Research Report
KTC-95-1

A USER'S GUIDE FOR BY PRODUCT AND DISCARDED MATERIAL UTILIZATION IN HIGHWAY CONSTRUCTION AND MAINTENANCE

by

Kamyar C. Mahboub, Ph.D., P.E.
Associate Professor of Civil Engineering

David Q. Hunsucker, P.E.
Transportation Research Engineer

Kentucky Transportation Center
College of Engineering
University of Kentucky
Lexington, Kentucky

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16. Abstract

This report presents a user's guide for an expert decision-making system that utilizes findings of an extensive literature search and review conducted as part of this study. The literature search and review were conducted to determine current attitudes and document available technical data relative to the use of recyclable and recoverable materials in highway construction and maintenance activities. Specifically, the literature search focused upon the engineering, economic, and performance aspects of using recyclable and recoverable materials in highway construction and maintenance projects. The effort centered upon asphalt and Portland cement concrete pavement recycling, discarded tire recycling, reuse of paint removal wastes, fly ash, glass, alternative fuels, and other miscellaneous recycled and recovered materials as related to construction and maintenance of highways. Additionally, regulatory and policy matters associated with the use of recyclable and recoverable materials in the transportation area were investigated during the review of pertinent literature.

The user's guide was developed for use by Kentucky Transportation Cabinet officials to address a large number of multi-disciplinary issues. These issues may include, but not be limited to, environmental impact, legal or legislative mandates, performance, cost and implementation. Since the aforementioned variables change with time, there is a user-friendly updating feature for the expert decision-making system. This feature of the expert system format presentation represents a major advantage over the familiar report format. An expert system has three major parts: a user interface, an inference engine, and stored expertise. When consulting the expert system, the user states a problem and interacts with the system. An expert system's inference engine is software that actually carries out the reasoning needed to solve a problem. This software draws upon the stored expertise in order to reach its conclusions.

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APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**	**Symbol**	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH					**LENGTH**		
in.	inches	25.40000	millimetres	mm	mm	millimetres	0.03937	inches	in.
ft	feet	0.30480	metres	m	m	metres	3.28084	feet	ft
yd	yards	0.91440	metres	m	m	metres	1.09361	yards	yd
mi	miles	1.60934	kilometres	km	km	kilometres	0.62137	miles	mi
		AREA					**AREA**		
in.^{2}	square inches	645.16000	millimetres squared	mm^2	mm^2	millimetres squared	0.00155	square inches	in.^{2}
ft^2	square feet	0.09290	metres squared	m^2	m^2	metres squared	10.76392	square feet	ft^2
yd^2	square yards	0.83613	metres squared	m^2	m^2	metres squared	1.19599	square yards	yd^2
ac	acres	0.40469	hectares	ha	ha	hectares	2.47103	acres	ac
mi^2	square miles	2.58999	kilometres squared	km^2	km^2	kilometres squared	0.38610	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57353	millilitres	ml	ml	millilitres	0.03381	fluid ounces	fl oz
gal.	gallons	3.78541	litres	l	l	litres	0.26417	gallons	gal.
ft^3	cubic feet	0.02832	metres cubed	m^3	m^3	metres cubed	35.31448	cubic feet	ft^3
yd^3	cubic yards	0.76455	metres cubed	m^3	m^3	metres cubed	1.30795	cubic yards	yd^3
		MASS					**MASS**		
oz	ounces	28.34952	grams	g	g	grams	0.03527	ounces	oz
lb	pounds	0.45359	kilograms	kg	kg	kilograms	2.20462	pounds	lb
T	short tons (2000 lb)	0.90718	megagrams	Mg	Mg	megagrams	1.10231	short tons (2000 lb)	T
		FORCE AND PRESSURE					**FORCE**		
lbf	pound-force	4.44822	newtons	N	N	newtons	0.22481	pound-force	lbf
psi	pound-force per square inch	6.89476	kilopascal	kPa	kPa	kilopascal	0.14504	pound-force per square inch	psi
		ILLUMINATION					**ILLUMINATION**		
fc	foot-candles	10.76426	lux	lx	lx	lux	0.09290	foot-candles	fc
fl	foot-Lamberts	3.42583	candela/m^2	cd/m^2	cd/m^2	candela/m^2	0.29190	foot-Lamberts	fl
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C	°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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EXECUTIVE SUMMARY

One of the objectives of the Kentucky Transportation Cabinet is to promote the utilization of recovered and recycled materials within the Department of Highways to the fullest extent possible. The Kentucky Transportation Cabinet selected the Kentucky Transportation Center to develop an expert system for the utilization of recovered and recycled materials in highway construction and maintenance applications. An expert system is a computer-based consultant that has access to stored expertise about some problem domain. The expert system developed during this study utilizes a multi-disciplinary data base that appraises all aspects of recyclable and recoverable materials utilization relative to highway construction and maintenance. Specifically, the expert system is designed to examine engineering, economic, regulatory and policy matters related to the use of recyclable and recoverable materials in transportation. Furthermore, the expert system has the flexibility to facilitate modular expansion of the system as new materials and regulations are developed in the future.

A comprehensive literature search relative to the use of recycled and recovered materials was conducted using the facilities of the University of Kentucky Transportation Center Library. Articles and reports related to the use of recyclable and recoverable materials in highway construction and maintenance activities were thoroughly reviewed for general and detailed information that was used for input to the expert system. The literature search identified engineering, economic, and performance aspects of using recyclable and recoverable materials in highway construction and maintenance projects. The materials focused upon during the literature search included asphalt and Portland cement concrete pavements, discarded tires, paint removal wastes, fly ash, glass, alternative fuels, and other miscellaneous recycled and recovered materials. Additionally, regulatory and policy matters associated with the use of recyclable and recoverable materials in the transportation area were investigated and included as data input to the expert system.

The expert system will enable Kentucky Transportation Cabinet administrators to provide practical recyclable and recoverable materials utilization plans and comply with any legislative mandates pertaining to recycled and recovered materials utilization in highway construction and maintenance applications. The expert system will provide an opportunity for transportation officials to pre-examine the impact of various potential legislative actions relative to the mandated use of certain materials.

INTRODUCTION

Various state and federal legislative actions mandate waste utilization plans by transportation agencies. Recent examples include: Kentucky Revised Statute 45A.520 mandates that every state agency require a minimum recycled content for goods, supplies, equipment, and materials purchased. The 1991 Intermodal Surface Transportation Efficiency Act requires utilization of up to 20 percent rubber recycling into asphalt pavements by 1997. Stricter controls over gaseous emissions have been established under the Clean Air Act of 1990, which will affect the quality, quantity and nature of solid wastes produced by the nation's coal-fired, electric generating plants. These mandates represent a paradigm shift: waste disposal is out, waste utilization is in.

Highway agencies are recycling a diverse number of solid waste materials into asphalt and concrete mixes for use in the nation's highways. Environmentalists appear to have targeted construction and maintenance of America's streets, roads, and highways to ease the congestion of landfills. Waste tires, glass, plastic, incinerator ashes, contaminated soils, and even roofing shingles are being utilized in highway construction and maintenance activities. This influence comes not only from environmentalists and legislators, but from inside the industry as well. Highway agencies are making the push to use as many solid wastes in road rehabilitation and new projects as possible for the betterment of both sides. Overall, society stands to reap the rewards of a successful partnership between the highway industry and their peripheral influences.

Recent years have seen as much as 180 million tons of solid waste produced in the United States. Of that figure, waste plastic has accounted for nearly 15 million tons, and discarded tires approximately 3.6 million tons. Around seven million tons of old roofing shingles are discarded each year, along with 12 to 13 million tons of waste glass. Meanwhile, the United States has an immense supply of existing aging asphalt and Portland concrete pavements that are in dire need of repair and replacement. Rehabilitation of the nation's highways results in nearly 40 million tons of aggregate waste being produced. Recycling of these worn out pavements appears to be the answer to the problem of conserving virgin materials and preventing pavement waste from being dumped into America's landfills. According to the National Stone Association, approximately 20 percent of the potentially recyclable pavements available are actually being recycled. Aggregate in asphalt is a limited resource and many recyclable materials can be used to take the place of aggregate, which accounts for 94 percent of an asphalt pavement. In deciding the applicability of a material in a potential recycling situation, there are a few basic rules to follow. Cost effectiveness, performance, availability, environmental and health concerns, and political issues are all determining factors in whether or not a material can be used effectively in highway construction and maintenance applications.

Kentucky Department of Highways' officials are committed to increased utilization of recycled and waste materials in highway projects where it appears promising, feasible, and needed. Department personnel have already utilized a significant number of waste materials in projects, including coal fly ash and bottom ash, boiler slag, blast furnace slag, steel slag and reclaimed pavement materials. Reclaimed pavement materials, fly ash and blast furnace slag are used on a routine basis throughout the state. Over 40,000 tons of blast-furnace slag are used each year within the state as additives in bituminous surface wearing courses [1]. During 1990, more than 130,000 tons of reclaimed asphaltic concrete paving materials were used throughout the state. During the five year period from 1985 to 1990, an average of 160,000 tons per year of reclaimed asphaltic concrete paving materials were used. The Kentucky Transportation Center is currently monitoring a section for the Department of Highways that contains a crumb rubber modifier, [2, 3]. The experimental surface was placed during the summer of 1993. Plans are also underway to develop Special Construction Notes for the proposed construction of a highway fill containing discarded tire chips.

The construction, rehabilitation, and maintenance of the nation's highways annually requires nearly 350 million tons of both natural and manufactured construction materials. Included in that figure are 20 million tons of asphalt, ten million tons of Portland cement concrete, and 320 million tons of natural aggregates, paving mixtures, and synthetic surfacing and coating materials [4]. As noted previously, questionable availability and rising costs of high-quality aggregates has warranted investigating the use of alternative materials such as recyclable wastes and industrial by-products in the highway construction industry. The threat of environmental and economic damage adds strength to the recycling argument. Kentucky Department of Highways' officials have developed and are continuing to develop and implement procedures to include a variety of waste and recycled materials in highway construction and rehabilitation in direct response to the increasing environmental concerns about waste disposal practices.

The Kentucky State Legislature directed the Finance and Administration Cabinet to establish and promulgate regulations for minimum recycled content for goods, supplies, equipment, materials and printing used in state agencies. The result of this action was Kentucky Administrative Regulation 200 KAR 5:330, which took effect January 1, 1992. The regulation covers state agency contracts for construction, repair, renovation and demolition of public facilities, and implements the provisions of Kentucky Revised Statute 45A.520. Every state agency must require, to the extent practicable, that every contractor use goods, supplies, equipment, materials, and printing which meet the requirements for the minimum recycled content indicated in the administrative regulation. Furthermore, every state agency authorized to issue bonds must require, to the extent practicable, that every project within the Commonwealth, fifty percent or more of the cost of which is financed with proceeds of bonds issued by the agency, be undertaken with goods, supplies, equipment, materials, and printing which meet the requirements for the minimum recycled content indicated in the regulation. A detailed account of this regulation and other laws affecting Kentucky has been reported previously, [5].

BACKGROUND

One objective of the Kentucky Transportation Cabinet is to promote the utilization of recovered materials, as well as recycled materials, within the Department of Highways to the fullest extent possible. The Cabinet requested Kentucky Transportation Center investigators to make an assessment of existing efforts within the Department of Highways to utilize recycled and recovered materials and to provide recommendations to Cabinet officials that would indicate where improvements and increased utilization of those materials could be successfully implemented [6]. Continuing with that investigation, Cabinet officials selected the Kentucky Transportation Center to develop an expert decision-making system for use by Kentucky Department of Highways' personnel. The expert system developed would utilize a multi-disciplinary data base that assessed all aspects of waste utilization relative to highway construction and maintenance. Specifically, the expert system would be designed to examine engineering, economic, regulatory and policy matters related to the use of waste materials in highway construction and maintenance activities. The expert system would be designed so that modular expansion would be possible as new materials and regulations are developed in the future.

The objective of this research study was accomplished by performing tasks deemed necessary to develop an expert decision-making system. A comprehensive literature search was conducted using the facilities of the University of Kentucky Transportation Center Library. Articles and reports related to the use of recyclable and recoverable materials in highway construction and maintenance activities were thoroughly reviewed for general and detailed information for data input for the expert system. The expert system decision model developed under this study was designed to assist in addressing a large number of multi-disciplinary issues. These issues include, but are not limited to, environmental impact, legal or legislative mandates, performance, life-cycle cost, and implementation. Data input to the model includes all aspects of waste utilization in highway construction; engineering considerations, economics of their use, and performance aspects of the use of the waste materials as compared with the performance of conventional materials. Regulatory considerations, as well as policy matters, are also input data for the expert decision-making system. Initial input data for development of the decision-making model were obtained from the literature review. However, for some data input to the expert system, follow-up interviews with principal engineers who have conducted research relative to the use of the waste materials may still be required to determine specific engineering and economic data associated with the use of the waste materials and the overall field performance of the materials. Additional input data for the expert system must be developed through laboratory evaluations and performance of field trials. Recyclable and recoverable materials that have been used successfully in highway construction and maintenance applications, but not in Kentucky, should be evaluated under laboratory and/or field conditions. Any application that would require putting waste materials in a confined condition should be worthy of serious consideration for field trial evaluations. Field trials and evaluations are required to document invaluable engineering experience and performance aspects related to the use of recovered and recyclable materials in highway construction and maintenance activities and the data used as input for the expert decision-making system.

The expert system for recyclable and recoverable material utilization in highway construction and maintenance applications will provide an opportunity for transportation officials to pre-examine the impact of various potential legislative actions relative to the mandated use of certain waste materials. The expert system will enable Kentucky Transportation Cabinet administrators to provide practical waste utilization plans and comply with future legislative mandates dealing with waste utilization. This report contains a summary of previously reported findings from a review of pertinent literature, legislative mandates regarding use of recycled and recovered materials in Kentucky, recommendations for future field trials, and a user's guide for the expert decision-making system developed under this study. The user's guide for the expert system is contained in Appendix A of this report. The user's guide provides an overview of the expert system developed during this study. Additionally, an example program is presented in order to facilitate the use of this software package. The Kentucky Transportation Center has staff available to provide detailed consultation assistance to Kentucky Transportation Cabinet staff relative to the software package and licensing issues. Further revisions and updates to the expert system will be necessary as additional information regarding the use of waste materials in highway construction and maintenance activities become available.

SUMMARY OF LITERATURE REVIEW

From using bioremediation to neutralize contaminated soil all the way to using roofing shingles in asphalt pavements, there are many recycling options that have the potential to impact roads in Kentucky. The discarded or by-product materials identified in the literature search that can be reclaimed or recycled for use in many highway projects include asphaltic and Portland cement concrete pavements, scrap tires, glass, coal ashes, slags, plastic waste, paint waste, and wood chips/lignins. Existing, aging asphalt and Portland concrete pavements are in need of repair and replacement all over Kentucky. Recycling these pavements by procedures such as cold planing, cold in-place recycling, hot in-place recycling, and hot mix recycling is a way of conserving virgin aggregates, and simultaneously keeping discarded pavement materials out of landfills.

The Kentucky Department of Highways currently permits a maximum of 30 percent (by weight of the total mixture) recycled asphalt pavement (RAP) to be used in bituminous mixtures (20 percent if the RAP is salvaged from other sources). The Kentucky Department of Highways should consider permitting higher percentages of reclaimed materials to be used, provided the mixtures produced using the RAP meet the required specifications. Typically, conventional hot-mix plants can produce hot mix asphalt mixtures containing up to about 50 percent RAP. Currently, there are only three processes that can successfully incorporate about 80 percent RAP into bituminous mixtures. These processes are cold in-place recycling, hot in-place recycling, and hot mix recycling. Cold in-place recycling involves milling or pulverizing the existing pavement to a predetermined depth, usually about two inches, and processing the material to a certain size; screening and crushing, if needed, to satisfy a required gradation; treating the millings with a polymer-modified asphalt emulsion and mixing; and placing the recycled cold mix on the roadway as one continuous procedure using conventional paving and compaction equipment. Pavements that exhibit excessive distress are not recommended for this process.

Hot in-place recycling of asphalt pavement is typically limited to two inches also. Hot in-place recycling is used to replace the old existing, cracked, rutted, or worn surface to the same condition as a new hot-mix overlay. Asphalt pavements suitable for this process generally have adequate structural condition (no structural flaws past localized sections that can be rehabilitated) and no previous treatments (rubberized asphalt, epoxy patching, surface treatment, etc.) that might prevent recycling, unless they are eliminated first (by milling, for example). Hot-mix recycling in-place is an economically advantageous alternative where pavements have become worn due to environmental factors. Signs of environmental pavement deterioration often include reflection cracking, block cracking, longitudinal or transverse cracking, or where weathering and raveling are apparent.

A number of states are currently recycling Portland cement concrete (PCC) pavements. Kentucky has been reusing PCC pavements for a number of years by breaking and seating the existing PCC pavements and overlaying them with thick layers of asphaltic concrete. The Kentucky Department of Highways also has used recycled concrete aggregate to construct an experimental section of crushed stone base. Other successful uses of recycled PCC aggregates identified in the literature review included use in concrete pavement mixtures and lean concretes. The Kentucky Department of Highways must continue to monitor the performance of the experimental crushed stone base and to evaluate the use of recycled concrete aggregates in other construction or maintenance applications. These data may be used to refine the expert decision-making system.

The use of discarded tires in highway construction has increased in recent years. The primary uses of discarded tires in highway construction and maintenance operations, identified through the literature review, included use as a crumb rubber additive to asphaltic concrete mixtures and as shredded tires for use in lightweight fills and embankments. Perhaps the most successful highway application is the use of tire chips in embankments. Far more tires can be utilized in the construction of a soil-tire embankment than in the construction of an asphalt rubber pavement layer. Engineered applications involving large volumes of discarded tires will be the key to eliminating the numerous waste tire piles that have accumulated across Kentucky. The first step in the utilization process is to identify these stockpiles and implement innovative construction techniques that are practical and cost effective. The Division of Waste Management of the Kentucky Department of Natural Resources and Environmental Protection Cabinet has identified numerous waste-tire stockpiles in Kentucky. The largest such stockpile, containing over 2,000,000 tires, is located in Campbell County. The Kentucky Department of Highways should make every effort to utilize this tire stockpile to construct highway embankments should an appropriate project become available. Other innovative uses of waste tires also were identified such as use of the tires in noise barriers and backfill materials for retaining walls.

Waste glass has been used successfully as a partial replacement of fine aggregate in asphaltic concrete mixtures for low-volume roads, fine aggregate replacement in unbound base courses, mixed with embankment soils, as glass beads in line striping, and as pipe bedding and filter materials in edge drain systems. Waste glass should not be used in Portland cement concretes. The availability of crushed glass appears to be limited to the larger metropolitan areas. Typically, if the haul distance for the glass exceeds 30 miles and the cost of crushing and processing the glass exceeds $3.00 per ton, then the costs associated with its use will be prohibitive. Glass is generally non-beneficial to the properties of conventional construction materials and the performance of highway pavements. The Kentucky Department of Highways should consider utilizing waste glass only in those instances that require minimal processing of the waste glass, i.e., mixed with embankment soils, and minimal transportation.

Fly ashes have been used as additives or partial replacements in Portland cement concrete for a number of years in Kentucky. Kentucky has also demonstrated that bottom ash aggregates can be used successfully as an aggregate replacement in asphaltic concrete mixtures. Fly ashes have been used successfully as mineral fillers in asphaltic concrete mixtures, as embankment and fill materials, stabilized aggregate base courses, and as a component in flowable fill applications. Significant accomplishments have been made in this area due to a recently completed study on the use of fossil-fuel related by-product materials in highway construction, [7, 8, 9, 10 and 11]. Specifications for the use of fossil-fuel related by-product materials in highway applications were developed during this study. Specifications developed under this study will be revised, as needed, as results of the long-term performance monitoring become apparent. Ashes from coal-fired electric generation plants are an excellent source of highway construction materials and their use in highway construction and maintenance is a valid option to the highway industry.

Use of virgin polymers to modify the characteristics of the asphalt cement binder in hot-mix asphalt (HMA) mixtures has been an acceptable practice in the highway construction industry. Now recycled plastic, in the form of polyethylene, is being used to produce polymer additives for asphalt cement. However, it is essential that the recyclability of asphaltic concrete pavements containing recycled plastics be determined. Limited studies have suggested that health hazards associated with recycled plastics are no different from those hazards associated with hot-mixed asphalt. Not only are recycled plastics being used as asphalt cement modifiers, but they are being utilized successfully in many other highway devices. The principal uses of recyclable plastics in the highway industry are in the production of construction and traffic safety products. Sign substrates, flexible delineator posts, rebar support chairs and bolsters, guardrail offset blocks, geotextiles, traffic cones, barricade bases, and plastic lumber are all being manufactured from recycled plastic polymers and recycled rubber polymers. However, it may be unrealistic to use some recycled plastic products in certain applications due to inherent impurities that can affect strength properties. The Kentucky Department of Highways should utilize those products containing recycled plastics that are currently available and meet standard specifications for the application. Because of increased costs associated with recycled plastic products, analyses must be conducted to assess the life-cycle costs of these products. Substantial increases in the economic lives of these products should be realized if they are to be feasible for use in highway construction and maintenance applications.

Thousands of bridges across the United States are coated with lead-based paints. Maintenance operations involving removal of the paint along with the abrasive from blasting create an enormous amount of waste. For this, and other reasons, the Kentucky Department of Highways now utilizes a paint overcoating system for bridges.

PROJECT SUMMARY AND RECOMMENDATIONS

The Kentucky Transportation Cabinet selected the Kentucky Transportation Center to develop an expert system for development and utilization of a multi-disciplinary data base that would appraise all aspects of recovered and recycled material utilization in highway construction and maintenance areas. An expert system is a computer-based consultant that has access to stored expertise about some problem domain. The expert system developed during this study is designed to examine engineering, economic, regulatory and policy matters related to the use of recyclable and recoverable materials in transportation. Furthermore, the expert system has the flexibility to facilitate modular expansion of the system as new materials and regulations are developed in the future.

A comprehensive literature search relative to the use of recycled and recovered materials was conducted using the facilities of the University of Kentucky Transportation Center Library. Articles and reports related to the use of recyclable and recoverable materials in highway construction and maintenance activities were thoroughly reviewed for general and detailed information that was used for input to the expert system. The literature search identified engineering, economic, and performance aspects of using recyclable and recoverable materials in highway construction and maintenance projects. The materials focused upon during the literature search included asphalt and Portland cement concrete pavements, discarded tires, paint removal wastes, fly ash, glass, alternative fuels, and other miscellaneous recycled and recovered materials. Additionally, regulatory and policy matters associated with the use of recyclable and recoverable materials in the transportation area were investigated and included as data input to the expert system.

The expert system developed during this study will enable Kentucky Transportation Cabinet administrators to provide practical utilization plans for recycled and recovered plans and comply with any legislative mandates pertaining to recycled and recovered materials utilization in highway construction and maintenance applications. The expert system will enable Cabinet administrators to operate in a proactive mode rather than a reactive mode with regard to environmental mandates. The expert system will provide an opportunity for transportation officials to pre-examine the impact of various potential legislative actions relative to the mandated use of certain materials.

Laboratory evaluations and/or field trials of recycled and recovered materials that were not accomplished during this study should be conducted and reported during a separate study. Data from the engineering, economic, and performance aspects of using recyclable and recoverable materials in Kentucky highway construction and maintenance projects must be documented for input to the expert decision-making system. Preliminary specifications for the use of recyclable and recoverable materials in highway construction and maintenance must be developed to guide construction and maintenance activities. The specifications and special construction notes related to use of recyclable and recoverable materials in highway construction and maintenance activities should be revised, if necessary, as results of long-term performance monitoring of the applications become apparent. All specification and construction data obtained from the experimental laboratory and field trial applications would be used for input to refine the expert decision-making system.

The solution for effective waste utilization in highway construction and maintenance operations is to find a common ground between what is beneficial for the state's highways and what is beneficial for the environment. If legislators, industry officials, and environmentalists can do this, it can only benefit all of society -- especially Kentucky's highways. The waste utilization expert system developed during this study will provide a unique instrument for engineers and administrators.

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APPENDIX A

USER'S GUIDE

USER'S GUIDE -- EXAMPLE PROBLEM

Introduction:

The purpose of this section is to provide an overview of the expert system developed in this study. Additionally, an example problem is presented in order to facilitate the use of this software package. The Kentucky Transportation Center computer experts will be available to provide consultation to the Cabinet staff on licensing issues.

The expert system decision model was developed to address a large number of multi-disciplinary issues. These issues may include, but not be limited to, environmental impact, legal or legislative mandates, performance, cost, and implementation. Since all of the aforementioned variables change with time, there is a need for a user-friendly updating feature. This may be easily accomplished through the expert system, which represents a major advantage of an expert system format of presentation as opposed to a report format.

An expert system is a computer-based consultant that has access to stored expertise about some problem domain. In this Waste Utilization Expert Systems, we use an expert system for consultation on utilization of waste materials in construction and maintenance of highways in Kentucky. When an end user presents a particular problem to the expert system, it uses the available expertise to infer some advise which it then reports to the end user.

An expert system has three major parts: a user interface, an inference engine, and stored expertise. When consulting an expert system, a person states a problem and interacts with the system. An expert system's inference engine is software that actually carries out the reasoning needed to solve a problem. This software draws upon the stored expertise in order to reach its conclusions.

Human experts sometimes need to reason about uncertain situations. They may even be uncertain about the validity of some rules used when reasoning about a particular problem. The degree of uncertainty about a situation or rule is factored into the human reasoning process. Similarly, techniques exist for factoring varying degrees of certainty into the reasoning performed by an expert system.

GURU is an expert system development environment developed by Micro Data Base Systems, Inc. (MDBS). It was the only expert system builder on the market when version 1.0 was released in 1985. The latest version has a comprehensive set of tools available for building applications that incorporate expert system reasoning. It supports a broad range of integrated knowledge processing capabilities: expert system creation and consultation, data management, ad-hoc inquiry, screen management, printed forms management, spreadsheet analysis, statistics generation, programming, graphics, general-purpose text processing, elaborate report generation, and remote communications. These integrated capabilities can be exercised within any GURU session. All capabilities are simultaneously available and multiple capabilities can be used together in a single operations.

GURU's facilities for expert system development allow the user to build intelligent application systems. One can use an expert system to control the behavior of the application software -- reasoning about when to perform what tasks. Conversely, the application software can itself consult various expert systems in the course of its execution or it can allows to directly consult expert systems.

The GURU software is available for a variety of computer platforms. The platform used in this Waste Utilization Expert Systems is IBM compatible PC running under MS-DOS or PC-DOS. It can also be run in a DOS session under the Microsoft Windows 3.0 or above. The version of GURU used in this development is version 3.1 for DOS. The price of the development system is $7,000 for a single user license and $15,000 for a LAN license on the DOS platforms. The LAN systems are licensed per server. At the Kentucky Transportation Center, we took advantage of the much lower educational price offered by MDBS to universities. Since the end user, Kentucky Transportation Cabinet, is not an educational institution, it must enter into a licensing agreement with MDBS to use this expert system. Instead of purchasing a full development system version, the Cabinet can purchase the license for run-time tokens in addition to the run-time master version of the software. The prices at the time of submission of this user's guide are listed in the following table for your reference.

Hardware requirements of GURU v3.1 for DOS:

- IBM PC/XT, AT, PS/2, or compatible
- DOS version 3.1 or greater
- 640K RAM minimum required
- 5 MB minimum hard disk space
- IBM PC LAN, LAN Manager, Novell, and other DOS 3.1 compatible networks supported.

Prices of GURU for DOS:

The account representative at MDBS for the region including Kentucky is Steven W. Garrison. He can be reached at (800)445-6327. MDBS's address is: Micro Data Base Systems, Inc. 1305 Cumberland Avenue, Post Office Box 2438, West Lafayette, IN 47906-0438.

	Single user version	Network version	Note
Full (developer's) GURU package	$7,000	$15,000	For development of GURU applications.
Run-time Master	$500	$1,000	**Not all functions in full GURU version are available in the run-time version.** The run-time master must be purchased to distribute the applications developed.
Run-time Token	$300 (for 1 to 2 machines)	$700 (for 1 to 2 machines)	A separate token is required for applications installed on each end-user (client) machine, or network, if it is network version. The token prices for more than 2 machines are progressively lower.

Note: There is a 90% discount for the full GURU version for educational use. There is no discount for state agency use.

Consulting the Waste Utilization Expert System:

To invoke the Waste Utilization Expert System, type the following command in the DOS prompt:

```
waste
```

(This command starts a batch file called WASTE.BAT stored in the DOS directory. Therefore your DOS directory must be in the PATH statement. or you have to type

```
c:\dos\waste
```

to start the expert system. The above command assumes that your DOS directory is called DOS and resides in the C drive of your machine.)

The GURU software and the Waste Utilization Expert System will then start. There is a "welcome" screen (Figure 1) showing the credit. Then the main menu screen (Figure 2) will show up. For the time being, there are 10 menu items:

```
Consult the Expert System
Legislative Information
Engineering Information
Cost Issues Information
Policy Matters Information
Waste Types Information
Const. Applications Information
Update the system databases
Reset the databases
Exit
```

This expert system is mostly menu-driven. Each screen is designed to be self-explained. The following screen shots show a consultation using the application of glass waste in asphaltic concrete pavement as an example.

Figure 1. The welcome screen.

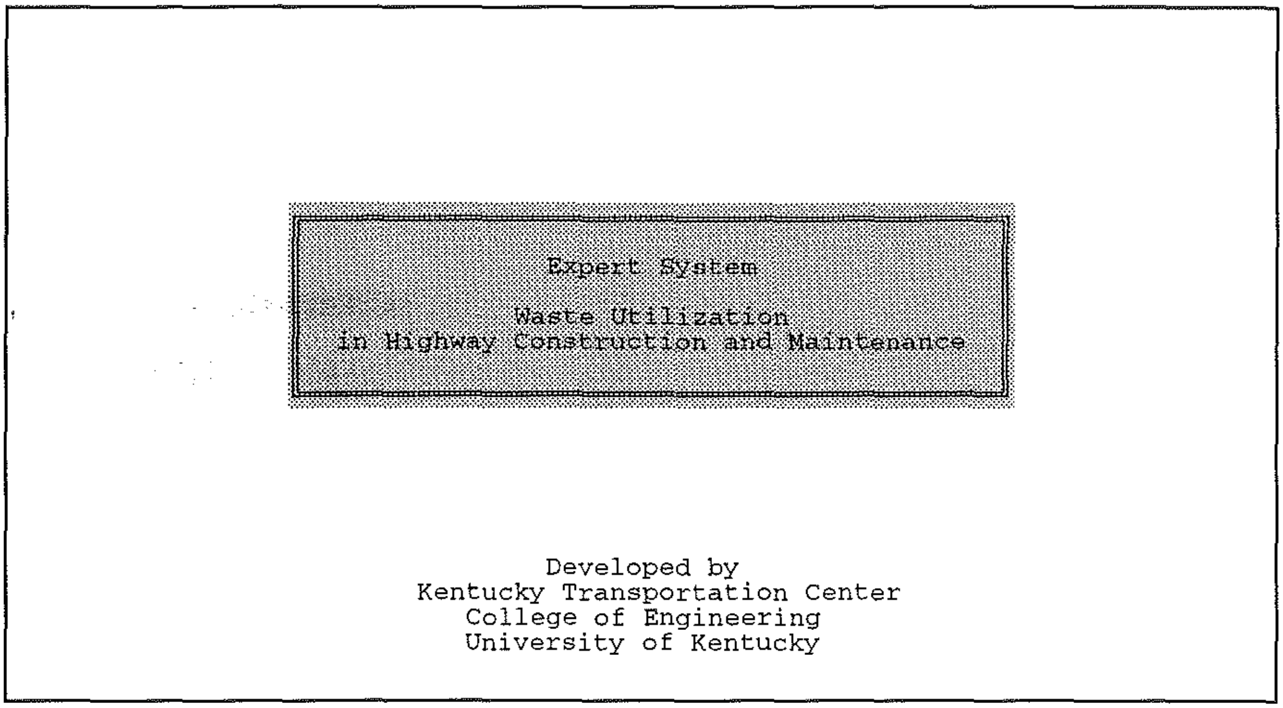

Figure 2. This is the main menu of the Waste Utilization Expert System. The user can select a menu item by using the arrow keys or pressing the first letter of a menu item. If the first letter pressed for a menu item is unique, then the pressing of that letter will start the module. If the first letter pressed is not unique, then the highlight will move to the next menu item that starts with the pressed letter.

```
                    Waste Utilization Expert System

 Consult the Expert System             Waste Types Information
 Legislative Information               Const. Applications Information
 Engineering Information               Update the system databases
 Cost Issues Information               Reset the databases
 Policy Matters Information            Exit

 Consult this waste utilization expert system.

                          Press F1 for Help
```

Figure 3. Menu item for the selection of a waste material

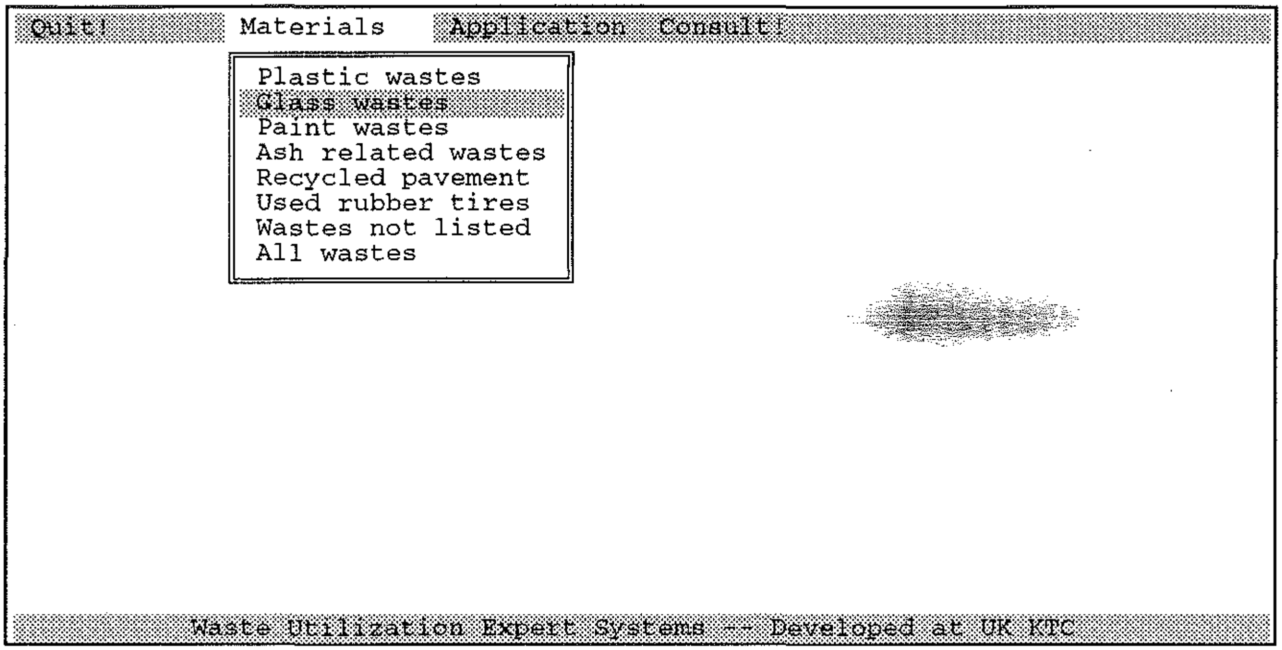

Figure 4. Menu item for the selection of an application.

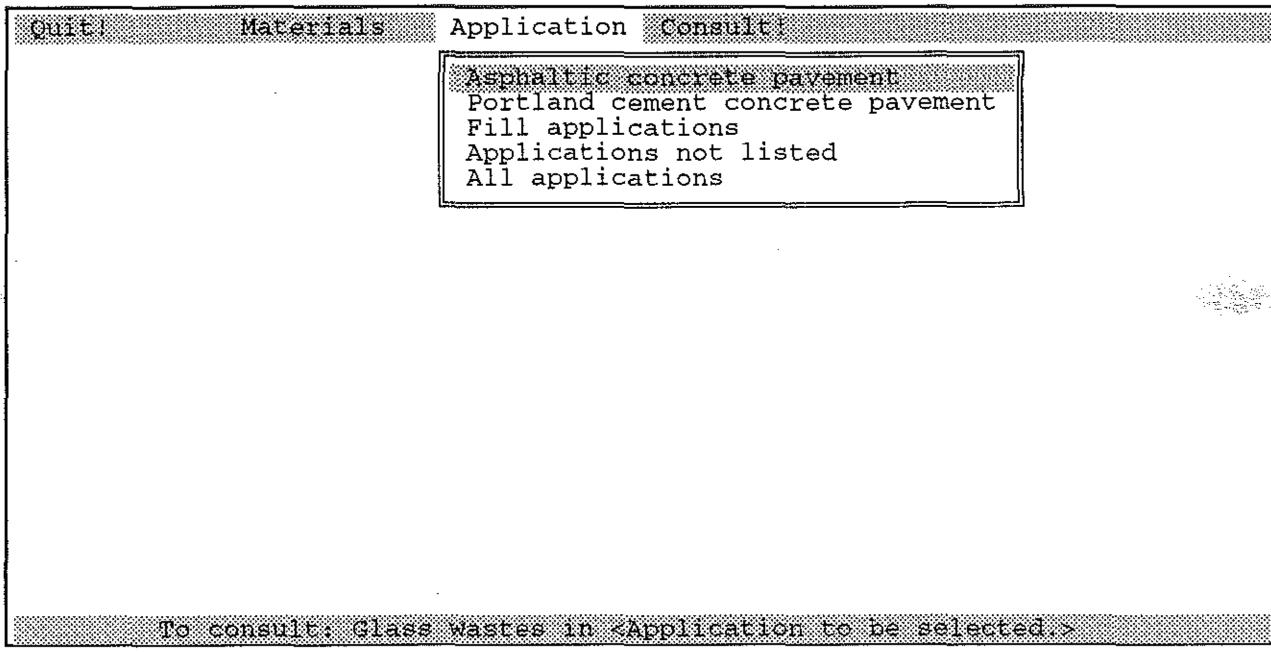

Figure 5. The system is ready for the user to consult the application of the glass waste in asphaltic concrete pavement.

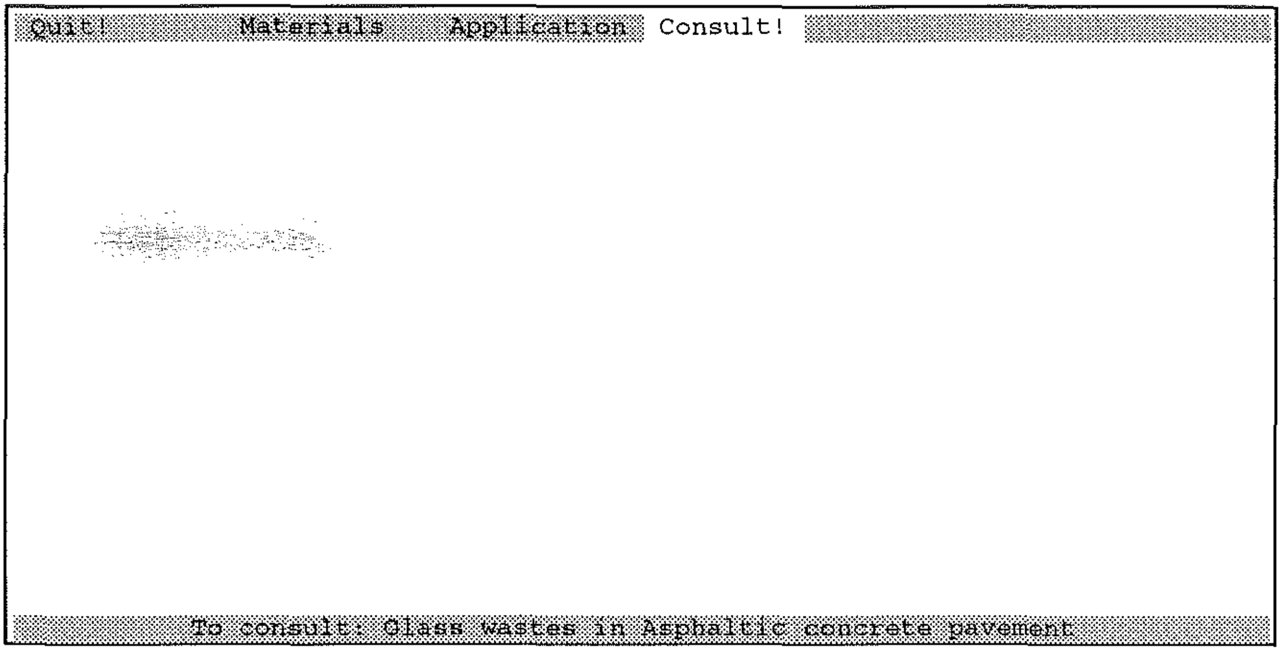

Figure 6. The system asks the user for information.

```
═══════ Glass waste in asphaltic concrete pavement ═══════
Engineering Considerations:

Is an antistrip agent used in the mix? Y

Reason:    An antistrip agent must be used to improve
           resistance to moisture damage.



Help: F1  Backward: F7  Forward: F8
```

Figure 7. The system asks the user for information.

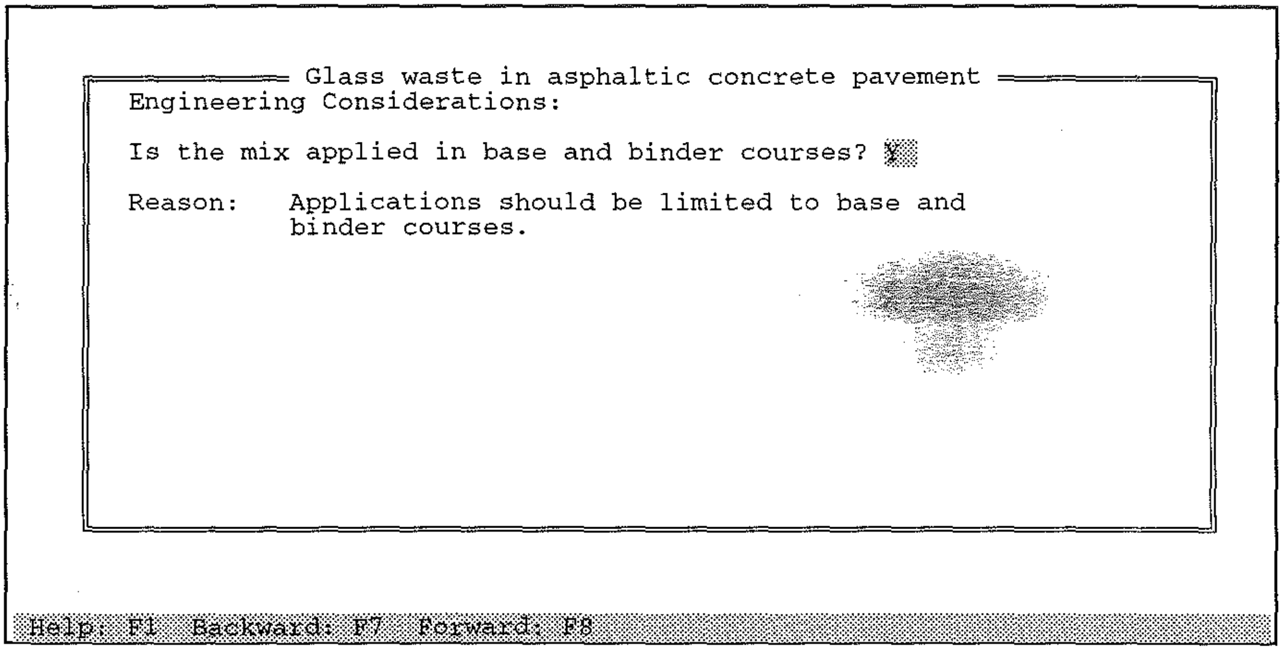

Figure 8. The system asks the user to input information.

```
Glass waste in asphaltic concrete pavement
Engineering Considerations:

Please select the desired percentage of glass by total weight
  in the aggregate: 15.00%  (should be less than 15%.)

What is the percentage of the glass particle that passes a
  3/8" (9.5 mm) sieve? ___.__%

What is the percentage of the glass particle that passes
  a No. 200 (75 mu-m) sieve? ___.__%

Reason:    the particle size (gradation) must be such that
           100 percent passes the 3/8" (9.5 mm) sieve and
           less than eight percent (8%) passes the No. 200
           (75 mu-m) sieve.

Help: F1  Backward: F7  Forward: F8
```

Figure 9. The system displays information for the user.

```
Glass waste in asphaltic concrete pavement
Policy Matters:

Mandated percentage of glass waste by total weight:  3.00%


     Reason: Regulation xxx  KRS xxx.xxx


Help: F1  Backward: F7  Forward: F8
```

Figure 10. The system displays information for the user.

```
Glass waste in asphaltic concrete pavement
Road Safety:

To avoid glare effect, it is currently not recommended to use
glass mixture in an east-west environment.

Help: F1  Backward: F7  Forward: F8
```

Figure 11. The system asks the user to input information.

```
Glass waste in asphaltic concrete pavement
Economical Considerations:

What is the approximate distance between the glass recycle
  center and your construction site? 10    miles

     Reason:    Current cost of fine aggregate for HMA is about
                $1 to $20 per ton depending on location (these
                costs include crushing and transportation to
                the construction site).

                Glass disposal costs also are location dependent
                and range from about $20 to $50 per ton.

Help: F1  Backward: F7  Forward: F8
```

Figure 12. The system displays information for the user.

```
Press any key to see a graph of
unit purchase price for sorted uncrushed clear glass waste.

Be Prepared to answer the following question
after you check the graph:
    how much are you willing to pay for
    a ton of sorted uncrushed glass?

Help: F1  Backward: F7  Forward: F8
```

Figure 13. A sample graph of unit purchase price for sorted uncrushed clear glass waste.

Figure 14. The system asks the user to input information.

```
Glass waste in asphaltic concrete pavement
Economical Considerations:

How much are you willing to pay for a ton of sorted uncrushed
  glass? 42.__ dollars

     Reason:   Purchase price for sorted uncrushed glass is
               location dependent, but is generally $40 to $50
               per ton for clear glass, $25 to $50 per ton for
               amber glass and $0 to $50 per ton for green glass

               Generally, if the haul distance is more than 30
               miles and processing costs exceed $3 per ton, the
               use of glass in an asphaltic concrete mixture is
               not economically feasible.

Help: F1  Backward: F7  Forward: F8
```

Figure 15. This is a summary of the user's input.

```
Glass waste in asphaltic concrete pavement
Summary of your answers:

Is an antistrip agent used in the mix?  Y

Is the mix applied in base and binder courses? Y

Please select the desired percentage of glass by total weight
  in the aggregate: 15.00%  (should be less than 15%.)

What is the percentage of the glass particle that passes a
  3/8" (9.5 mm) sieve?  100.00%

What is the percentage of the glass particle that passes
  a No. 200 (75 mu-m) sieve? 8.00  %

What is the approximate distance between the glass recycle
  center and your construction site?   10 miles

How much are you willing to pay for a ton of sorted uncrushed
  glass?  42.00 dollars

Do you want to change any of them?
```

Figure 16. The recommendation produced by the expert system.

```
Glass waste in asphaltic concrete pavement (Glasphalt)

Recommendation:

Up-front cost increase of the hot-mix asphalt: 84.00%

Life cycle cost increase: (To be determined later.)

Press any key to continue
```

Figure 17. The user can select the menu items for the available information. Here the menu item for legislative information is selected.

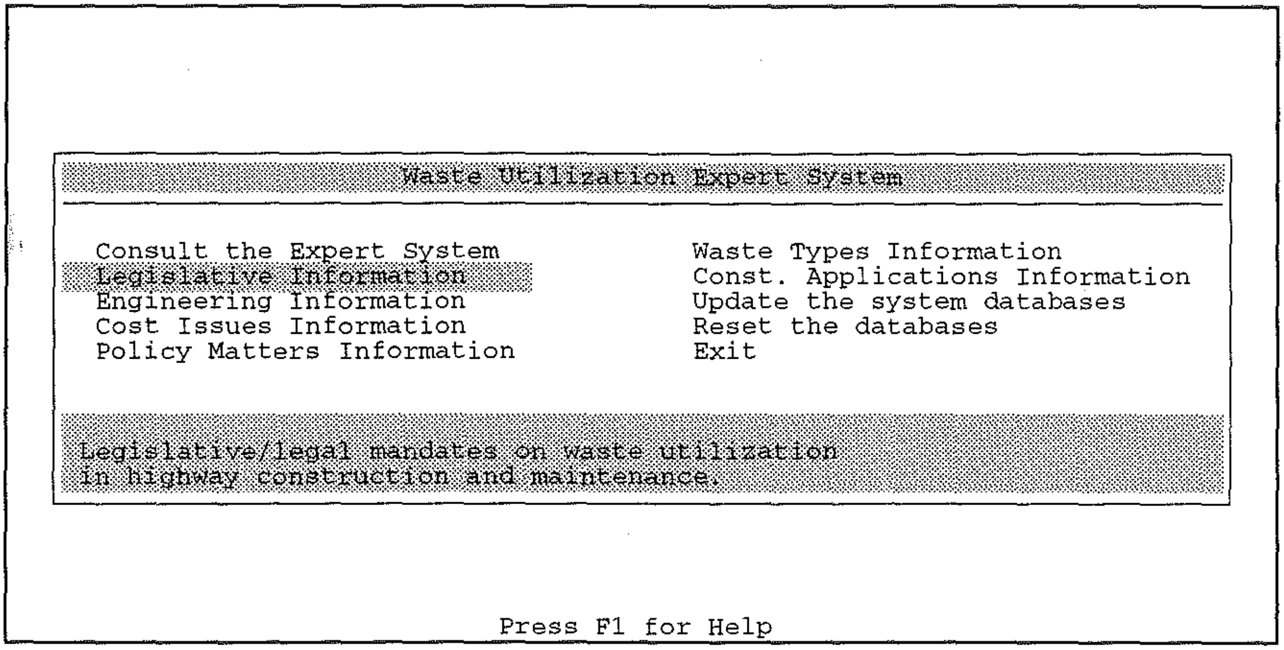

Figure 18. The user can select the menu items for the available information on a waste material in an application on this screen.

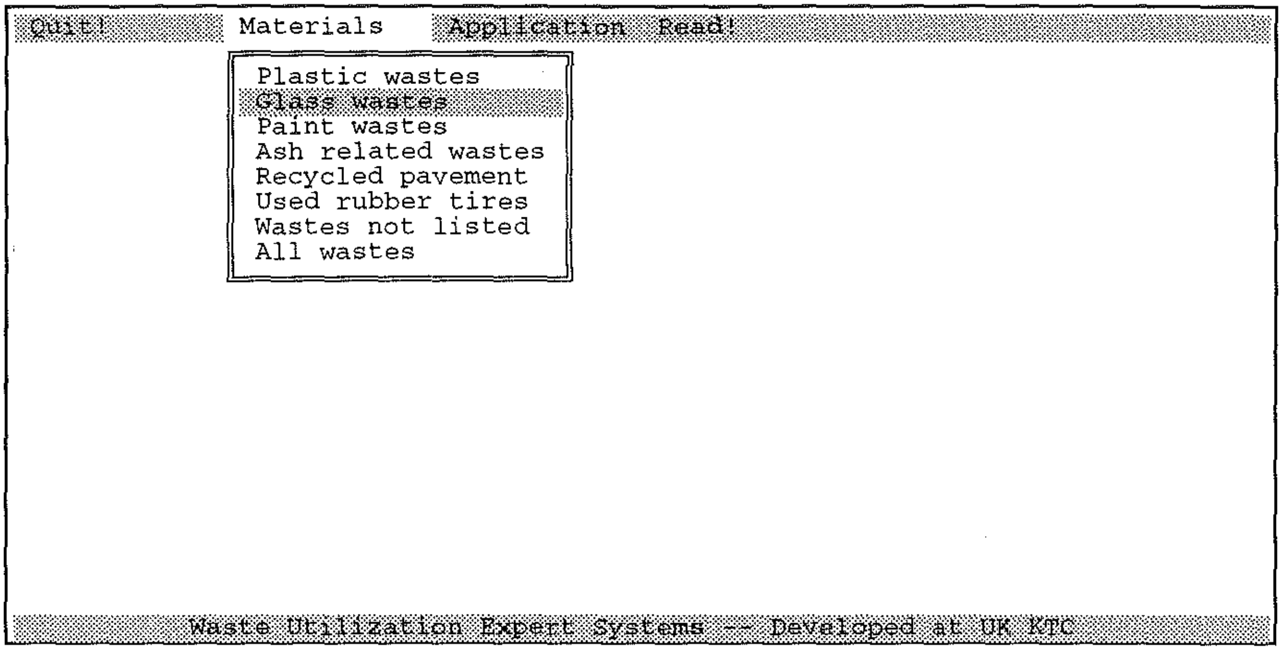

Figure 19. This is one of many information screens available in this system.

```
Information on Glass wastes in Asphaltic concrete pavement:

 Information (Press ESC to quit, PgUp or PgDn to scroll)
Glass waste in asphaltic concrete pavement --
Legislative/Legal Mandates:

      The Kentucky State Legislature directed the Finance and
Administrative Cabinet to establish and promulgate regulations
for minimum recycled material content for goods, supplies,
equipment, and materials used in state agencies.

      The result of this action was Regulation 200 KAR 5:330,
which took effect January 1, 1992.

      The regulation covers state agency contracts for
construction, repair, renovation and demolition of public
facilities and implements the provisions of KRS 45A.520.

      Every state agency must require, to the extent practicable,
that every contractor use goods, supplies, equipment, and
materials, which meet the requirements for the minimum recycled
content indicated in the regulation.
```

Figure 20. This screen shows the engineering factors to be considered when using glass waste in asphaltic concrete pavement.

```
Information on Glass wastes in Asphaltic concrete pavement:

Information (Press ESC to quit, PgUp or PgDn to scroll)
Glass waste in asphaltic concrete pavement --
Engineering Feasibility:

      Successful applications require:

o     Quantity of glass by total weight of the aggregate must be
      limited to 15 percent or less.

o     The particle size or gradation must be such that 100 percent
      passes the 3/8" (9.5 mm) sieve and less than eight percent
      (8%) passes the No. 200 (75 mu-m) sieve.

o     An antistrip agent must be used to improve resistance to
      moisture damage.

o     Applications should be limited to base and binder courses.
```