 RESEARCH SCOPE

The scope of this research is limited to the evaluation of materials used in roadbases. However, the methodology being developed can be modified and used for other applications of WRMs, with proper re-evaluation of objectives and cost factors set up for each potential use. The funding and time frame available for this project make it feasible to develop the methodology and to apply it to one or two test cases, including the development of a trial specification for use in the field. It will subsequently be important to modify the methodology and test it on other applications.

1.4 RESEARCH APPROACH

This research effort began with a literature search on the types of WRMs available, as well as their performance in engineering applications. We also attempted to gauge public attitudes regarding the use of these materials, environmental costs and benefits, and the costs of landfilling versus recycling.

The literature search was followed by a statewide material availability and location survey. The survey provided information about the location and quantities of various WRMs in TxDOT districts. The latest survey techniques, including the "chain referral" method, were used to identify individuals having personal knowledge of the availability of suitable WRMs.

1.5 REPORT ORGANIZATION

Chapter 2 reports the results of the literature search. Information discussed includes the types and performance of WRMs being utilized in various engineering applications. Chapter 3 provides an insight into the problem of waste materials in Texas by classifying the WRMs based on type, location, and quantity.

Factors important in the development of the WRM evaluation method are discussed in Chapter 4. Chapter 5 then describes the developed method. Finally, Chapter 6 describes the conclusions and recommendations of this research effort. Future research needs are also identified.

CHAPTER 2. LITERATURE SURVEY

2.1 INTRODUCTION

This chapter describes the results of a detailed literature search undertaken to identify available information on the use of recycled materials in roadbase. The searching procedure involved key word searches through the Transportation Research and Information System (TRIS) data base. In the initial search, approximately 100 articles relating to recycling in pavements were retrieved. From these, one-page abstracts of selected articles were obtained. After reviewing this information, we requested selected articles from libraries all over the U.S.

Several documents describing recycling efforts in Texas were provided by the Texas Natural Resource Conservation Commission (TNRCC). TxDOT also made available their annual reports to the Texas Legislative Audit Committee regarding recycled asphaltic pavement (RAP) consumption. The information obtained from the literature search is summarized in the following sections.

2.2 DISPOSAL OF WASTE MATERIALS

There are three techniques used for disposing waste materials: (1) incineration, (2) burial, and (3) recycling. As indicated by the Environmental Protection Agency (EPA), the bulk of the domestic refuse is either buried or incinerated, with or without the generation of energy [EPA 90]. Both burial and incineration usually involve landfills. Public concern is often expressed about the large quantities of useful materials being discarded or destroyed in landfills. A number of states, including Texas, are in the process of developing legislation intended to stimulate recycling efforts [Ahmad 91, Ahmad 92].

2.3 ENGINEERING APPLICATIONS OF WASTE AND RECYCLED MATERIALS

This section discusses the various uses of recycled materials in pavements/roadbase in the U.S. Information is provided on the production, use, and performance of various materials of interest to this project. These materials include: (1) recycled asphalt pavement (RAP), (2) old concrete, (3) iron blast furnace slag, (4) coal ash, (5) steel slag, (6) building rubble, and (7) rubber tires.

2.4 RECLAIMED ASPHALTIC CONCRETE PAVEMENT (RAP)

The recycling of asphalt pavements is not a new concept. With the increase in the price of asphalt brought about through the oil crisis of the early 1970s, the recycling of asphalt pavements became a feasible way of lowering highway construction costs [Ahmad 91, 92]. There have been numerous laboratory, field, and synthesis studies on the various aspects of hot mix and cold mix recycling [TRB 78, Ferreira 87, and Wood 89].

There are several established and viable processes available for recycling asphalt pavements. However, there is a need to standardize the design, construction, testing, performance, and quality of the evaluation processes [Ahmad 92]. Table 2.1 lists the states that have used RAP in roadbase construction. Information is also provided about the extent of states' experience and performance of the final product.

Table 2.1 Use of Recycled Asphalt Product (RAP) in Roadbase by State

State	Experience	Performance	Remarks
Kentucky	Limited	No Data	
Nebraska	Moderate	Excellent	Base for PCC pavements

Source: AASHTO 94

2.5 RECLAIMED PORTLAND CEMENT CONCRETE PAVEMENT (RPCP)

Recycling of PCC pavements has been underway in the U.S. for a number of years [Calvert 77, Marks 84]. A 1991 Purdue University study analyzed the experiences of a few state DOTs to determine the feasibility of recycling PCC pavements [Ahmad 91]. The analysis concluded that, in addition to reducing the waste disposal problem, recycling PCC pavements is technically and economically feasible. However, further research is needed to address the performance problems of recycled PCC pavements, and to refine the mix design and construction procedures. Table 2.2 lists the states that have used recycled PCC pavements in roadbase construction. It also includes information on the states' experience, as well as the performance of the final product.

Table 2.2 Use of Recycled PCC Pavement in Roadbase by State

State	Experience	Performance	Remarks
New York	Moderate	Excellent	Limited geographically
Arizona	Limited	Good	Only on one/two projects
California	Limited	Good	
Connecticut	Moderate	Good	Recycled PCC pavements
Georgia	Limited	Good	
Iowa	Extensive	Good	Under new PCC pavement
Indiana	Moderate	Good	Separator/filter layer
Kansas	Moderate	Good	
Kentucky	Limited	Good	Agg. Base, Subg. Stab.
Louisiana		Good	Base / Subbase
Massachusetts	Limited	Good	Base for Con. Walkway
Maryland	Moderate	Poor	Graded agg. base/subbase
Michigan	Moderate	No Data	Base under PCC
Minnesota		Good	As base
Montana	Limited	Good	Lean concrete base
N. Carolina	Moderate	Good	Base under flexible pavement
Nebraska	Moderate	Good	Base for PCC pavement
New Jersey	Extensive	Excellent	In place of Dgraded base
Ohio		Poor	
Virginia	Limited		
Wisconsin		Good	
Wyoming	Moderate	Good	Granular base

Source: AASHTO 94

2.6 IRON BLAST FURNACE SLAG

Iron blast furnace slag, a by-product of the iron industry, has historically been used in the construction of highways. Given its wide availability and broad range of uses, iron blast furnace slag is the waste material of greatest interest to the highway industry. In its production process, iron ore, coke, and limestone are heated in the blast furnace to produce both pig iron and blast furnace slag. Iron blast furnace slag is defined as "the non-metallic by-product consisting of silicates and aluminosilicates of lime and other bases;" it leaves the blast furnace resembling molten lava [Miller 76]. Four distinct types of blast furnace slag are produced as a result of its selective cooling. These types are defined below [Emery 82].

2.6.1 Air-cooled Blast Furnace Slag

In this manufacturing process, the blast furnace slag is cooled under ambient air temperature conditions. This type of blast furnace slag finds extensive use in conventional aggregate applications. Most of the blast furnace slag produced in the U.S. falls under this category.

2.6.2 Expanded or Foamed Blast Furnace Slag

Controlled quantities of water are added to the blast furnace slag during the solidification process. Water is sometimes added in the form of steam and, on other occasions, with air. The expanded or foamed blast furnace slag is used mainly as a lightweight aggregate.

2.6.3 Granulated Blast Furnace Slag

Granulated blast furnace slag is manufactured by cooling the molten blast furnace slag to a vitrified state using water. This product is used mostly in the manufacture of slag cement.

2.6.4 Palletized Blast Furnace Slag

This type of blast furnace slag is manufactured by quick quenching in a spinning drum using either water or air. This product finds use as lightweight aggregate and as an ingredient in the manufacture of slag cement.

2.6.5 Summary of Blast Furnace Slag Properties

Miller et al. [Miller 76], after conducting an NCHRP study, reported that, among the waste materials available for highway construction, iron blast furnace slag has a high potential for extensive use. Properties of air-cooled blast furnace slag that make it attractive for highway applications include its low compacted bulk density (1200-1450 kg/m^3), high stability (CBR > 100), high friction angle (Ø = 45°), high durability, high resistance to weathering and erosion, free draining and non-frost susceptibility, and resistance to steel and concrete corrosion [Emery 82].

According to Ahmad et al. [Ahmad 91, 92], the current practice indicates that the use of iron blast furnace slag in various highway applications is economical and technically feasible. However, lingering doubts about its environmental impacts need to be investigated further. Table

2.3 lists the states that have used iron blast furnace slag in roadbase construction. Information is also provided on the extent of the states' experience, as well as on the performance of the final product.

Table 2.3 Use of Iron Blast Furnace Slag in Roadbase by State

State	**Experience**	**Performance**	**Remarks**
New York	Limited	Fair	Granular Subbase
California	Limited	Good	
Michigan	Moderate	Good	Dense graded bases
Montana	Moderate	Good	Discontinued Use
New Jersey	Extensive	Good	
Ohio		Excellent	Air-cooled type used

Source: AASHTO 94

2.7 STEEL SLAG

Steel slag, as the name implies, is a by-product of the steel industry. It is formed when lime flux reacts with molten iron ore, scrap metal, or other ingredients charged into the steel furnace at temperatures around 1538°C [Ahmad 92]. During this process, part of the liquid metal becomes entrapped in the slag. It solidifies in the pit area after flowing from the blast furnace, after which it is transferred to cooling ponds. Metallics are removed by magnetic separation [Miller 76].

Steel slag properties can vary even when manufactured under the same processes and in the same plant. Having a high bulk density, steel slag can increase in volume by up to 10 percent, owing to the presence of calcium and magnesium oxides. Steel slag has been used in the highway industry in asphalt mixes, pavement bases, shoulders, fills, and in ice control. However, one study has identified the leachates from this material as an environmental problem [Ahmad 92]. Table 2.4 lists the states that have used steel slag in roadbase construction. Information is also provided on the extent of states' experience and on the performance of the final product.

Table 2.4. Use of Steel Slag in Roadbase by State

State	**Experience**	**Performance**	**Remarks**
California	Limited	Good	
Michigan	Moderate	Poor	Frost sus. dense graded
Ohio	Extensive	Poor	Clogged underdrains, precipitate problems

Source: AASHTO 94

2.8 COAL ASHES

Coal burned at power plants for the generation of electricity leaves a residue known as power plant ash. These are formed into the following two products [Huang 90, Ahmad 91, 92].

2.8.1 Bottom Ash

Bottom ash refers to the slag that builds up on the heat-absorbing surfaces of the furnace, and which ultimately falls through the furnace bottom to the ash hopper below. Bottom ash is also distinguished as dry bottom ash (its solid state at the furnace bottom), or wet bottom ash (its molten state when it falls in the water). The ash type depends on the type of boiler being used in the power plant. Most of the coal bottom ash produced in the U.S. is dry bottom ash. Coal bottom ash is non-radioactive and has no effect on the underground water sources. And while it has a low erosion potential, it is corrosive by nature.

2.8.2 Coal Fly Ash

Coal fly ash is the fine residue that results from the combustion of powdered coal in coal burning power plants. This is transported from the burning chamber by exhaust gases [Ahmad 92]. In the presence of water, this siliceous material assumes structural properties that are comparable to cementious materials. These properties are dependent on the coal-burning furnace in use. There are three types: (1) stoker-fired furnaces, usually not good for highway purposes; (2) cyclone furnaces, generally not good for use in PCC and not widely available; and (3) pulverized coal furnaces, usually the best quality and produced in large quantities [Boles 86].

Because most U.S. power plants use powdered coal, coal fly ash constitutes 75 percent of all the ashes produced, with the majority of it buried in landfills. Presently, only 20 percent of all the fly ash produced is recycled [Ahmad 92]. While it is widely used in PCC mixes, it is not recommended for use in bridge decks or in heavily loaded PCC pavements.

A number of state DOTs (though not many) have used coal ash in their roadbases, with performance ranging from poor to excellent. Although large quantities of coal ash could be consumed in roadbase construction, the implications of its application are unknown, especially its impact on groundwater quality [Ahmad 91]. Table 2.5 lists the states that have used coal bottom ash in roadbase construction. Information is also provided about the extent of the states' experience and the performance of the final product. Table 2.6 then lists the states that have used coal fly ash in roadbase construction.

Table 2.5. Use of Coal Bottom Ash in Roadbase by State

State	Experience	Performance	Remarks
S. Carolina	Limited	Poor	Ponded ash for base
Wisconsin	No Data	Good	Under study as of 1990

Source: AASHTO 94

Table 2.6 Use of Coal Fly Ash in Roadbase by State

State	Experience	Performance	Remarks
New York		Good	Stab. subbase
Florida	Limited	Poor	Under study
Kansas	Moderate	Excellent	
Kentucky	Moderate	Good	Stab. of agg. base, subg.
Louisiana		Good	Lime / Fly Ash mix
Michigan	Limited	Poor	W/ cement or AC
Missouri		Good	Fly Ash treated base
Montana	Moderate	Good	Use in CTB as cement
Nebraska	Limited	Good	Subgrade Stabilization
S. Carolina	Limited	Poor	In Subgrade
Tennessee	Limited	Good	Used w/ Lime to stab.
Virginia	Limited	Good	Mix w/ 2-3% cement
Wyoming	Extensive	Excellent	Use in CTB as cement

Source: AASHTO 94

2.9 BUILDING RUBBLE

Building rubble is defined as any suitable construction material produced from the demolition of existing structures. Building rubble is generally a heterogeneous mixture of concrete, plaster, wood, steel, brick, piping, asphalt cement, glass, and so on [Ahmad 92, Paulsen 88]. It is estimated that roofing waste contains approximately 36 percent asphalt cement, 22 percent hard rock granules, 8 percent filler, and smaller amounts of coarse aggregate and miscellaneous materials [Paulsen 88, Ahmad 92]. Substantial variation in the composition of building rubble should be expected.

Both research and experience in the use of building rubble indicate that it has potential for use as subbase and subgrade/embankment material [Paulsen 88]. However, its technical and environmental feasibility must be determined before widespread use. The economics of using building rubble depends on many factors that can vary with local conditions [Ahmad 92]. Table 2.7 lists the states that have used building rubble in roadbase construction.

Table 2.7 Use of Building Rubble in Roadbase by State

State	Experience	Performance	Remarks
Connecticut	Moderate	Good	Reclaimed misc. agg.
Missouri		Good	

Source: AASHTO 94

2.10 GLASS

The use of glass in unbound aggregate base is technically feasible [Ahmad 92, Hughes 90]. The only requirements are that it be crushed to a specific gradation and that the level of contaminants be within acceptable limits. The economics of usage depends on local conditions [Ahmad 92]. Although a detailed discussion of glass is beyond the scope of this research project,

Table 2.8 nevertheless lists the states that have used glass in roadbase construction. Information is also provided about the extent of states' experience and about the performance of the final product.

Table 2.8 Use of Glass in Roadbase by State

State	Experience	Performance	Remarks
Alaska	Limited	Fair	
California	Limited	Good	
Idaho	Limited		
Minnesota		Good	Add @ 10% to base
N. Carolina	Limited	Good	Utilized in subgrade
New Jersey	Limited	Poor	Dense graded agg. base

Source: AASHTO 94

2.11 RUBBER TIRES

An estimated 240 million waste tires are discarded annually (mostly into landfills) in the U.S. Disposal of large quantities of tires has many economic and environmental implications. Besides being an ideal breeding ground for mosquitoes, scrap tires represent a fire hazard [Ahmad 92]. There is no information available in the current literature regarding the use of tires for roadbase construction. The following discussion provides some insight on the current use of tires in highway construction.

Crumb rubber additive (CRA) is the generic term for the product of scrap tires used in asphalt products. The manufacture of CRA involves the following two processes: (1) the wet process blends CRA with hot asphalt cement and allows the rubber and asphalt to fully react in mixing tanks to produce an asphalt-rubber binder; (2) the dry process mixes CRA with hot aggregate at the hot mix asphalt (HMA) facility before adding the asphalt cement to produce a rubber-modified HMA mixture. The four general categories of asphalt paving products that use CRA include crack/joint sealant, surface/interlayer treatments, HMA mixtures with asphalt-rubber binder, and rubber modified HMA mixtures [Ahmad 91, Ahmad 92].

There are two techniques used to incorporate waste tires in subgrade/embankment. One involves using shredded tires as a lightweight fill material; the other involves using whole tires or their sidewalls for soil reinforcement in embankment construction. The concept of using tires in embankment is also extended to enhance the stability of steep slopes along highways, for temporary protection of slopes, for retaining forest roads, and for erosion protection of coastal roads [Keller 90, Read 90].

2.12 SUMMARY OF LITERATURE SURVEY

This literature search provided insight into the recycling of waste materials in pavement construction. Surprisingly, most of the research so far has been directed towards the goal of incorporating these WRMs in the wearing course in AC pavements and in the slab for PCC pavements. Very little effort has been directed to the use of WRMs in base or subbase layers.

The WRMs used had DOT sources as well as non-DOT sources. These materials included old pavements, slag from the metal industry, and wastes from mining operations.

It should also be noted that all the materials were evaluated using technical laboratory studies, and that only a limited number of field experiments have been performed. Of those field experiments, few were set up for long-term performance evaluation.

CHAPTER 3. WASTE AND RECYCLED MATERIALS AVAILABILITY AND LOCATION SURVEY

3.1 INTRODUCTION AND PURPOSE OF SURVEY

Before state and local governments in Texas can make maximum use of recycled materials in roadbase construction and maintenance, they must know, among other things, the types, properties, quantities, and sources of materials available. Some of these materials include recycled asphalt pavement (RAP), old concrete, coal combustion byproducts (CCBP), tire chips, and foundry wastes. To promote the increased utilization of recyclable materials in road construction, the Texas Legislature enacted enabling statutes, among them Senate Bills 352 and 1340, which require TxDOT to maximize the use of RAP when feasible, and to maintain a public record of the amount of TxDOT-owned RAP.

The objectives of the location and availability survey are consistent with the requirements of these statutes. Specifically, the survey was conducted to determine the quantities of potential roadbase materials available in TxDOT districts, and to classify them by quantity, location, and type.

3.2 RESEARCH METHODOLOGY

Data collection methods for this segment of the research included (1) mail questionnaires administered to TxDOT district office engineers, (2) telephone interviews of individuals with personal knowledge of potential material sources, and (3) limited site visits designed to enable the research team to verify the existence of waste materials and to collect samples.

The original design for the survey in this project called for using the chain referral sampling method at two levels. At the primary level are TxDOT's 25 district offices. Several respondents from TxDOT recommended individuals for the second-level survey. Presently, the number of second-level respondents is not known. Those respondents are primarily individuals in the private sector who produce, stockpile, or have knowledge of recycled materials for roadbase applications. Thus, the results presented in this report are limited to responses obtained from TxDOT district offices. Data from the second-level respondents were not collected on any meaningful scale, owing to the late start on the research project.

At the first sampling level, 84 percent (21) of the 25 districts responded to the research questionnaire. Twelve sets of questions covered in the questionnaire are presented as an attachment to this document. The questions were designed to obtain information regarding such issues as: types of recycled materials available for roadbase construction; locations where materials are stockpiled; approximate amounts of stockpiled materials; shipment facilities available; locations where materials have been used; performance of recycled materials where used; availability of scientific/engineering test results; and the supply of sample materials for additional testing.

3.3 AN ANALYSIS OF QUESTIONNAIRE RESPONSES

With respect to the question on materials available to be recycled for roadbase construction, Tables 3.1 and 3.2 summarize responses from 21 districts. While Table 3.1 shows the types of construction materials that respondents believe have potential for application in the districts, Table 3.2 gives a summary listing of 12 materials identified by the responding districts.

Table 3.1 Types of Potential Base Recycled Materials Identified by TxDOT

District	Material Types												
	OA	OC	BF	FA	BA	OG	PA	TC	CD	PL	RH	CP	OR
Abilene	X	X		X				X					
Amarillo													
Atlanta	X	X		X	X		X	X					
Austin	X	X											
Beaumont	X	X											
Brownwood								X					X
Bryan	X												
Childress	X	X		X	X		X						
Corpus Christi													
Dallas		X											
El Paso	X							X					
Fort Worth	X	X	X	X		X		X	X				
Houston	X	X						X			X		
Laredo													
Lubbock				X									
Lufkin													
Odessa	X	X						X	X				
Paris	X	X			X		X						
Pharr	X	X											
San Angelo	X	X	X	X	X	X						X	
San Antonio	X	X	X	X		X		X				X	
Tyler	X												
Waco	X											X	
Wichita Falls	X	X											
Yoakum	X												

OA = Old Asphaltic Concrete
OC = Old Portland Cement Concrete
BF = Blast Furnace Slag
FA = Fly Ash
BA = Bottom Ash
OG = Open Graded Aggregate
PA = Power Plant Pond Ash
TC = Tire Chips and Other Rubber Products
CD = Cement kiln Dust
PL = Plastics
RH = Rice Husks
CP = Ceramic Products
OR = Other
T = Truck, R = Rail, B = Barge

Table 3.2 Types of Materials with Potential Roadbase Applications Identified in TxDOT Districts

Materials Identified	Percent of Districts
Old Asphaltic Concrete (OA)	90
Old Concrete (OC)	67
Blast Furnace Slag (BF)	14
Fly Ash (FA)	33
Bottom Ash (BA)	19
Open-graded Aggregate (OG)	14
Power Plant Pond Ash (PA)	14
Tire Chips & other Rubber Products (TC)	38
Cement Kiln Dust (CD)	10
Plastics (PL)	5
Rice Husks (RH)	5
Ceramic Products (CP)	14
Other (OR)	5

Of the 21 responding TxDOT districts, 19 (90 percent) reported that old asphaltic concrete and old concrete could be used as roadbase material, with 90 percent favoring old asphaltic concrete and 67 percent selecting old concrete. Table 3.2 gives these figures and those for other materials, including tire chips and related products (38 percent), fly ash (33 percent), bottom ash (19 percent), blast furnace slag (14 percent), and ceramic products (14 percent).

As Table 3.3 shows, nine TxDOT districts indicate that four or more materials have potential for roadbase use. The materials associated with Table 3.3 are identified in Table 3.1.

Table 3.3 Nine TxDOT Districts Identifying Four or More Types of Potential Roadbase Materials

District	Number of Potential Roadbase Materials Identified
Abilene	4
Atlanta	6
Childress	5
Fort Worth	7
Houston	4
Odessa	4
Paris	4
San Angelo	7
San Antonio	7

Districts showing one or two potential materials include Austin, Beaumont, Brownwood, Bryan, Dallas, El Paso, Lubbock, Pharr, Tyler, Waco, Wichita Falls, and Yoakum.

Tables 3.4 and 3.5 show the types of recycled materials stockpiled in TxDOT districts. In addition to listing the 25 districts, Table 3.4 identifies the types of materials available in each district. These materials and associated percentage responses are listed in Table 3.5.

Table 3.4 TxDOT Districts, Types of Recycled Materials, and Shipment Facilities Available

District	Material Types													
	OA	OC	BF	FA	BA	OG	PA	TC	CD	PL	RH	CP	OR	Ship
Abilene	X	X		X				X						TR
Amarillo														
Atlanta	X	X		X	X		X	X						T
Austin	X	X												T
Beaumont	X	X												TRB
Brownwood								X					X	TR
Bryan	X													T
Childress	X	X		X	X		X							TR
Corpus Christi														
Dallas		X												T
El Paso	X							X						T
Fort Worth	X	X	X	X		X		X	X					T
Houston	X	X						X			X			TRB
Laredo														
Lubbock				X										
Lufkin														
Odessa	X	X						X	X					TR
Paris	X	X			X		X							T
Pharr	X	X												T
San Angelo	X	X	X	X	X	X						X		T
San Antonio	X	X	X	X		X		X				X		TR
Tyler	X													T
Waco	X											X		T
Wichita Falls	X	X												T
Yoakum	X													T

OA = Old Asphaltic Concrete
OC = Old Portland Cement Concrete
BF = Blast Furnace Slag
FA = Fly Ash
BA = Bottom Ash
OG = Open Graded Aggregate
PA = Power Plant Pond Ash
TC = Tire Chips and Other Rubber Products
CD = Cement kiln Dust
PL = Plastics
RH = Rice Husks
CP = Ceramic Products
OR = Other
T = Truck, R = Rail, B = Barge

Table 3.5 Types of Recycled Materials Stockpiled in TxDOT Districts

Types of Materials	Percent of Districts
Old Asphaltic Concrete (OA)	90
Old Concrete (OC)	43
Blast Furnace Slag (BF)	14
Fly Ash (FA)	33
Bottom Ash (BA)	19
Open-graded Aggregate (OG)	14
Power Plant Pond Ash (PA)	14
Tire Chips and other Rubber (TC)	29
Cement Kiln Dust (CD)	10
Plastics (PL)	5
Rice Husk (RH)	5
Ceramic Products (CP)	14

As Tables 3.4 and 3.5 show, nearly all of the responding districts — 19 out of 21 (90 percent) — have stockpiles of old asphaltic concrete. Of the 21 responding districts, 9 (43 percent) stockpile old concrete. Fly ash has 33 percent and tire chips with other rubber products have 29 percent stockpile availability in the districts. Approximately, 19 percent of the districts report bottom ash stockpiles in commercial operations. Open-graded aggregates, power plant pond ash, and ceramic products are stockpiled at levels of approximately 14 percent each.

Additionally, the last column of Table 3.4 identifies shipment facilities available in each responding district. Truck shipment is available in all districts, rail in seven (33 percent), and barge in two (10 percent). One implication for recycled materials utilization is that shipment costs, via trucking, may restrict the use of these materials to those geographic areas where they are generated.

Table 3.6 identifies those TxDOT districts reporting stockpiles of four or more materials. A comparison of Table 3.3 and Table 3.6 indicates that seven of the nine districts listed in Table 3.3 report stockpiles of four, five, and seven types of materials.

Table 3.6 TxDOT Districts Reporting Stockpiles for Four or More Types of Roadbase Materials

District	Potential Roadbase Materials Identified
Atlanta	5
Childress	5
Fort Worth	7
Houston	4
Paris	4
San Angelo	7
San Antonio	7

3.4 ESTIMATES OF MATERIAL AMOUNTS IN STOCKPILES

With respect to the stockpile amounts, eleven TxDOT districts report the following materials, each in excess of 1,812 metric tons:

Table 3.7 Districts with Stockpiles of 1,812 metric tons or more

District	Material	Estimated Quantity
Abilene	OA	5,436
Atlanta	OA	181,200
Beaumont	OA	6,342
Bryan	OA	3,624
Childress	FA	1,812
Childress	BA	1,812
Childress	PA	1,812
Fort Worth	OA	1,812
Paris	OA	1,812
Pharr	OA	3,624
Pharr	OC	11,778
San Antonio	OA	1,812
Waco	OA	1,812
Wichita Falls	OA	3,624

Key: OA = Old Asphaltic Concrete; OC = Old Concrete
FA = Fly Ash; BA = Bottom Ash;
PA = Power Plant Pond Ash

As Table 3.7 indicates, old asphaltic concrete has the largest amount of tonnage stockpiled in ten TxDOT districts. Current survey data indicate that old asphaltic concrete has thirteen stockpiles, each with more than 1,812 metric tons, and, comparatively, old concrete has two stockpiles with 1,812 metric tons or more. Districts having the largest amounts of old asphaltic concrete stockpiles include Atlanta, Beaumont, Pharr, Abilene, Childress, Bryan, and Wichita Falls.

Similarly, Childress has extensive amounts of ash, including fly ash, bottom ash, and power plant pond ash. The Atlanta District produces these types of ash in large commercial quantities.

In terms of the use of these and other recycled materials in roadbase construction and maintenance, information from this survey suggests that the following types of materials are being used throughout Texas: old asphaltic concrete, old concrete, ash, tire chips and other rubber products, ceramic products, open-graded aggregate, blast furnace slag, and cement kiln dust. Tables 3.8 and 3.9 show the patterns of recycled materials use in roadbase among TxDOT districts.

Table 3.8 Pattern of Recycled Materials Utilization in TxDOT Districts

Type of Material	Percent of Districts Using Material
Old Asphaltic Concrete (OA)	80
Old Concrete (OC)	25
Fly Ash (FA)	10
Bottom Ash (BA)	10
Power Plant Pond Ash (PA)	5
Tire Chips and other Rubber (TC)	10
Rice Husk (RH)	5
Ceramic Products (CP)	10

Table 3.9 TxDOT Districts and Types of Recycled Materials Used in Roadbase

	Material Types												
District	OA	OC	BF	FA	BA	OG	PA	TC	CD	PL	RH	CP	OR
Abilene	X												
Amarillo													
Atlanta	X	X		X	X		X						
Austin	X	X											
Beaumont	X	X											
Brownwood	X												
Bryan	X												
Childress	X			X									
Corpus Christi													
Dallas		X											
El Paso													
Fort Worth	X												
Houston	X	X						X			X		
Laredo													
Lubbock													
Lufkin													
Odessa	X												
Paris					X								
Pharr	X												
San Angelo	X												
San Antonio	X							X				X	
Tyler	X												
Waco	X											X	
Wichita Falls													
Yoakum	X												

OA = Old Asphaltic Concrete
OC = Old Portland Cement Concrete
BF = Blast Furnace Slag
FA = Fly Ash
BA = Bottom Ash
OG = Open Graded Aggregate
PA = Power Plant Pond Ash
TC = Tire Chips and Other Rubber Products

CD = Cement kiln Dust
PL = Plastics
RH = Rice Husks
CP = Ceramic Products
OR = Other
T = Truck,
R = Rail,
B = Barge

As these tables indicate, a great majority of districts — 16 out of 20 (80 percent) responding to the relevant question — have used old asphaltic concrete as roadbase material. For old concrete, a comparable figure for its usage is 25 percent. Each of the following four types of materials has a 10 percent rate of utilization: fly ash, bottom ash, tire chips and other rubber products, and ceramic products.

In some districts, including El Paso and Wichita Falls, respondents indicated they had no knowledge of any locations where old asphaltic concrete has been used. In other districts, the use and performance of certain materials, such as rice husks in Houston and ceramic shells in the Waco district, need to be tested and promoted.

3.5 ASSESSMENT OF PERFORMANCE OF MATERIALS WHERE USED

How well do these materials perform where they are used? To answer this question, thirteen districts evaluated the performance of old asphaltic concrete, while six districts rated that of old concrete. Of the thirteen districts evaluating old asphaltic concrete, eight (62 percent) rated its performance as good. However, four out of six districts (67 percent) gave a rating of "excellent" to old concrete, while two districts (33 percent) rated it "good."

TxDOT engineers have rated as excellent the performance of old concrete in Abilene, Atlanta, Beaumont, and Dallas. Similarly, in the Yoakum District, old asphaltic concrete has been assessed to be excellent in Fayette, Victoria, Calhoun, Wharton, and Gonzales. In eight districts, engineers rated the performance of old asphaltic concrete "good." These districts include Abilene, Austin, Waco, Odessa, Childress, Fort Worth, San Antonio, and Tyler. The accompanying table summarizes respondents' performance assessments of these materials.

Table 3.10 Performance Evaluation for Selected Materials

Material	Evaluation				
	Excellent	Good	Fair	Poor	No Opinion
OA	15 (2)	62 (8)	15 (2)	8 (1)	
OC	67 (4)	33 (2)			
BF					
FA		50 (1)	50 (1)		
BA		50 (1)			50 (1)
OG					
PA	100 (1)				
TC				100 (1)	
CD					
PL					
RH					
CP					100 (1)

Number in parenthesis indicates the number of districts giving performance assessment

Two types of recycled materials — old asphaltic concrete and tire chips and other rubber products — have received "poor" performance ratings, the former in Carthage and Mt. Pleasant in the Atlanta District, and the latter in San Antonio. Elsewhere in Childress, Paris, Greenville, Sulphur Springs, and Atlanta, Texas, fly ash, bottom ash, and power plant pond ash have received "good" performance ratings.

3.6 CONCLUDING OBSERVATIONS

The data from this study suggest that there is room for expanded utilization of recycled materials in roadbase other than asphaltic concrete and old concrete. Private ownership of operations that produce most of the potential base materials may limit the availability of suitable materials. Table 3.11 summarizes selected materials available from commercial operators, including blast furnace slag, fly ash, bottom ash, power plant pond ash, spent foundry sand, tire chips and other rubber products, cement kiln dust, rice husks, and ceramic products.

Problems associated with widespread use of these materials include limited knowledge about the availability of materials, environmental regulations, costs for shipping materials to project sites, and gaps in scientific and engineering knowledge about the behavior of these materials in roadbase applications. Dealing effectively with these problems requires collaborative research and project implementation efforts from TxDOT, other government agencies, private companies, academic institutions, and other business organizations. For example, Cercon of Hillsboro, Texas, continues to collaborate with TxDOT's Waco District in expediting measures to facilitate the use of ceramic waste materials in roadbase construction. The company produces approximately 50 tons of the materials each year in its aluminum casting operations.

Similarly, the Texas Metals Association, Inc. (TCMA), works closely with the Texas Natural Resources Conservation Commission (TNRCC) in investigations designed to promote "safe and legitimate use of foundry sand" in Texas. Among other things, TCMA is exploring the use of foundry sand in cement, concrete, brick, asphalt, sub-grade fill, and roadbase.

In conducting the survey and limited interview for the present project, the research team learned that other commercial operations produce several potential roadbase materials, such as gypsum wastes in Houston and blast furnace slag from Seguin, Texas. Among other things, the team learned that seven companies in the state produce slag, which they market through sole distributors. Also, at least three companies produce ceramic waste molds, similar to the materials that Cercon produces. Ash from several power plant operations in Texas is marketed through sole agents.

Whether the recyclable material is gypsum waste, ceramic shell, spent foundry sand, cement dust, or fly ash, questions remain to be answered: How much of the material is produced? Where is it produced? What are the alternate uses for the material? How much of the production could be available as roadbase material? Are engineering test results available concerning the suitability of these materials for roadbase construction? These and other questions suggest the need for more research regarding recycled roadbase materials from commercial operations.

CHAPTER 4. DISCUSSION OF MAJOR ISSUES

4.1 INTRODUCTION

From the start of this project, the research team understood that, given limited financial resources, a broad goal had to be accomplished. In addition, the time available to develop specifications was limited to 1 year. With such a tight deadline, it was clear that specifications could not be developed for all the materials encountered in the material availability and location survey described in Chapter 3. From the outset of the project, it was understood that a quick and innovative approach would have to be developed to assure effective utilization of WRMs in roadbase.

4.2 WASTE AND RECYCLED MATERIALS EVALUATION METHODOLOGY

These constraints prompted the development of a methodology that could evaluate the potential waste/recycled materials based on technical, economic, societal, and environmental evaluations. We also incorporated in this methodology an initial screening process that could eliminate (before undertaking the above-mentioned evaluations) waste/recycled materials that had very low potential for use in transportation projects.

The advantage of this waste and recycled material evaluation methodology is that it gives a good representation of the utilization potential of a particular WRM without undertaking expensive and time-consuming laboratory studies. This method considers all the interrelated factors that are important in assessing the potential utilization of waste/recycled materials in construction projects. The WRMs showing the highest potential can then be subjected to laboratory testing, with a very high probability of their being utilized in the end. This chapter briefly describes this methodology.

Although the outlined method evaluates WRMs for utilization in roadbase, the evaluation process can easily be modified to evaluate WRMs for other engineering applications. This can be achieved by modifying the evaluation criteria and by collecting data specific to the problem at hand.

4.2.1 Systems Methodology

Systems methodology comprises a body of knowledge that has been developed for the efficient planning, design, and implementation of new systems, for structuring the state of knowledge on an existing system, and for modeling system operation. It is a comprehensive problem-solving process that will be followed closely to ensure that all interrelated factors important in WRM utilization are properly addressed.

4.2.2 What is Important? Building a "Value Tree"

A value tree is a hierarchical representation of objectives and their corresponding attributes. The problem is to determine the relevant objectives and how to measure the attributes (or the operational measure of the extent to which an objective is fulfilled). A value tree begins with several fundamental objectives as main branches, five in our case, each of which is further expanded and explained with more specific objectives. Identifying the fundamental objectives is a key step in building the value tree.

4.2.3 Initial Screening

Initial screening is used to eliminate WRMs having low utilization potential in roadbase construction projects. This would be the first process in the whole evaluation methodology, where materials having very low utilization potential are discarded and not subjected to any further evaluation. Such an elimination process saves both time and human resources.

4.2.4 Technical Evaluation

The WRM must be able to fulfill two aspects of technical evaluation for it to be a potential candidate for transportation construction. First, it must possess fundamental physical, chemical, mechanical, and thermal properties required of a material used in highway construction projects; second, some knowledge of future performance of the material must be available from previous study or estimation. Such aspects as particle shape and hardness, resistance to load, and temperature-induced degradation are evaluated.

4.2.5 Economic Evaluation

The main purpose of economic evaluation is to identify those WRM resources that are most viable in an economic sense for cost-effective utilization in transportation projects. This would be accomplished by taking into account all the costs related to the production of construction aggregate from WRM sources, and comparing these with costs incurred in the production of virgin aggregate and in the disposing of the waste material.

4.2.6 Societal Evaluation

Societal and ecological implications most often cannot be measured directly in dollar terms. However, the interest or desire expressed by society in general, and by the government and the private sector in particular, may provide the impetus for problem solving. For this reason, societal factors are important when use of waste/recycled materials is considered. Societal evaluation is undertaken in order to bring into the evaluation process the public benefits of using WRMs.

4.2.7 Environmental Evaluation

The environmental impact of using a WRM includes some factors that are related, directly or indirectly, to technical, economic, and social evaluation. However, environmental impacts are important and must be considered separately from the other three evaluations. Environmental evaluation considers technical criteria to judge the feasibility of using WRMs in construction projects, as opposed to public perception about their use (which was the case in the societal evaluation).

4.3 COMBINED EVALUATION

Combining the four evaluations, along with the initial screening procedure, yields a method for evaluating WRM use in roadbase construction projects. While it is desirable to achieve a host of technical, economic, societal, and environment objectives, these objectives may conflict; that is, the four evaluations simply may not permit high achievement in all aspects at once and, consequently, a combined weighted rating is necessary.

CHAPTER 5. WASTE AND RECYCLED MATERIAL EVALUATION METHOD

5.1 INTRODUCTION

Recycled materials are not necessarily inferior to conventional, time-tested construction materials. However, one must guard against the use of recycled materials based on the claims of researchers who have investigated the material only in laboratory studies. The feasibility of using a specific recycled material depends on a large number of interrelated factors, as outlined in Chapter 4. In order to make meaningful recommendations, these factors need to be evaluated objectively.

The methodology described in this chapter considers four aspects of recycled materials use, including technical, economic, social, and environmental evaluations (all of which follow initial screening). Each recycled material that has potential for use in roadbase construction is evaluated separately. Figure 5.1 shows the material evaluation system.

5.2 INITIAL SCREENING

Initial screening is undertaken to eliminate WRMs having low potential for use in roadbase construction. The factors that serve to determine the minimum acceptability of recycled materials include (1) accumulated or annually produced quantity, (2) material location, (3) material toxicity, (4) water solubility, and (5) material durability. The recycled material is not considered for further evaluation if it does not meet these initial screening requirements. If all the requirements of the initial screening are met, then the recycled material is subjected to technical, economic, social, and environmental evaluations. The initial screening criteria are discussed below.

5.2.1 Accumulated or Annually Produced Quantity

Miller et al. [TRB 76] recommend that an annual production quantity of 453,555 kg, or an accumulated quantity of at least 4.5 million kg, be considered the minimum material amounts capable of fulfilling a reasonable portion of the aggregate requirements for a road project. These recommended values are used to eliminate WRMs based on accumulated or annually produced quantity.

5.2.2 Material Location

The location of the recycled material with respect to its intended destination site has an impact that is dependent on the transportation mode available and the distance involved. The recycled material must be located within a reasonable distance from the place of potential use; otherwise the transportation costs will be very high and may ultimately make its use prohibitive. Distances of 80.5 km for truck transport, 161 km for rail transport, and 483 km for barge transport are considered to be maximum economical hauling distances. It must, however, be noted that transportation costs will vary with the region of the state, so judgment must be used when making use of these approximate distances.

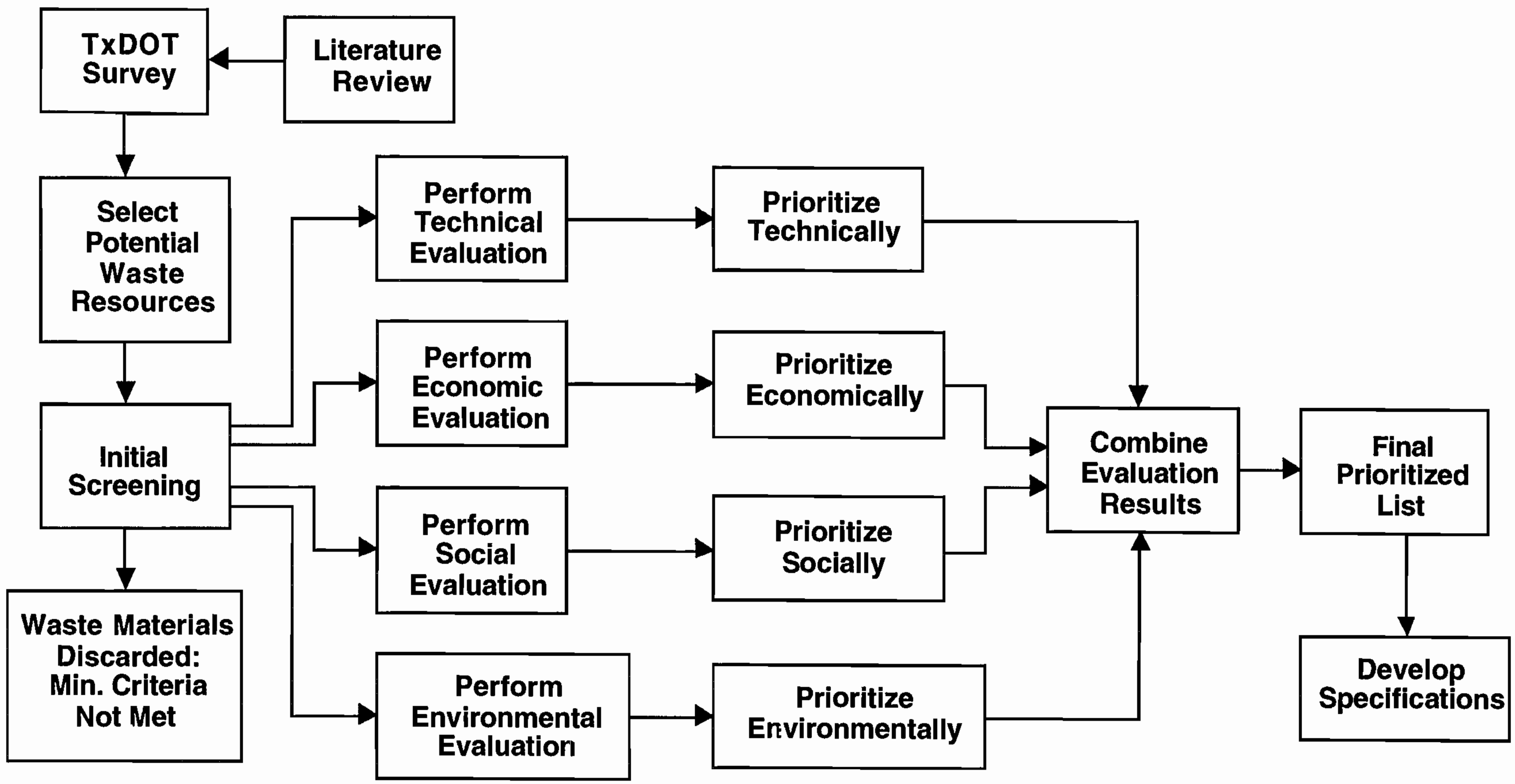

Figure 5.1 Material Evaluation System

5.2.3 Material Toxicity

Processing WRMs to produce aggregate for roadbase construction must not render them more toxic than permitted by the Environmental Protection Agency (EPA). It must also be noted whether the material was toxic to begin with. If so, did recycling increase, reduce, or maintain toxicity?

5.2.4 Water Solubility

In the case of thinly surfaced pavements, the base material is the primary load-carrying element of an asphaltic concrete pavement, one that provides a stable support structure when used under portland cement concrete pavements. When some base materials come in contact with water they lose their ability to carry load, owing to their solubility in water (or other reason). This criterion eliminates WRMs based on their inability to carry applied loads in the presence of water.

5.2.5 Material Durability

As outlined by the American Society for Testing and Materials (ASTM) specification ASTM D2940-92 [ASTM 92], roadbase aggregate material must be durable and capable of withstanding the effects of handling, spreading, and compacting without degradation productive of deleterious fines. Roadbase aggregate produced from WRM sources must be able to withstand these degrading operations.

5.3 TECHNICAL EVALUATION

WRMs must possess the adequate physical, chemical, mechanical, and thermal properties required of a material used in roadbase construction projects. The material properties listed in Table 5.1 must be considered when evaluating materials technically. Properties such as particle shape and hardness, resistance to load, and/or temperature-induced degradation are evaluated.

A quantitative rating system was developed to examine the relevant properties. Then a weighted average approach was adopted to measure the relative importance of each of the properties with respect to its effect on the recycled material performance as an aggregate for roadbase use. The forms for technical evaluation are shown in Figures 5.2 and 5.3. Because the gradation of the material is normally more critical than the maximum aggregate size, it would be assigned a higher weight in the total technical evaluation.

Table 5.1 Aggregate Properties Considered for Roadbase Use

CLASSIFICATION	PROPERTIES
General Properties	Uniformity, previous performance
Physical Properties	Presence of deleterious substances, gradation, particle size, maximum particle size, porosity and pore structure, particle specific texture, specific gravity
Mechanical Properties	Particle hardness and soundness, particle strength, mix permeability, mass stability
Chemical Properties	Solubility, resistance to chemical attack, resistance to volume changes due to wetting and drying, resistance to degradation from freeze-thaw cycling, oxidation and hydration reactivity, slaking
Thermal Properties	(if possible)

The advantage of this approach is that it makes it possible to examine all properties without basing the evaluation on any single property. Furthermore, the relative importance of these properties is also considered.

Each candidate recycled material will be ranked on a scale of zero to five, where zero is the poorest and five is the best, for the selected six properties shown in Figure 5.2. This was then transferred to Figure 5.3 to arrive at the total score shown. The total score also takes into account the importance of each property by assigning different weights to each property.

5.4 ECONOMIC EVALUATION

The main purpose of economic evaluation is to identify those WRM resources that are the most economically feasible for use as an aggregate in roadbase construction. The same five-point scale evaluation process is used as described earlier in the technical evaluation section. The six attributes evaluated on a five-point scale for economic evaluation included:

- Disposal costs
- Processing costs
- Transportation costs
- Location and quantity
- Resource value
- Practicality of use as roadbase

While a benefit-cost analysis is a well-developed tool useful in highway planning, widespread use of this technique has not overcome the problem of assessing costs and benefits for intangible factors. It must be noted that approximate costs for processing, transportation, and construction can be used to make a gross economic analysis only within broad terms. In local, competitive, real-life situations, an extensive marketing study, supported by exact current costs, should be conducted in order to determine more precise costs [TRB 76].

The cost of disposing waste material is an important variable in determining the economic feasibility of using that product as a recycled material. Furthermore, probably the most influential factor in determining the overall economic feasibility of using a WRM as an aggregate product is the cost of that material's processing and conversion. In most cases, the processing costs will represent the most costly input into the economic evaluation process. Processing costs for recycled/waste aggregate materials are meaningful only when compared with the cost of conventional aggregate material, which varies from location to location for obvious reasons.

Material: ____________

Gradation / Additional Processing	5	4	3	2	1	0
Particle Shape	5	4	3	2	1	0
Particle Strength	5	4	3	2	1	0
Hardness and Soundness	5	4	3	2	1	0
Resistance to Applied Load Degradation	5	4	3	2	1	0
Resistance to Freeze-Thaw Degradation	5	4	3	2	1	0

Figure 5.2 Form for Estimating Technical Evaluation Scores

Materials* / Weight	Gradation / Additional Processing	Particle Shape	Particle Strength	Hardness And Soundness	Resistance To Applied Load Degradation	Resistance To Freeze-Thaw Degradation	Total Score
	W 1	W 2	W 3	W 4	W 5	W 6	
Rubber Tires							
Building Rubble							
Old Asphalt							
Old Concrete							
Fly Ash							
Blast Furnace Slag							

Figure 5.3 Form for Technical Prioritization of Waste and Recycled Materials

Several alternatives are available for the transport of waste materials. The most feasible of these include truck, rail, and barge. Air transport is not practical because of expenses involved. The most reasonable form of transportation, where available, is barge transport. Although rates vary from origin to destination, barge rates for the same commodity are normally about one-fourth those of rail rates.

The costs for processing and transporting WRMs are subject to wide variations. Furthermore, economic factors related to the disposal of wastes and to the generation of markets for their use are not always clearly defined. When evaluating the economics of WRMs, based on the six attributes mentioned previously, the following factors, are also considered either directly or indirectly.

5.4.1 Location and Quantity

The location and quantity factor takes into account the location of potential market areas, aggregate deficiencies, transportation modes relative to the sources, and available amounts of the waste material. The factors considered include:

- Accumulated and/or annually produced waste quantities
- Proximity to potential aggregate markets, particularly near metropolitan areas
- Location with respect to existing or projected aggregate shortages
- Access to cheap transportation modes (i.e., barge and rail)
- Location with respect to other wastes for potential mixing
- Location in areas with growing demand for aggregates

5.4.2 Application

The application factor relates to the actual use or potential application for use of the recycled material as an aggregate in roadbase.

5.4.3 Resource Value

This factor takes into account the possible value of a material based on other potential or developed uses, heat value, and extent of required processing to produce a usable product. The factors considered include the following:

- Developed a variety of current or potential uses
- Exists in large supply as inert, combinable material
- Separation or retrieval of material is required
- Material possess some heat value
- De-watering or thickening required before processing
- Palletizing and / or sintering required in processing
- Crushing and sizing are the only required processing steps

- High percentage of available waste material is usable after processing
- Processed material posses low unit weight

5.5 SOCIAL EVALUATION

Social and environmental implications most often cannot be measured directly in dollar terms. However, the interest or desire expressed by society in general, and by government and the private sector in particular, most often provides the impetus for solving problems. Some waste materials, because of their volume, location, or disposal problems, pose environmental threats that, accordingly, provoke groups concerned with ecology, wildlife, and preservation. Other materials, though not attracting such attention, nevertheless are objectionable owing to their proximity to major arterials, developed areas, parks and recreation areas, and public lands. There is an implied societal pressure to find the means to stabilize, remove, or reuse these wastes (TRB 76). The social evaluation system evaluates the following six social interests/attributes on a scale of zero to five:

- Material is nuisance due to accumulation/disposal
- Unsightly, especially near urban areas
- Disposal site/cost problems
- Safety/health hazard
- Government interest
- Special group interest

5.6 ENVIRONMENTAL EVALUATION

The potential environmental impact of a WRM should be evaluated before actual field use. Some factors included in the environmental evaluation are directly or indirectly related to technical, economic, and social evaluations. The environmental effects associated with the processing and use of WRMs in roadbase were considered as described below.

5.6.1 Effects of Recycling Waste Materials

What benefits might be derived from altering the present method of waste disposal or of removing existing stockpiles by recycling? The factors considered include [TRB 76, NSA 90]:

- Severity of existing ecological problems caused by disposal of waste
- Amount of waste material currently being disposed of or accumulated
- Reduction of a possible health and safety hazard by recycling
- Degree by which highway use of waste will help
- Type of ecological area where disposal or accumulation exists
- Proximity of waste material to population centers

- Extent of conservation of natural aggregate due to recycling

5.6.2 Effects of Processing Waste Materials

This takes into account the effects of processing a specific waste resource as part of the recycling system. The factors considered include (TRB 76, NSA 90):

- Possible effects to the environment owing to required processing type
- Environmental effects owing to disposal of processing by-products
- Quantities of by-products generated owing to the processing operation
- Processing operation location with respect to the populated areas

5.6.3 Effects on Environment of Waste Material Use in Roadbase

This considers how WRMs used in roadbase applications might impact the immediate environment. The factors taken into account include (TRB 76, NSA 90):

- Effect on ground water quality owing to leaching from road base
- Effect on surface water quality owing to runoff
- Effect on surrounding atmosphere owing to dusting during construction
- Possible effect on surrounding soil owing to leaching
- Possible effect of waste material use on plant life
- Possible effect of waste material use on surrounding wildlife
- Possible effect of waste material use on surrounding land use

The environmental evaluation system, like the other evaluation systems, utilizes a five-point scale to rank the materials by assigning scores to the following six attributes:

- Benefits of recycling
- Proximity of waste to population centers
- Environmental effects of processing
- Processing facility proximity to population
- Effect of material use on the environment
- Future recycling concerns

5.7 OVERALL RANK OF THE EVALUATED MATERIALS

Figure 5.4 shows the method used to rank the material evaluated. It represents the sum of the previously discussed four evaluations. It must, however, be noted that the four evaluations can be assigned different weights. For example, if, in the judgment of the engineer, the technical evaluation carries more importance than the environmental evaluation, then the technical evaluation must be assigned a higher weight. The materials are further divided into four classes based on their respective attributes. These classes are described below.

5.7.1 Category I

Category I contains those recycled materials that appear to have the highest potential for roadbase use. In general, these recycled materials require a minimum of processing (e.g., crushing, grading, and blending) prior to use. The non-conventional aggregates obtained from these recycled materials are characterized by their having reasonably adequate properties of soundness, hardness, gradation, particle shape, and resistance to chemical or physical deterioration.

5.7.2 Category II

Category II contains those recycled materials that, in general, require more extensive processing and/or whose physical properties are not considered to be as adequate as those in Category I.

5.7.3 Category III

Category III contains those recycled materials that show less promise than those in Category I or Category II, for a number of reasons. They may require much processing or may have an undesirable physical property. In general, it could be said that these materials can be used in local, isolated cases.

5.7.4 Category IV

Category IV contains those recycled materials that show little or no potential for roadbase use. At best, they might be used in small quantities as a filler or in very specialized applications.

5.8 DEVELOPMENT OF SPECIFICATIONS

Using the tests undertaken in the technical and environmental evaluations, the current roadbase specification can be updated to accommodate recycled materials. This will be addressed at a later stage of this research project.

Materials* \ Weight	Technical Evaluation Score	Economic Evaluation Score	Social Evaluation Score	Environmental Evaluation Score	Total Score	Rank	Category
	W T	W E	W S	W En			
Building Rubble							
Old Asphalt							
Old Concrete							
Fly Ash							
Blast Furnace Slag							
Bottom Ash							

Figure 5.4 Form for Determining Combined Evaluation Score and Rank of Selected Materials

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

This report described the results of a comprehensive literature search conducted to determined the state of the art in WRM engineering applications. This was followed by a summary of a detailed survey of TxDOT personnel to determine what WRMs are available in TxDOT. Evaluation of available information suggested the need to develop a comprehensive method to evaluate WRMs for use in roadbase. As a result, a tentative method was developed and described. This method considers many factors that affect engineering applications of WRMs, including technical, economical, social, and environmental evaluations. This report presented the results of the first-year study of the use of WRMs in roadbases.

6.1 CONCLUSIONS

The conclusions of this research effort to date can be summarized as follows:

1. A wide variety of waste materials have been used in engineering applications in the past.
2. Earlier efforts have focused on the use of WRMs in the pavement wearing course, either for flexible pavements or in the portland cement slab.
3. Little effort to date has been devoted to field testing WRM uses in bases. Some field tests carried out were not followed up to determine the long-term performance of these materials.
4. The material and location availability survey determined that only two materials, namely, reclaimed asphaltic pavement (RAP) and reclaimed portland cement concrete pavement (RPCP), were stockpiled in sufficient volumes by TxDOT. Other materials, ranging from slag and ash to broken ceramic products, had commercial sources.
5. Most of the TxDOT districts have stockpiles of RAP and RPCP. Currently, TxDOT owns more than of 81 million metric tons of RAP and 18 million metric tons of RPCP, respectively.
6. Most technical studies reported in the literature fail to consider the socio-economic benefits of using WRMs. These are important factors as far as the utilization of WRMs is concerned.
7. A new WRM evaluation method outlined in Chapter 5 considers WRM utilization in terms of technical, economic, social, and environmental factors.

6.2 RECOMMENDATIONS

The recommendations and future research needs of this study are listed below:

1. The evaluation of WRMs' potential utilization should not be based on the technical aspects alone. Socio-economic factors must also be considered.
2. The evaluation method outlined in this report should be further developed and used to screen WRMs. Only then can we ensure that WRMs having high utilization potential

will be forwarded to a technical evaluation. At that point, the material has a high probability that it will be useful in roadbase construction.

3. Results of the material availability and location survey should be fine-tuned by visiting one or two TxDOT districts and completing the survey of the commercial sources.
4. The WRM evaluation method must be finalized and verified by conducting laboratory studies on selected WRMs.
5. Results from the verification laboratory studies should be used to prepare draft specifications for implementation.
6. A number of 0.8-km-long test sections should be constructed (with TxDOT's cooperation) in one or two districts; they should then be monitored periodically to determine long-term WRM performance.

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