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INVESTIGATION OF THE POTENTIAL FOR ACHIEVING SUSTAINABLE CONSTRUCTION IN THE FDOT'S WORK PROGRAM

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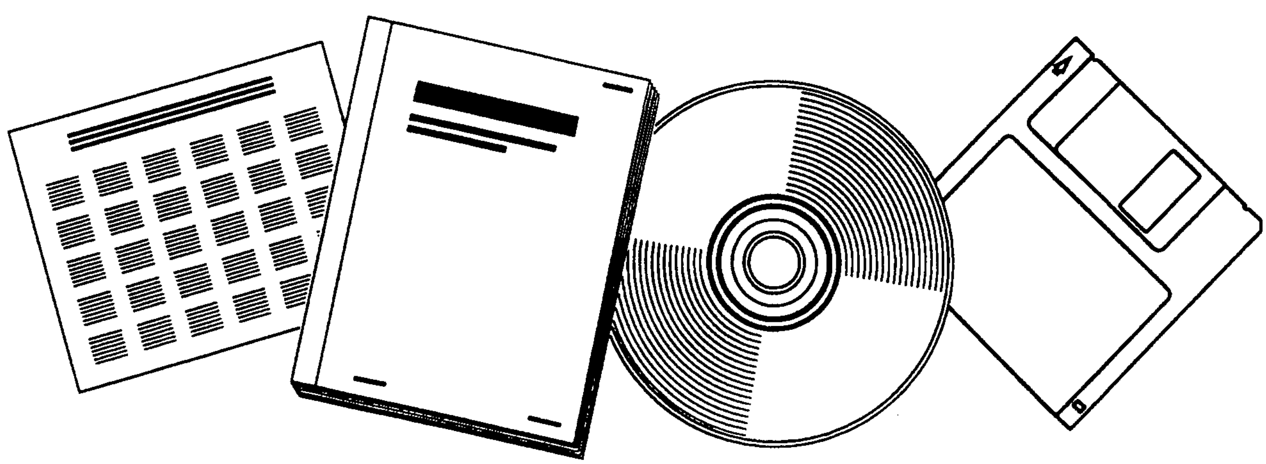

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FINAL REPORT

INVESTIGATION OF THE POTENTIAL FOR ACHIEVING SUSTAINABLE CONSTRUCTION IN THE FDOT'S WORK PROGRAM

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TABLE OF CONTENTS

Page

LIST OF FIGURES . . . iii

LIST OF TABLES . . . iv

CHAPTER

1 BACKGROUND AND PROBLEM STATEMENT . . . 1

Introduction . . . 1
Research Objectives . . . 4
Research Approach . . . 4

2 SUSTAINABILITY AND HIGHWAY CONSTRUCTION . . . 5

Introduction . . . 5
Sustainable Development . . . 5
Principles for Sustainable Construction . . . 7

3 RECYCLING EFFORTS IN HIGHWAY CONSTRUCTION . . . 8

Hot Mix Asphalt Recycling . . . 8
Hot In-Place Recycling . . . 8
Using Microwave for the Heating Process . . . 8
Cold In-Place Recycling . . . 9
Waste Materials Used in Highway Construction . . . 9
Blast Furnace Slag . . . 10
Steel Slag . . . 10
Glass and Ceramics . . . 11
Scrap Tires . . . 12
Wet Process . . . 12
Dry Process . . . 12
Plastics . . . 12
Construction and Demolition Debris . . . 13
Reclaimed Asphalt Pavement . . . 13
Reclaimed Concrete Pavement . . . 14
Fly Ash . . . 14
Sulfur Binder . . . 15
Carpet Fiber Waste . . . 15
Incinerator Ash . . . 15
Roofing Shingle Waste . . . 16
Petroleum Contaminated Soil . . . 16
Wood Lignin . . . 17
Rice Husk Ash . . . 17
Chat Wastes . . . 17
Phosphogypsum . . . 18

4 DATA COLLECTION 19

Introduction 19
Definition of Existing Available Construction Resources 19
Highway Construction Rates of Consumption 19
Asphalt Concrete Pavement 20
Portland Cement Concrete Pavement 22
Portland Cement Concrete 22

5 CONSTRUCTION RECYCLING EFFORTS 28

Introduction 28
Analysis of Data Obtained by Questionnaire 28
Ranking of Used Wastes and By-Products 34

6 MODELING AND FORECASTING PROCEDURES 37

Introduction 37
Selection of Variables 37
Population 37
Households 37
Taxes 43
Road Miles 43
Consumption Model Development 48
Forecasting for Future Expenditures 49

7 CONCLUSIONS 56

Recycling and Savings 56
Using of Fly Ash 56
Using Reclaimed Asphalt Concrete Pavement 56
Using Ground Tire Rubber 57
Estimated Future Savings 58
Conclusions 64

8 IMPLEMENTATION PLAN 69

Establishing Goals 69
Monitoring Performance 69
Research Efforts 69

REFERENCES 70

LIST OF FIGURES

Figure Page

4.1 Quantities of asphalt concrete pavement. 21

4.2 Quantities for Portland cement concrete pavement 23

4.3 Concrete quantities in pipelines. 24

4.4 Portland cement concrete quantities. 25

4.5 Total limestone quantities used in highway construction by the FDOT. 27

5.1 Number of uses for waste materials by states 30

5.2 Percentages of highway agencies using waste material in different pavement courses. 31

6.1 Observed and modeled population in Florida. 40

6.2 Observed and modeled households in Florida. 42

6.3 Observed and modeled taxes in Florida. 45

6.4 Road miles in Florida 48

6.5 Final model represents the future consumed limestone quantities. 52

6.6 Expected future expenditure by the FDOT. 55

7.1 Expected consumed limestone materials and savings associated with recycling. . . . 59

7.2 Accumulated future limestone quantities. 62

7.3 Using RAP and future savings. 66

LIST OF TABLES

Table		Page
1.1	Estimated annual quantities of waste materials in different categories.	2
3.1	Air-Cooled Blast Furnace Slag Sold or Used in the United States by Use	10
3.2	Steel Slag Sold or Used in the United States	11
5.1	Number of uses of waste materials and corresponding pavement courses by highway agencies.	29
5.2	Economical evaluation for waste materials.	32
5.3	Engineering Performance evaluation for waste materials.	33
5.4	Ranking of wastes and by-products according to highway agencies survey.	35
6.1	Observed population in Florida.	39
6.2	Model to forecast the population in Florida using logarithmic transformation.	39
6.3	Observed and modeled households in Florida.	40
6.4	A presentation for number of households in Florida	41
6.5	Taxes in Florida.	44
6.6	Model for taxes in Florida	44
6.7	Road miles in Florida.	46
6.8	Model for road miles in Florida.	47
6.9	Listing of some models used in the quantities model.	50
6.10	Final model for limestone quantities.	51
6.11	Listing of some models used in the Expenditures model.	53
6.12	Statistical analysis for the final expenditures model.	54
7.1	Energy savings when using RAP.	58
7.2	Expected consumed and saved materials quantities.	59

7.3 Accumulated quantities used when invoking no recycling versus that of recycling. 60

7.4 Future cost savings associated with RAP 62

7.5 Savings when using RAP in construction program 65

CHAPTER 1

BACKGROUND AND PROBLEM STATEMENT

INTRODUCTION

The amount and type of waste being generated grows as the world population grows. Numerous waste materials result from manufacturing, sewage treatment plants, industries, households, and mining. Many of the wastes produced today will remain in the environment for a long time. While the volume of waste is continuing to grow, approval of facilities and proper disposal is becoming more difficult to obtain.

In 1979 there were more than 15,000 landfills operating in the USA. In 1988 there were only 6,500, and it is estimated that this number will drop down half that number by the year 2000 (Dashefskey, S., 1993).

The reduction in landfill drove the tipping fees to rise. In Rhode Island, the tipping fees for dumping one cubic yard has risen from $6.5 in 1988 to between $15 and $20 in 1990 (Stezler, S., 1990). In Pinellas county, Florida, which burns 95% of its solid waste, tipping fees has risen from $15 or $20 a ton to $25 a ton (in 1987 dollars) (Tuchman, J.,1987). With landfill space shrinking, solid wastes radically increasing, and disposal costs escalating, have forced the public attitude regarding the ways society handles its wastes. In addition, an awareness of the importance of conserving and preserving our valuable natural resources arises. This awareness has focused on recycling the wastes into useful products.

Each year, approximately 4.2 billion metric tonnes (4.6 billion tons) of non-hazardous solid wastes are produced in the United States. Table 1.1 provides a summary of the estimated quantities and components of four major solid waste categories as well as breakdown of estimated annual quantities of domestic and industrial waste materials (Collins, R., 1994). To achieve sustainable con-

Table 1.1 Estimated Annual Quantities of Waste Materials in Different Categories

Category	Description	Annual Quantity (Million Tons/Year)	Total Annual Quantity (Million Tons/Year)
Agricultural	Animal Manure	1,600	2,100
	Crop Wastes	400	
	Logging and Wood Waste	70	
	Miscellaneous	30	
Domestic	Household and Commercial Refuse	185	200
	-Paper and Paperboards (71.8)		
	-Yard Waste (32)		
	-Plastics (14)		
	-Incinerator Ash (9)		
	Sewage Sludge	8	
	Scrap Tires	2.5	
	Used Oil	2	
Industrial	Coal Ash	72	400
	Domestic Debris	25	
	Blast Furnace Slag	16	
	Steel Mill Slag	8	
	Non-Ferrous Slag	10	
	Cement and Lime Kiln Dust	24	
	Reclaimed Asphalt Pavement	100	
	Reclaimed Concrete Pavement	3	
	Foundry Wastes	10	
	Silica Fume	0	
	Roofing Shingle Waste	9	
	Sulfate Waste		
	Lime Waste	2	
	Ceramic Wastes	3	
	Paper Mill Sludge	N.A.	
	Contaminated Soils	N.A.	
Mineral	Waste Rock	1,020	1,800
	Mill Tailings	520	
	Coal Refuse	120	
	Washery Rejects	105	
	Phosphogypsum	35	
		TOTAL	**4,500**

struction, non-renewable resources consumption should be significantly decreased, the environment--the air, the ground water, rivers, lakes and oceans should not be polluted, nor should disposal problems or toxic wastes be created.

Materials should be used in the most effective way possible, structures should have long lives and materials should be recyclable (Jansson, M., 1994). Consumption of energy in the construction development should be optimized. Alternatives for conventional resources should be considered.

The Construction industry, being a major consumer of non-renewable resources, is responsible for achieving sustainability with respect with material it employs. Approximately 2 billion tons of construction aggregate (crushed stone, sand, and gravel) are produced and sold each year in the United States (MIS, 1990). A significant percentage of this production is used for highway and bridge construction. These materials are exhaustible. The continuing demand of raw materials is gradually depleting natural resources. Access to these materials is increasingly limited by growing environmental regulations and permitting requirements, restrictive zoning laws, land uses, and other economic considerations. The community oppositions are restricting the expansion of or even forcing the closure of existing quarry and gravel pit operations. This has created localized shortages of construction aggregates and borrow materials in many areas. Acceptable alternatives are needed to alleviate such shortages and to conserve natural resources, directing to a sustainable development.

Research into new and innovative uses of waste materials is continually advancing. Many highway agencies and private organizations have completed or in the process to complete a wide variety of studies and projects concerning the feasibility, environmental suitability, and performance of using recycled products in highway construction. Recycling is not the only accepted way for waste management. Some other techniques are: reduction of waste material at its source; and reuse of the construction wastes.

RESEARCH OBJECTIVES

The objectives of this study: 1) to perform an assessment of non-renewable resources current rates of consumption with allowances for reuse and recycling efforts; 2) to develop a model for predicting and analyzing future construction sustainability; 3) to structure a preliminary construction management approach for minimizing paving operation non-sustainability.

RESEARCH APPROACH

The research methodology included a comprehensive review of information on this subject. This was conducted through an electronic database literature review to involve a thorough review of published literature concerning sustainability, waste reduction, and various waste materials and by-product and implementing these material in highway construction. It also contains various methods and available waste that have shown promise as a substitute for conventional materials.

Other state Highway Agencies were contacted to obtain their current recycling efforts and evaluations of the use of recycled materials. Available natural resources quantities and their production rates were determined. In addition, an analysis of FDOT past and current rates of resource consumption were prepared. Data collected in the past phase is used to develop the projection of FDOT's future consumption rates and material availabilities. These data are from construction projects throughout the state of Florida. More than 750 activities included in approximately 17 thousand activities were reviewed. These activities are for the available 10 years data. These 750 activities were included in approximately 2000 contracts between FDOT and approximately 100 contractors.

CHAPTER 2

SUSTAINABILITY AND HIGHWAY CONSTRUCTION

INTRODUCTION

Sustainability can be expressed in the simple terms of an economic golden rule for the restorative economy: Leave the world better than you found it, take no more than you need, try not to harm life or the environment.

Sustainability encompasses the concept of living within the means of resources available. For the last several decades, dwellers of Planet Earth, particularly those in the industrialized nations, have been living beyond the means of resources available. If continued upon this course, Earth's supply of fossil fuels and other natural resources will be depleted within the next century. In addition, Earth's environment will be ravaged to such an extent that it will be unhealthy, if not unfit, for humans. The United States and other industrialized nations, particularly Japan, Sweden and Canada, have taken significant steps toward recognizing environmental concerns. However, all the clean air and water acts, reducing the chlorofluorocarbons and other environmental controls will be meaningless unless the world's population controls its appetite for fossil fuel energy (Hill, R., 1994).

SUSTAINABLE DEVELOPMENT

There are many definitions to address the concept of sustainable development:

- The sustainability of a given society means the standards of behavior which ensure that the future generation will be able to enjoy the same level of well-being as ours.
- The link between the level of current development and the ability to satisfy future needs, determined by the amount of resources that one generation passes to the next. These resources include: renewable natural resources, non-renewable natural resources, knowledge, and traditions.

Waste can be reduced by using materials that are entirely or partially made of recycled materials because using of recycled material reduces the amount of virgin material used, and subsequently reduces the amount of virgin material that ends up as landfill.

In architecture and sustainable technology, a group of architects see that sustainability as a set of principles must change the way the architects think and work. Architects address sustainability and environmental ideas to two new issues. First, is the issue of good indoor air quality which means looking for material which are friendly to the Earth as a whole, and to the people who use and build the buildings. The kinds of building material which cause allergies should be replaced by inert ones (though recyclable) such as metals, glass, and concrete. Second, is the relation between sustainability and urban design. Building an efficient building must be obtainable in more sustainable ways.

Building construction has done some research in achieving sustainability. One research showed that reducing construction wastes at its source is an effective factor (Floyed, G., 1993). For example, it is essential that constructors are sure the correct amount of each material is brought to the site. In addition, orders such as wallboard, must be consistent with room dimensions, since wallboard is available in different sizes. Purchasing pre-cut lumber can also minimize wastes resources on the construction site. Ordering oversize lumber is a waste of money and resources.

The highway construction industry has a long history of using discarded materials and by-products in the construction of highway facilities. On October 19-22, 1991, the Federal Highway Administration (FHWA) and the Environmental Protection Agency (EPA) cosponsored a symposium entitled "*Recovery and Effective Reuse of Discarded Materials and By-Product for Construction of Highway Facilities.*" The symposium addressed the requirement to determine the economic savings, technical performance qualities, threats to human health and the environmental, and environmental benefits of using recycled material in highway construction.

Materials that had previously been disposed of through land-filling include old asphalt, old concrete, waste glass, slags, fly ash, roof shingles, rubber tires, incinerators, foundry sand, and motor oil, showed a great potential of supporting sustainable development in highway construction.

PRINCIPLES FOR SUSTAINABLE CONSTRUCTION

Principles for sustainable construction should cover the resources to create and build the environment, and could be defined as: materials, energy, water, and land. These principles introduced as the following six items (Kibert, C, 1994):

- Minimize resource consumption (Conserve)
- Maximize resources reuse (Reuse)
- Use renewable or recyclable resources (Renew/Recycle)
- Protect the natural environment (Protect Nature)
- Create a healthy, non-toxic environment (Non-Toxic)
- Pursue quality in creating the built environment (Quality).

CHAPTER 3

RECYCLING EFFORTS IN HIGHWAY CONSTRUCTION

Research into new and innovative uses of waste materials is continually advancing. Many highway agencies, private organizations, and individuals have completed or are in the process of completing a wide variety of studies and research projects concerning the feasibility, environmental suitability, and performance of using recycled products in highway construction.

HOT MIX ASPHALT RECYCLING

Hot-mix asphalt (HMA) recycling is a process in which reclaimed asphalt pavement (RAP) materials, is combined with new aggregate and/or asphalt, and/or recycling agent as necessary in a central plant blending and mixing operation to produce hot-mix paving mixture. The disadvantages of hot-mix recycling when compared to in-place methods are that 100 percent RAP generally cannot be used in the recycled mix. Additional costs result from transporting the material to and from the central plan, and traffic can be disrupted for longer periods of time.

HOT IN-PLACE RECYCLING

This operation is a single-step process. In this process, the existing pavement is heated, milled off, then mixed with new aggregate, modifiers, new asphalt concrete mixtures or recycled materials (Hufman, J.,1993). American Recycling and Reclamation Association (ARRA) estimated that over 18 million metric tons (20 million tons) of pavement was recycled in this manner in 1991 (ARRA, 1992).

USING MICROWAVE FOR THE HEATING PROCESS

The microwave recycling process was developed by a firm in Georgetown, Texas. This method uses microwave energy to heat and recycle asphalt. With this technique, up to 100 percent of used asphalt can be recycled into new reusable blacktop. The Pennsylvania's Members of the Turnpike's Environmental Action Team (EAT) have begun looking into the microwave recycling of asphalt, and are convinced that microwave recycling offered a good alternative. The microwave recycling was used successfully in Texas where it was being used on a resurfacing project for the Texas Department of Transportation.

COLD IN-PLACE RECYCLING

In the cold recycling process under consideration, a three unit train which consist of a milling machine which pushes an emulsion tanker and pulls a conventional asphalt paver is used. The milling machine grinds off the existing bituminous pavement and a portion of the base material. This mixture is fed into a hopper where an asphalt emulsion is added from the tanker. After thorough mixing, the material is conveyed to a paver, and laid in a normal paving operation (AI, 1983). Follow the paving operation, a vibrator roller used for finishing. American Recycling and Reclamation Association (ARRA) estimated that over 2 million metric tons (2.1 million ton) of pavement was recycled by this process in 1991 (ARRA, 1992).

One of the claimed advantages of this process is that traffic can be permitted on the pavement immediately following proper operation. Another cost advantage of cold in-place recycling over HMA is that transporting the material to and from a hot-mix plant is saved.

WASTE MATERIALS USED IN HIGHWAY CONSTRUCTION

Waste material can be broadly described as industrial wastes, Municipal/domestic wastes, and mining wastes. A general overview of waste materials included in the research work done in the past and their potential for use in pavement recycling in given here in this chapter.

BLAST FURNACE SLAG

Blast furnace slag is an industrial byproduct of iron produced in a blast furnace. This slag consists primarily of silicates and alumino-silicates of lime and other bases. The Bureau of Mines reports that 14 million metric tons (15.4 million tons) of blast furnace slag was sold in the United States in 1992 with a value of $ 99.5 million. Table 3.1 summarizes current uses for blast furnace slag in the United States.

Table 3.1 Air-Cooled Blast Furnace Slag Sold or Used in the United States by Use.

Use	1991		1992	
	Quantity (1000 Ton)	Value* ($1000)	Quantity (1000 Ton)	Value* ($1000)
Asphaltic Concrete Aggregate	1,634	$9,577.0	2,212	$13,270.0
Concrete Aggregate	1,333	$9,683.0	1.325	$9,193.0
Concrete Product	358	$2,333.0	469	$2,863.0
Fill	855	$3,950.0	1,229	$5,328.0
Glass Manufacture	W	W	W	W
Mineral Wool	449	$3,056.0	745	$4,872.0
Railroad Ballast	221	$1,288.0	177	$829.0
Road Base	5,339	$30,282.0	5,894	$31,183.0
Roofing Shingles	68	$771.0	70	$844.0
Sewage Treatment	W	W	W	W
Soil Conditioning	W	W	W	W
Other**	633	$5,455.0	665	$6,238.0
Total* **	**10,889**	**$66,393.0**	**12,697**	**$74,720.0**

* Value Based on Selling Price at Plant
** Includes ice control and miscellaneous uses
*** Data may not add to totals because of rounding
W Withheld; Data are included with "Other"

Source: U.S. Department of the Interior, Bureau of Mines, Washington, DC, 1992.

STEEL SLAG

Steel slag, a by-product of the steel-making process, contains fused mixtures of oxides and silicates, primarily calcium, iron, and magnesium. In 1992, 6.9 million metric tons (7.6 million ton) steel slag was sold in United States at a total value of $21.9 million (The Average selling price for steel slag at the plant was $3.02 per metric ton). Table 3.2 summarizes current uses for steel slag in the United States.

Table 3.2 Steel Slag Sold or Used in the United States

Use	1991		1992	
	Quantity (1000 Ton)	Value* ($1000)	Quantity (1000 Ton)	Value* ($1000)
Asphaltic Concrete Aggregate	1,085	$4,617.0	903	$4,272.0
Fill	828	$2,374.0	1,037	$3,067.0
Railroad Ballast	186	$585.0	224	$772.0
Road Base	3,238	$10,625.0	2,400	$7,256.0
Others **	1,623	$5,53.0	2,256	$6,064.0
Total* **	**6,959**	**$23,732.0**	**6,857**	**$21,972.0**

* Value Based on Selling Price at Plant ** Includes ice control and miscellaneous uses
*** Data may not add to totals because of rounding
Source: U.S. Department of the Interior, Bureau of Mines, Washington, DC, 1992.

GLASS AND CERAMICS

Glass contributes approximately 7 percent of the total weight of U.S. municipal solid waste, or about 12 million metric ton (13.2 million Ton). Approximately 20 percent of this glass is being recycled, primarily for cullet in glass manufacturing.

The use of waste glass in asphalt (glasphalt) is not new. It was originated more than twenty years ago through experimental work at the University of Missouri-Rolla.

Current researches concentrate on using glass as aggregate in asphalt pavements, pipe bedding, and as addition to soil embankments.

SCRAP TIRES

It is estimated that 285 million tires are discarded annually in the United States. Of these, about 55 million are reused (resold), and about 42 million are diverted to various alternative uses such as fuel for generating power and additives to asphalt pavement (Huffman, J., 1993).

The use of crumb rubber to modify asphalt cement has been developed over the past 25 years. Crumb rubber is primarily used in Hot Mix Asphalt (HMA) mixes by the two processes:

Wet process where crumb rubber is blended with asphalt cement prior to incorporating the binder into the project. This modified binder is called "asphalt-rubber." Approximately 18 to 26 percent of crumb rubber by weight of asphalt cement is reacted with asphalt cement at 190 to 218°C for one to two hours.

Dry process is mixing the crumb rubber with aggregate before incorporating the asphalt cement. About 3 to 5 percent of coarse rubber particles by weight of aggregates are generally used. The amount of rubber that can be used in the dry process is approximately 2 to 4 times that used in wet process (Swearingen, D., 1992).

PLASTICS

Plastics comprise more than 8 percent of the total weight of the municipal waste stream and about 12 to 20 percent of its volume. In 1992, approximately 14.7 million metric tons (16.2 million tons) of plastics were discarded in the United States; only 0.3 million tons (0.33 million ton) -- or 2.2 percent -- were recycled. Current research on the use of recycled plastics in highway construction is wide and varied. The use of virgin polyethylene as an additive to asphaltic concrete is not new; however, two new processes also use recycled plastic as an asphalt cement additive.

Michigan State University is looking into the use of recycled plastic in portland cement concrete. In this study, recycled high-density polyethylene (HDPE) was used to replace from 20 to

40 percent of fine aggregate by volume (7.5 to 15 percent by total volume) in a lightweight concrete mix.

Many agencies and private companies have been experimenting with the use of recycled plastic for items such as guardrail posts and block-outs, fence posts, noise barriers, sign posts, and snow poles. (Collins, R., 1993).

CONSTRUCTION AND DEMOLITION DEBRIS

It is estimated that at least 20 to 30 million tons per year of construction and demolition (C&D) debris are generated in the United States (Lauritzen, D., 1993). C&D debris consists largely of wood and plaster, but also includes concrete, glass, metal, brick, shingles, and asphalt. Portions of this debris that are reclaimed, crushed, and processed into aggregate include concrete, bricks, glass, and old asphalt (Gorle, D., 1988). Recycling of C&D debris is done regularly at numerous processing locations around the country, mainly in large metropolitan areas.

RECLAIMED ASPHALT PAVEMENT

It is estimated that approximately 46 million metric tons (50 million tons) of asphalt paving material are currently being milled annually. Much of this material is returned to producers' yards for use in paving mixes. In order to maintain mix temperatures satisfactorily, only about 20-50 percent of all the milled asphalt paving material is able to be recycled into hot-mix asphalt paving mixtures (Pukman, K., 1988). Reclaimed asphalt pavement (RAP) can be recycled into hot mixes, cold mixes, or in-place mixes. RAP can also be used in other highway uses, as in unbound aggregate base and subbase, stabilized base course. shoulder aggregate, and open-graded drainage courses (Gross, A., 1980).

RECLAIMED CONCRETE PAVEMENT

The American Concrete Pavement Association (ACPA) has indicated that approximately 328 kilometers (200 miles) of concrete pavement are being recycled each year. Assuming these pavements are two lanes wide and 25 cm (10 inches) thick, and using a recovery factor of 75 percent, then approximately 5450 metric tons (6000 tons) of concrete can be reclaimed from every mile of concrete pavement (Lane, K. 1982). This indicates that roughly 2.6 million metric tons (2.9 million tons) of reclaimed concrete are being recycled annually. Generally speaking, recycled coarse aggregate (material larger than 3/8 in.) is more suitable than recycled fine aggregate (material smaller than 3/8 in.), especially when reused in concrete mixes (Lloyd, S. 1996). Reclaimed concrete pavement (RCP) is also useful as an unbound base course aggregate, in cement-treated base, as an asphalt paving aggregate, as embankment base material, and as riprap.

FLY ASH

The primary components of coal fly ash are silicon dioxide, aluminum oxide, iron oxide, and calcium oxide. Approximately 45 million metric tons (49.6 million tons) of fly ash are produced annually in the United States. About 34 million metric tons (37.5 million tons) are disposed of either onsite or in state-regulated disposal areas; 11 million metric tons (12.1 million tons) are reclaimed (Schroeder, R., DOT, 1994).

The leading use of fly ash is a partial replacement for portland cement in ready-mix concrete or as a component of the blended portland-pozzolan cement. Fly ash should meet the requirements of ASTM C618 specifications to be acceptable for use in cement or concrete.

Highway agencies are investigating the use of fly ash as a cement replacement in portland cement concrete, as an embankment material, in stabilizing base course applications, using fly ash in soil subgrade stabilization, and as a mineral filler in asphalt (Collins, R., 1994).

SULFUR BINDER

Sulfur has been used experimentally as a pavement binder in three different ways. In sulfur extended asphalt, a significant amount of the asphalt binder ordinarily used in pavement construction is replaced with elemental sulfur. Asphalt can dissolve from 14 to 19 percent by weight of sulphur. Additional sulphur is dispersed into the asphalt as micron sized particles (Gross, A., 1980).

Sand-asphalt- sulfur is a hot mix paving material made of sand, bitumen, and sulfur. A small portion of the sulfur, which represents 8 to 14 percent of the total mix by weight, is dissolved in the bitumen while the bulk of the molted sulfur acts as a structural agent (Gross, A., 1980).

CARPET FIBER WASTE

The carpet industry in the United States produces about 1 billion square meters of carpet per year. Of this, approximately 70 percent is used to replace existing carpet; this translates into 12 million metric tons (13.2 million tons) of carpet waste produced annually. Additional wastes produced by the carpet-making industry increase the total amount of waste fibers to an estimated 2 million metric tons (2.2 million tons). Several research efforts are addressing ways to include these waste fibers in both asphalt pavements and portland cement concrete (Gordon, G., 1993).

INCINERATOR ASH

The United States has approximately 140 thermal reduction facilities with the ability to burn at least 50 tons of solid waste per day (Collins, R., 1994). This Facilities burns approximately 26 million metric tons (28.6 million tons) per year of municipal solid waste (MSW), generating approximately 7.8 million metric tons (8.6 million tons) of incinerator ash or residue. It was estimated that about 10 percent of this ash is fly ash and the remainder is bottom ash (Collins, R., 1994).

Several studies have focused on using incinerator residue as a partial aggregate substitute in an asphaltic concrete base course. Results showed that this use resulted in performance equal to that obtained from conventional asphalt pavements. A recent research involved the use of combined MSW ash as an aggregate in stabilized and unstabilized bases and sub-bases (Passto, M., 1993).

ROOFING SHINGLE WASTE

It is estimated that between 8 and 12 million metric tons (8.8 and 13.2 million tons) of roofing shingles are manufactured each year in the United States. Since approximately 65 percent of these shingles is used for re-roofing, between 5 and 8 million metric tons (5.5 and 8.8 million tons) of old waste shingles are produced annually. In addition, between 400,000 and 900,000 metric tons (440,000 and 990,000 tons) of waste are produced annually from the manufacture of roofing shingles.

The Minnesota Department of Transportation completed a project in 1991 that used from 5 to 7 percent asphalt shingles by weight of mix. The shingles were ground to a uniform consistency resembling coffee grounds and were added to a drum mix plant as if they were recycled asphalt pavement. No construction problems were noted; further, there have been no problems reported regarding pavement performance.

The New Jersey Department of Transportation (NJDOT) experimented with an asphalt cold-patch material made from old roofing material. The resulting patch material showed only minor signs of distress after 22 months of service. In comparison, conventional cold-patch material generally lasts only three to six months.

PETROLEUM CONTAMINATED SOIL

It is estimated that there are approximately 0.8 to 1.2 million leaking under ground storage tanks (UST) in the United States. Most of these leaking tanks contain petroleum by-product such as gasoline and fuel oil. Leaking petroleum products from USTs contaminate soil and move to contaminate ground water (Meegoda, N., 1993). In 1984 US congress regulated leaking of USTs. Now almost all the fifty states require removal and proper disposal of petroleum contaminated soils (PCS) to prevent further contamination of ground water. Excavated PCS are disposed using one of two methods: Disposing in landfills, and disposed in highway industry as construction material.

Most states encourage the removal of tanks after 25 years of service. It is estimated that the removal of a leaking tank generate approximately 37 to 58 cubic meter of contaminated soil (Meegoda, N., 1993).

WOOD LIGNIN

One of the promising approach is to use wood lignins as a mean of reducing the dependence of the use of asphalt cement in paving operations. Lignin is a cementious material that binds fibers together in wood and lignin derivatives are a major by-product of the paper making industry. Aside from being one of the nation's more valuable renewable resources, lignin is one of the few materials which is expected to be in large supply. On the other hand, though there exist some natural occur in the future (Terrel, L., R.1980).

RICE HUSK ASH

Rice husk, an agricultural waste, contributes about 20 percent of the 300 million metric tons (330 million tons) of rice produced annually in the world. Due to environmental concerns and the need to save energy and resources, efforts has been made to burn the husks at a controlled temperature and atmosphere, and to utilize the ash so produced as a cementing material (Zhang, M., 1995).

Present investigations concentrates on the use of rice husk ash (RHA) as a cement replacement material in concrete. A recent research was conducted on an air-entrained concrete mixtures.

CHAT WASTES

The U.S. Environmental Protection Agency (EPA) is developing a regional policy on chat that will encourage its continued use as a resource in road construction. Chat is the waste rock that was left after the host rock was milled to free the lead and zinc ores. At one time, there were mountains of chat in the Tri-State Mining District. More than 80 percent of it has been shipped out, but millions and millions of tons remain (Joplin, M., 1995).

The EPA says one of the best uses for chat is an ingredient in concrete or asphalt. Another good use for chat is roadbed construction. When used in those ways, the lead is encapsulated and does not pose a risk as a potential pathway for human exposure.

PHOSPHOGYPSUM

The potential of phosphogypsum as a low-cost, high-strength substitute for limestone and other aggregates in road-building is encouraging aggregate deficient states along the Gulf Coast to test the controversial fertilizer byproduct in base and surface road mixtures (FIPR, 1989).

Fertilizer producers are under pressure from state and federal authorities to find new ways to dispose of the nearly 44 million tons of phosphogypsum they generate each year. Since landfills at plants in Florida and Louisiana have turned to academicians to find new ways to use the material. Highway construction is at the top of their list (Boyle, B., 1990)).

At the Florida Institute for Phosphate Research in Bartow, for example, researchers are testing the structural and environmental aspects of the material on two small stretches of county highway in central Florida. According to the institute's research team for chemical processes, they claimed that the industry participants know in reality there's no danger from radiation, but there is no proof of it (ENR, 6/18/87).

CHAPTER 4

DATA COLLECTION

INTRODUCTION

The measurements of the rate of consumption for the limestone as a natural resource, in the highway construction, is an essential requirement to the development of a prediction model as well as achieving a management approach for a sustainable construction. The structures of the model and its prediction of future consumption rates, though future needs of natural resources, are based upon historical consumption data.

DEFINITION OF EXISTING AVAILABLE CONSTRUCTION RESOURCES

Mineral resources to be considered will be limited to the use of the limestone in this research. Limestone underlies all of Florida, but in many parts of the state it is covered by sand and clay that forms the land surface. Limestone in Florida is divided into the following types; Key Largo limestone, Miami Oolite, Coquina, Ocala limestone, Suwannee limestone, and Tampa limestone.

Limestone is used on a wide scale in highway construction activities. For example, limestone is used in base, embankment, asphalt concrete aggregate, Portland cement concrete, and in the production of Portland cement.

HIGHWAY CONSTRUCTION RATES OF CONSUMPTION

Due to expanded highway paving operations, raw materials are systematically converted into waste, as by-product in the construction process. In most cases, depletion of these wastes is slower than nature can absorb resulting contamination, environmentally-regulated wastes, and subsequent costs. Highway construction typically consumes tremendous amounts of raw materials and produces huge quantities of wastes. Therefore, consumption should be optimized through models. To consider recycling as a part of the highway construction process, the types of material to be used and methods of implementation must be studied. In this research, sources of consumption rates of materials are from Florida Department of Transportation's construction contract history. The objective of this research step is to collect and analyze data that will assist in understanding the problems surrounding the responsible management of sustainable methods in handling construction and demolition waste (C&D). To identify past and current quantities used in highway construction, data were extracted from the Construction Contract History of Florida Department of Transportation for the last ten years. Some of the data was collected electronically from the FDOT main frame, and the rest were encountered as documented copies. Data obtained from FDOT is used in statistical analysis as well as models development in this research.

It was noted that about five percent of the number of activities for each year account form approximately forty percent of the total expenditure for that specific year as shown in Figure 4.1. As an example, activities that have the higher weight in highway construction are: asphalt concrete pavement, cement concrete pavement, embankment, limestone optional base, and other optional bases. Some of these items are considered in this research, while other items are left for future investigations.

The research data is obtained from highway construction projects throughout the state of Florida for the years 1986 to 1995. More than 750 activities selected from approximately the total 17 thousand activities for the available ten years data were chosen. These activities included in about 2000 contracts between Florida Department of Transportation and approximately 100 contractors in the last 10 years.

ASPHALT CONCRETE PAVEMENT

The asphalt concrete pavement which is known also as the flexible pavement is built up of several layers and consists of friction, structural, and base courses. The highway construction

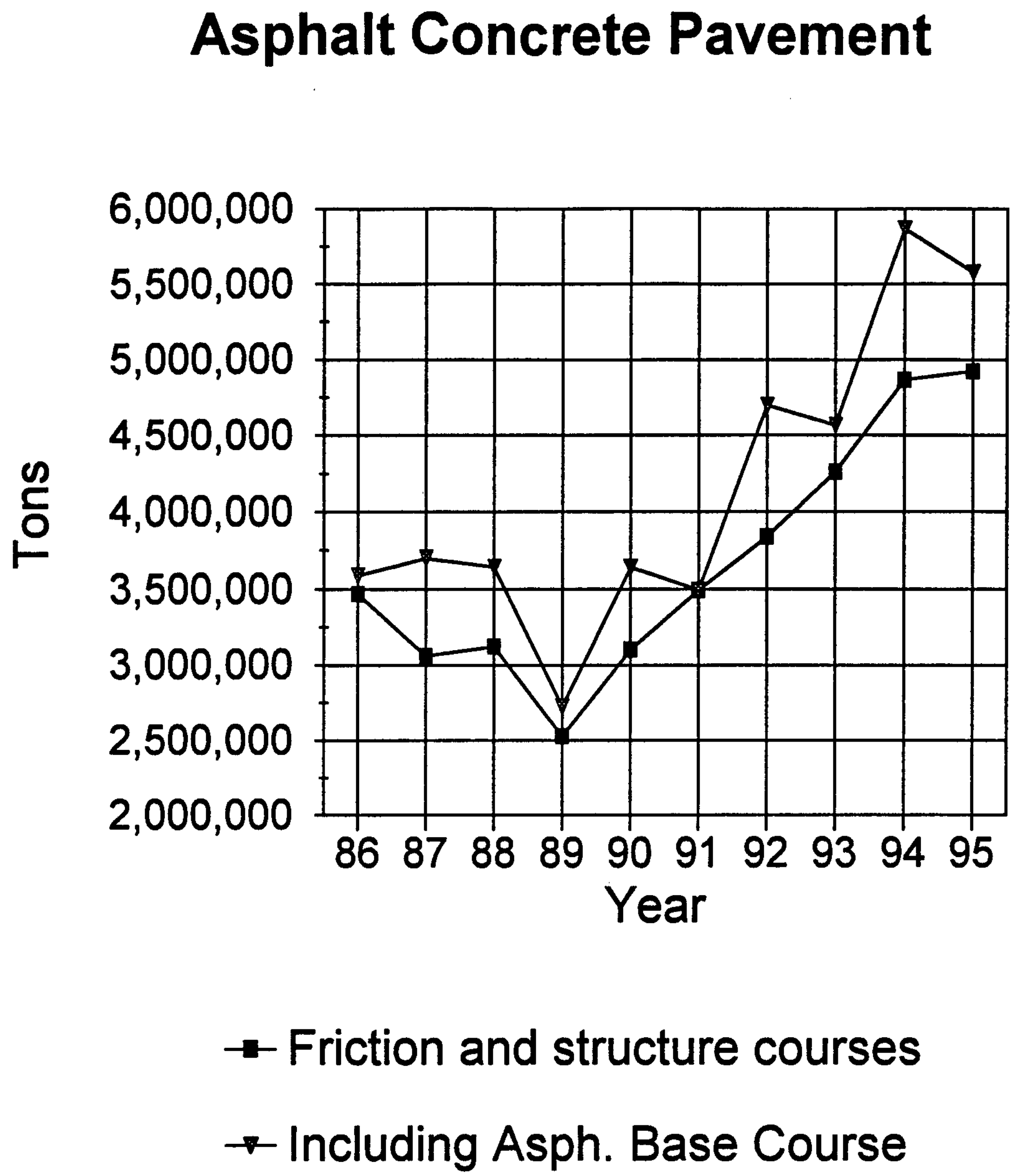

Figure 4.1 Quantities of asphalt concrete pavement.

industry consumes a tremendous amount of asphalt concrete every year. Different materials are used for asphalt concrete pavement, such as limestone, crushed rock, and gravel. These aggregates are attached together using a bituminous cement, generally asphaltic, which is the basis of the flexible pavement. Figure 4.1 illustrates the trend of asphalt concrete pavement quantities for the years 1986 to 1995. It was noted that the used quantities vary on a yearly bases depending on the highway construction activities; i.e., building new roads, maintenance for old roads, interstate and turnpike activities.

PORTLAND CEMENT CONCRETE PAVEMENT

Portland cement concrete pavement is also known as rigid pavement. Thickness of rigid highway pavements range between 15 to 25 centimeters (6 to 10 inches). The quantities of concrete were collected from 123 different jobs within Florida. These quantities were converted from cubic yards to tons to gather limestone quantities that involved in Portland cement concrete. Limestone work as course aggregate in concrete, as course aggregate in composition of Portland cement concrete, and in the production of Portland cement. Figure 4.2 illustrates the Portland cement concrete pavement used by the FDOT in the years 1986 to 1995.

PORTLAND CEMENT CONCRETE

Portland cement concrete is used in a wide scale in highway construction. Portland cement concrete is used in substructures, end walls, bulkheads, culverts, and the manufacturing of concrete pipelines. All these quantities are added together to calculate the amount of Portland cement concrete used in the available 10 years period. Then, limestone quantities were obtained. In order to calculate concrete quantities in pipelines, all lengths of pipelines were collected, multiplied by the circumference and pipe thickness to obtain the concrete volume. Data for Portland cement concrete were obtained through 4596 different jobs, and the pipelines data were collected through 6540 different job within Florida. The concrete quantities are shown in Figures 4.3 and 4.4.

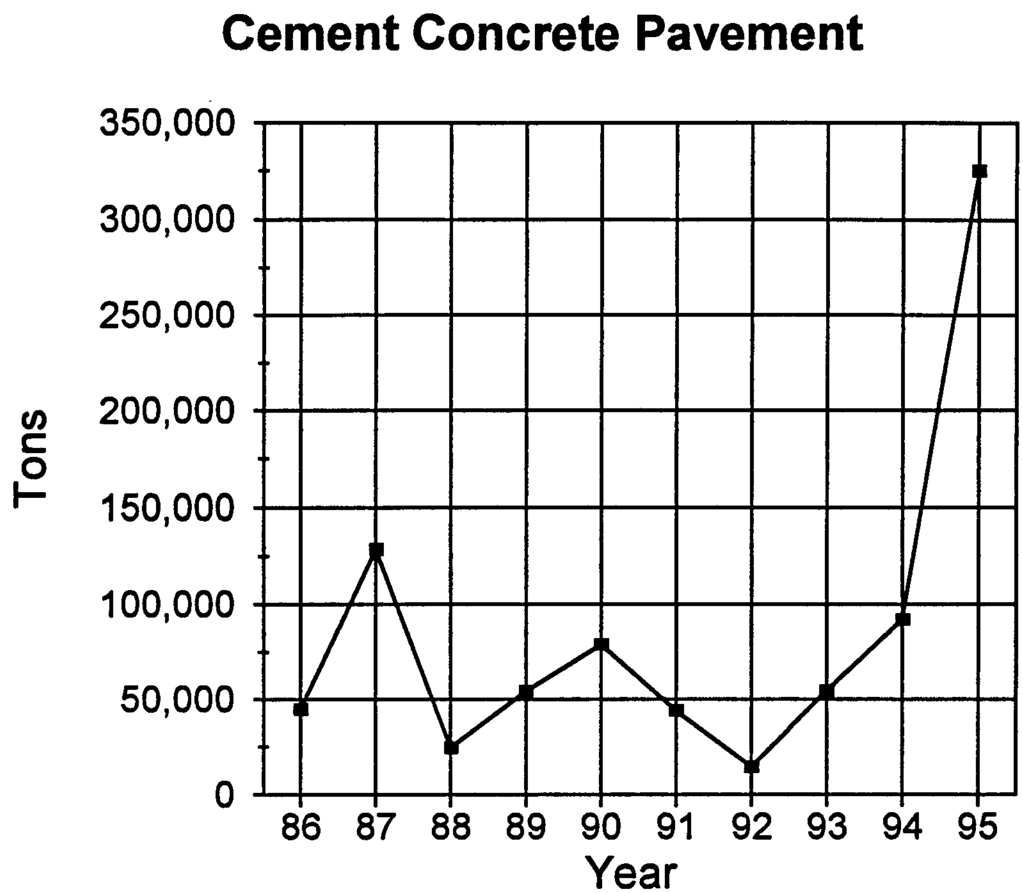

Figure 4.2 Quantities for Portland cement concrete pavement.

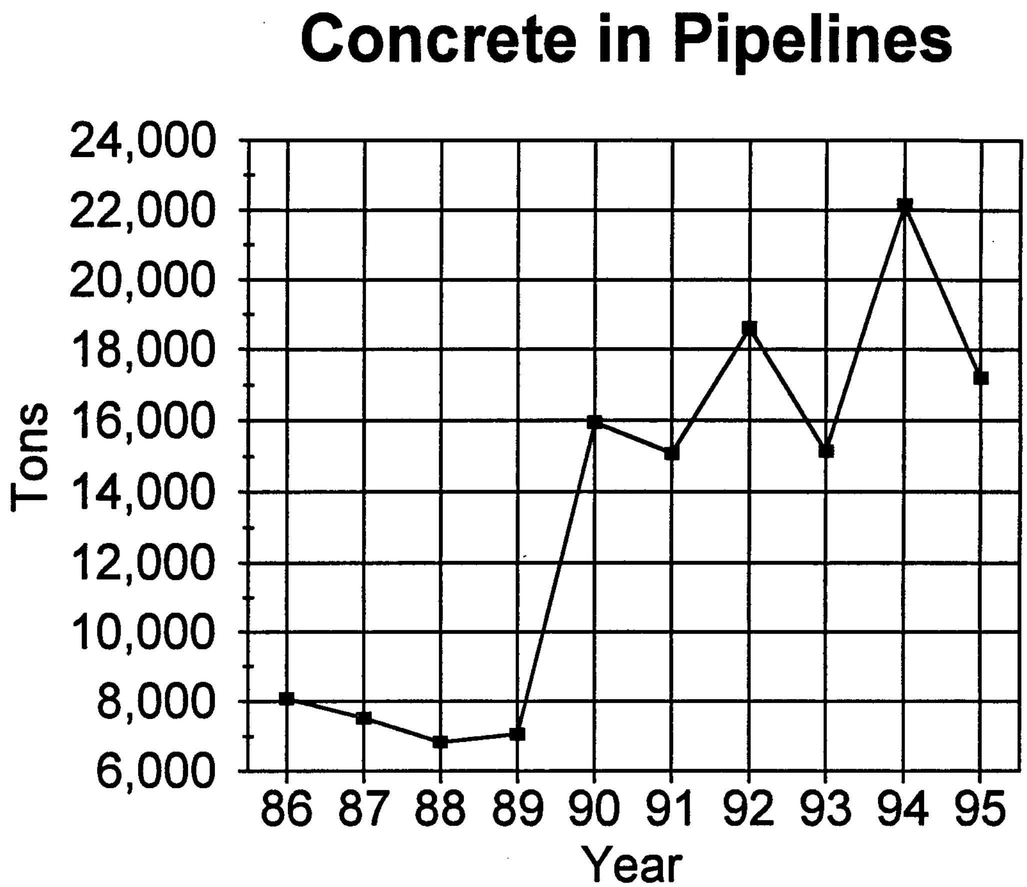

Figure 4.3 Concrete quantities in pipelines.

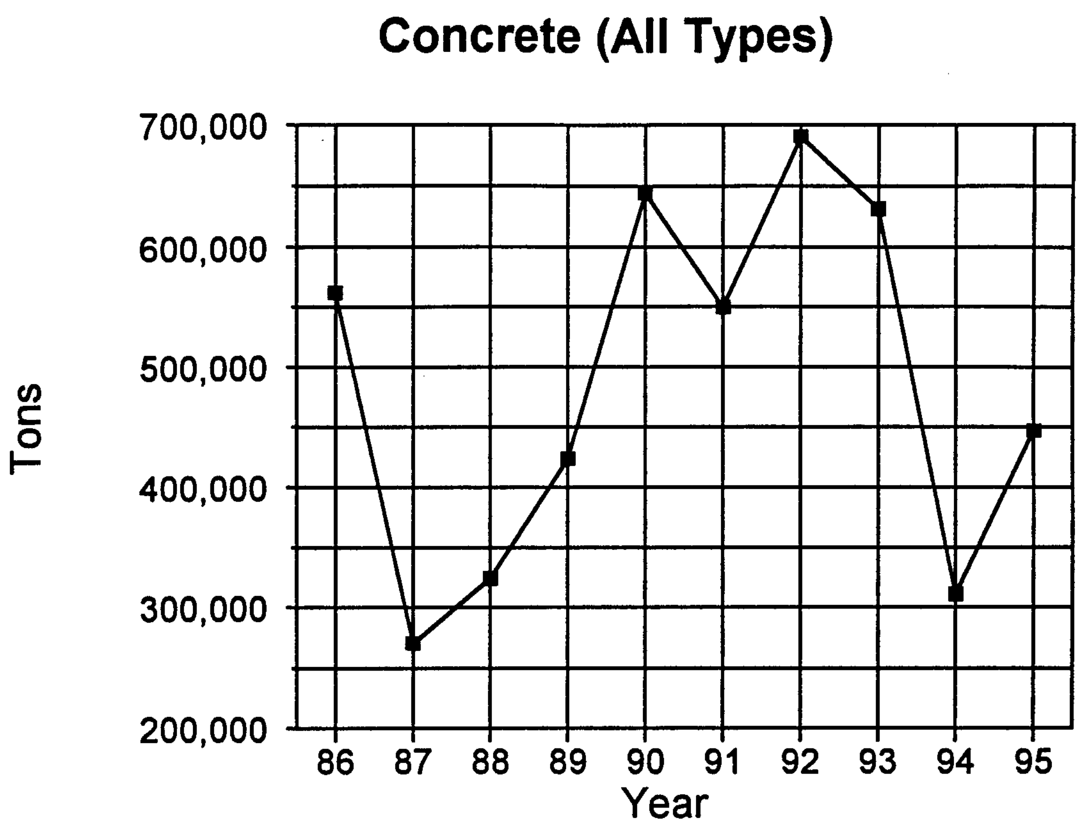

Figure 4.4 Portland cement concrete quantities.

All the previous calculated limestone quantities are added to obtain the total consumption of this natural resource. Total consumed limestone quantities for the years 1986 to 1995 are illustrated in Figure 4.5

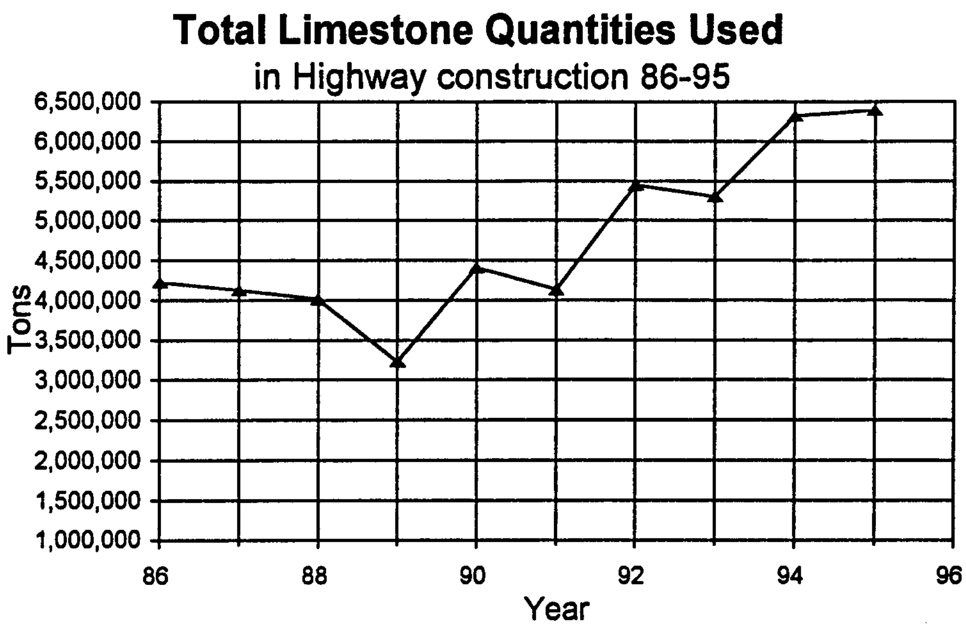

Figure 4.5 Total limestone quantities used in highway construction by the FDOT.

CHAPTER 5

CONSTRUCTION RECYCLING EFFORTS

INTRODUCTION

For the purpose of recycling and waste management evaluations, all the Departments of Transportation (DOTs) within the U.S. were contacted to obtain their current practice: which materials are being used in their construction programs, the effect of adding waste materials to overall costs, and the effect of adding wastes to engineering performance. The obtained data will assist in understanding the potential of using waste materials recycling in reducing the consumption of non-renewable resources, and will provide a feed back in the model development. Surveys are shown in Appendix (A).

ANALYSIS OF DATA OBTAINED BY QUESTIONNAIRE

A questionnaire was sent to all state highway agencies within the United States. Thirty five responses were received. The purpose of the survey was to obtain information concerning the various states' practice in recycling. Information were obtained about the type of waste materials or by-product they are using, in which pavement course types, and their evaluations of the use of these additives in both economical and engineering performance aspects.

The result of using different types of waste materials and their pavement courses are illustrated in Table 5.1 and is summarized in Figure 5.1. The percentage of highway agencies using waste materials in different pavement courses is presented in Figure 5.2. The result of the survey of state highway agencies (SHA) for the economical evaluation is shown in Table 5.2. For the engineering performance, the SHA evaluation is shown in Table 5.3.

Table 5.1 Number of uses of waste materials and corresponding pavement courses by highway agencies.

Waste Material	States Responded	Asphaltic Con Pav.		Portl. Cem. Pavement	Pavement Base	Subgrade
		Friction course	Structural course			
Reclaimed Asphalt Concrete	35	11	32	1	23	6
Fly Ash	31	3	3	28	9	10
Scrap Tires	18	7	9	-	-	5
Blast Furnace Slag	15	7	7	9	8	5
Waste Glass	10	1	4	-	5	5
Steel Slag	9	7	1	1	2	2
Bottom Ash	7	2	1	1	4	3
Mining Waste	7	4	4	2	2	3
Building Rubble	6	-	-	-	3	4
Roof Shingles	6	3	5	-	-	-
Plastics	3	-	3	-	-	-
Rec P C	3	-	2	3	2	-
Used Motor Oil	2	2	1	-	-	-
Combustion Ash	1	-	-	-	-	1
Waste Paper	1	-	-	-	1	-
Others	1	-	-	-	-	1

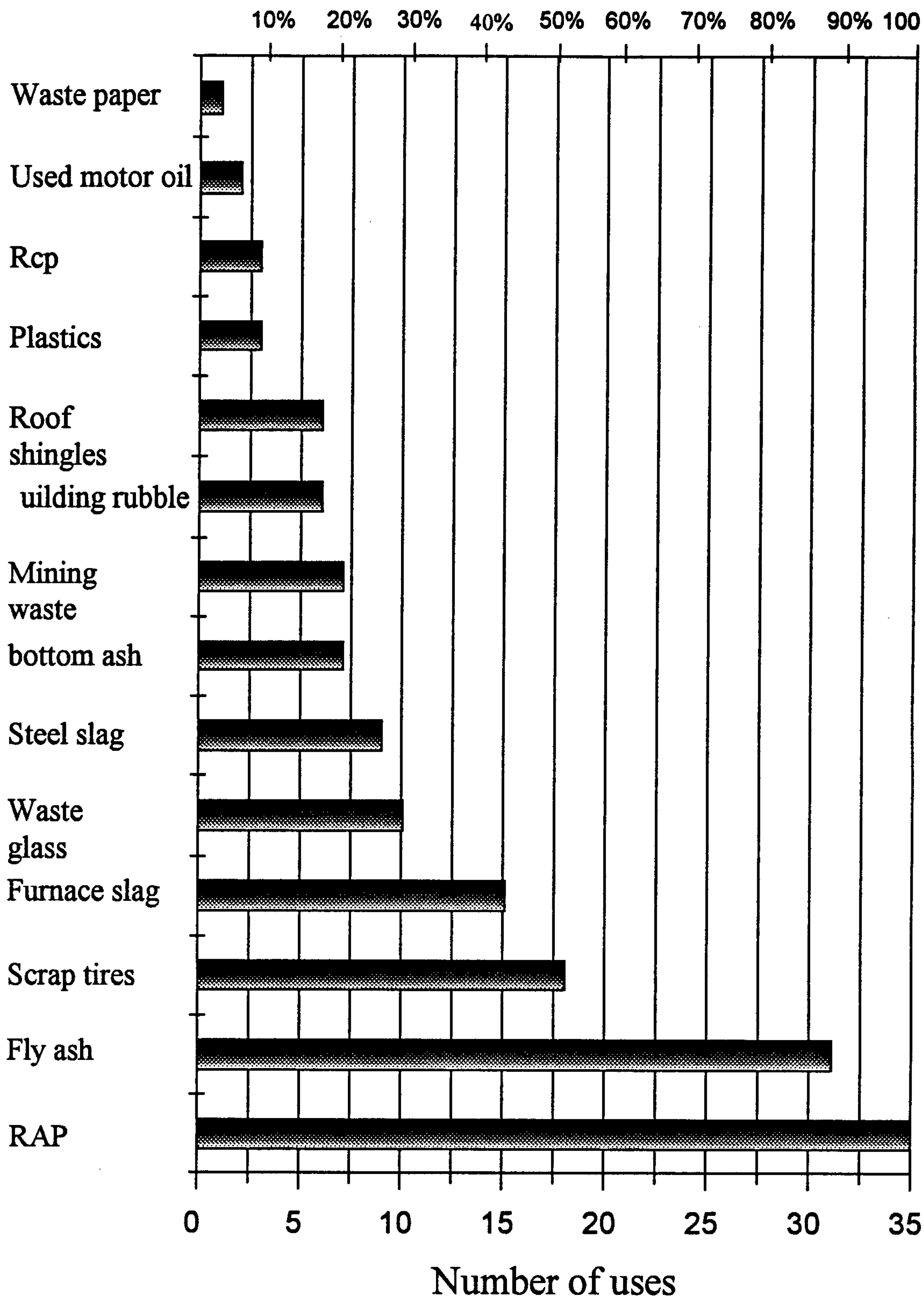

Figure 5.1 Number of uses for waste materials by states

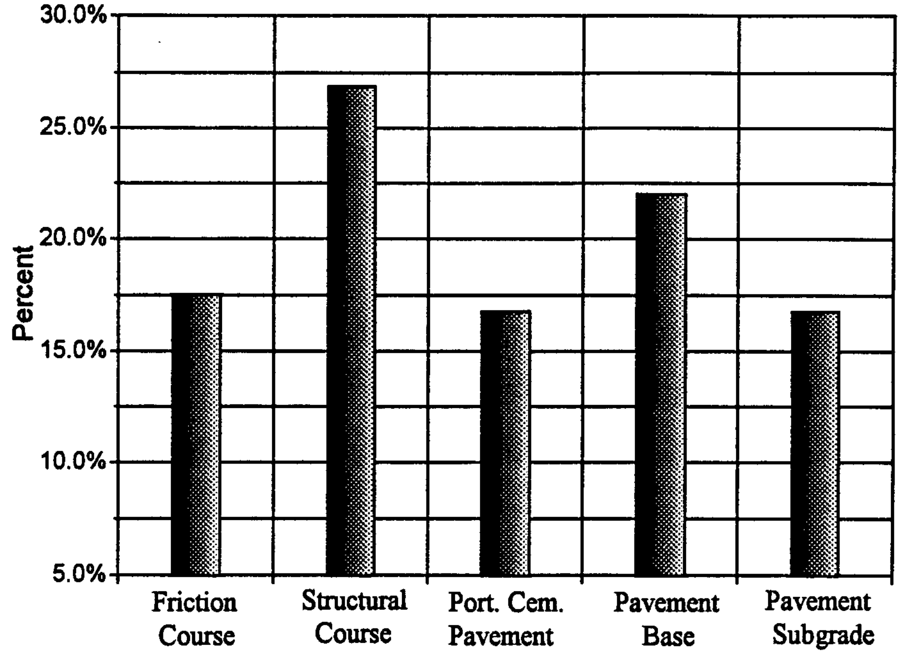

Figure 5.2 Percentages of highway agencies using waste material in different pavement courses.

Table 5.2 Economical evaluation for waste materials.

Waste Material	States Responded	More cost	Equal cost	Less cost
Reclaimed Asphalt Concrete	35	-	6	28
Fly Ash	31	2	9	20
Scrap Tires	18	17	-	-
Blast Furnace Slag	15	1	11	3
Waste Glass	10	4	4	2
Steel Slag	9	3	4	2
Bottom Ash	7	2	3	1
Mining Waste	7	1	3	3
Building Rubble	6	-	1	5
Roof Shingles	6	-	2	4
Plastics	3	2	-	1
Rec P C	3	-	1	2
Used Motor Oil	2	-	-	2
Combustion Ash	1	-	-	1
Waste Paper	1	-	1	-
Others	1	1	-	-

Table 5.3 Engineering Performance evaluation for waste materials.

Waste Material	States Responded	Better	Equal	Worse
Reclaimed Asphalt Concrete	35	1	32	1
Fly Ash	31	10	19	2
Scrap Tires	18	2	8	7
Blast Furnace Slag	15	4	9	1
Waste Glass	10	-	10	-
Steel Slag	9	5	2	2
Bottom Ash	7	-	5	1
Mining Waste	7	2	4	1
Building Rubble	6	-	5	1
Roof Shingles	6	-	6	-
Plastics	3	1	1	-
Rec P C	3	-	3	-
Used Motor Oil	2	-	2	-
Combustion Ash	1	-	-	1
Waste Paper	1	-	-	1
Others	1	-	-	1

RANKING OF USED WASTES AND BY-PRODUCTS

A ranking of wastes and by-products of greatest interest for reuse and recycling in transportation construction is conducted based on results found in the survey of highway agencies (SHA). The overall economic and technical feasibility of these wastes was based on number of uses, cost evaluations and savings through dumping charges and/or reduced landfill fees, transportation costs, and engineering performance, when competing with conventional materials.

The ranking was performed by assigning certain values for different categorical evaluations. In cost category, the evaluation of a waste material of being more cost is assigned the value of 1, being equal and less costs, are assigned the values of 2 and 3, respectively. From the technical performance point of view, the highest value of 3 is given to the better performance evaluation, 2 is given to the equal performance, and the number 1 is given when the performance of the additive is less than of the conventional material.

To find the rank of the wastes and by-products, the total score for each waste material should be calculated based on the highway agencies evaluations. Each cell containing number of voted states for each different categorical evaluation. Each of these number is multiplied by its assigned score, i.e., by 1 for less cost, 2 for equal and 3 for more cost. Each cell enclosing the number of voted states for the engineering performance category is multiplied by the assigned number; i.e., 3 for better, 2 for equal, and 1 for worse performance. All these figures are added together on a row basis, for each specific waste material, then added to the number of states responded for that specific material. Then, the total score for each row of the matrix is obtained. These total scores are ranked from highest to lowest. The waste material that accumulated the highest total score is ranked number one, and so on, until reaching the lowest total score which was assigned to rank number 16. The ranking for wastes extracted from the SHA is summarized in Table 5.4. It was noted that the reclaimed asphalt

Table 5.4 Ranking of wastes and by-products according to highway agencies survey.

Waste Material	States Responded	More cost	Equal cost	Less cost	Better	Equal	Worse	Total Score	**Rank**
Reclaimed Asphalt Concrete	35		12	84	3	64	1	199	**1**
Fly Ash	31	2	18	60	30	38	2	181	**2**
Scrap Tires	18	17			6	16	7	64	**4**
Blast Furnace Slag	15	1	22	9	12	18	1	78	**3**
Waste Glass	10	4	8	6		20		48	**5**
Steel Slag	9	3	8	6	15	4	2	47	**6**
Bottom Ash	7	2	6	3		10	1	29	**10**
Mining Waste	7	1	6	9	6	8	1	38	**7**
Building Rubble	6		2	15		10	1	34	**8**
Roof Shingles	6		4	12		12		34	**9**
Plastics	3	2		3	3	2		13	**12**
Rec P C	3		2	6		6		17	**11**
Used Motor Oil	2			6		4		12	**13**
Combustion Ash	1			3			1	5	**14**
Waste Paper	1		2				1	4	**15**
Others	1	1					1	3	**16**

concrete and the fly ash earned the ranks one and two, and their total scores are very close values. Meanwhile, the blast furnace slag was ranked number 3, but their was a big drop in its total score.

CHAPTER 6

MODELING AND FORECASTING PROCEDURES

INTRODUCTION

Data collection, and data analysis were presented in the previous chapter. These information and techniques are the knowledge needed to construct the model which can simulate the past and current construction materials consumption rates and allow for future forecasting.

This chapter will cover the model development method including influencing factors on the rate of consumption, and a simulation for the past and current FDOT expenditure. This simulation will allow the expenditure projection, and management approach for achieving a sustainable program for highway constructions.

SELECTION OF VARIABLES

The general problem to be discussed in this section is as follows; we have one dependent variable Y, which is consumed lime stone quantities, and a set of k independent variables X_1, X_2, ..., X_k. We want to determine the best fitting regression model for describing the relationship the Y and the X's which employs the best subset of these k independent variables.

To construct the consumption model, the dependent and independent variables should be defined. These dependent variable are used in developing to calculate to forecast the dependent variable, which is one objectives of this research, is the consumed materials quantities in highway construction program. This dependent variable is limited to the consumed limestone quantities. Some of the independent variables were thought to have influence on the highway construction and the decision making for development. These independent variables are defined as: population, number of vehicles, roads miles, annual miles traveled by residents, oil prices, number of housing, and taxes. These variables were studied and analyzed. The past data was collected from the Florida Statistical Abstract (FSA, series)for the years 1980 to 1995 for the purpose of the statistical analysis.

POPULATION

Florida is the most rapidly growing states in the United States (Smith, S., 1996). Population is one of the significant factors which affect the highway construction trend in Florida. The past data for population was collected from the Florida Statistical Abstract (FSA, Series) for the years 1980 until 1995. These data was used to construct the model to forecast the future population in Florida which will be used in the consumption rate model.

The regression analysis was used to construct the population model. Several modeling methods were used. The population model was validated by the prediction conducted by Eileen Kalb and Stanley Smith (Kalb, E., 1995) and (Smith, S., 1994). The population model showed a good projection in the validation phase. The population data is shown in Table 6.1, the model to forecast the population is shown in Table 6.2. Figure 6.1 illustrates the observed and the forecasted population.

HOUSEHOLDS

Average household size can change dramatically over time. The United States Bureau of the Census (BOS, 1990) estimated that the average house hold size was 2.76 in the 1980 and 2.63 in the 1990. Average house hold size remained relatively constant since the 1990.

Average household size is a good representative of number of housing. Building new communities, which is directly related to the number of population, requires building of new houses. These new houses require new services and new roads.

The number of households was modeled as a function of old data, population, and time. This household model is used to construct the consumption rate which will predict the future needs of raw materials as well as to forecast for the future expenditures. Table 6.3 illustrates the number of households, Table 6.4 presents the selected model to forecast the future households in Florida, and Figure 6.2 presents a plot for the observed and the modeled data.

Table 6.1 Observed population in Florida.

Year	Observed	Model
1980	9,747,200	*9,684,035*
1981	10,106,000	*10,049,055*
1982	10,375,300	*10,396,597*
1983	10,591,700	*10,734,669*
1984	10,982,500	*11,050,532*
1985	11,322,300	*11,364,319*
1986	11,654,100	*11,663,665*
1987	12,000,200	*11,958,932*
1988	12,327,600	*12,249,418*
1989	12,650,900	*12,534,420*
1990	12,938,100	*12,813,233*
1991	13,196,000	*13,098,247*
1992	13,242,400	*13,376,219*
1993	13,608,600	*13,646,436*
1994	13,878,900	*13,908,197*
1995	14,149,317	*14,174,979*

Table 6.2 Model to forecast the population in Florida using logarithmic transformation.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	0.21283	0.10642	2044.701	0.0001
Error	13	0.00068	0.00005		
C Total	15	0.21351			

Root MSE	0.00721	R-square	0.9968
Dep Mean	16.29783	Adj R-sq	0.9963
C.V.	0.04426		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	Prob > |T|
INTERCEP	1	16.039407	0.00847131	0.0001
TIME	1	0.109113	0.01365975	0.0001
TIME2	1	-0.062431	0.01012281	0.0001

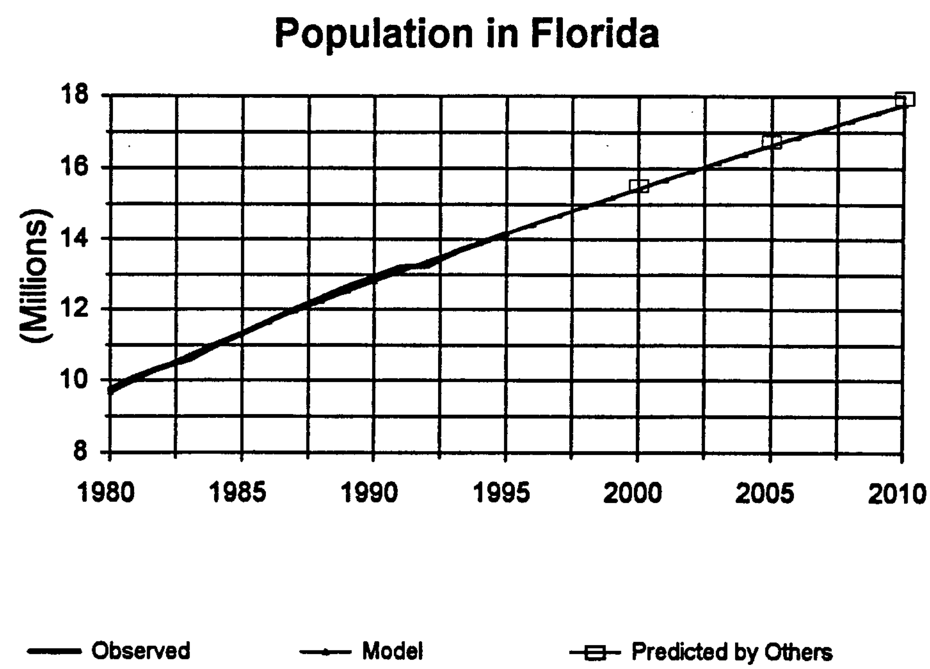

Figure 6.1 Observed and modeled population in Florida.

Table 6.3 Observed and modeled households in Florida.

Year	Observed	Model
80	3,744,254	*3,680,453*
81	3,883,771	*3,867,772*
82	4,023,287	*4,040,593*
83	4,135,881	*4,205,556*
84	4,287,718	*4,352,098*
85	4,448,535	*4,496,917*
86	4,612,822	*4,629,758*
87	4,789,135	*4,759,214*
88	4,966,487	*4,884,704*
89	5,145,115	*5,005,645*
90	5,134,869	*5,121,451*
91	5,257,518	*5,242,403*
92	5,348,609	*5,357,512*
93	5,428,896	*5,466,188*
94	5,521,943	*5,567,850*

Table 6.4 A presentation for number of households in Florida

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	4.9525789E12	2.4762895E12	657.563	0.0001
Error	12	45190330895	3765860907.9		
C Total	14	4.9977693E12			

Root MSE	61366.61069	R-square	0.9910
Dep Mean	4715256.00000	Adj R-sq	0.9895
C.V.	1.30145		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter = 0	Prob > |T|
INTERCEP	1	-4237343	2683166.0600	-1.579	0.1403
POPUL	1	0.829538	0.28200399	2.942	0.0123
TIME	1	-115479	84400.547267	-1.368	

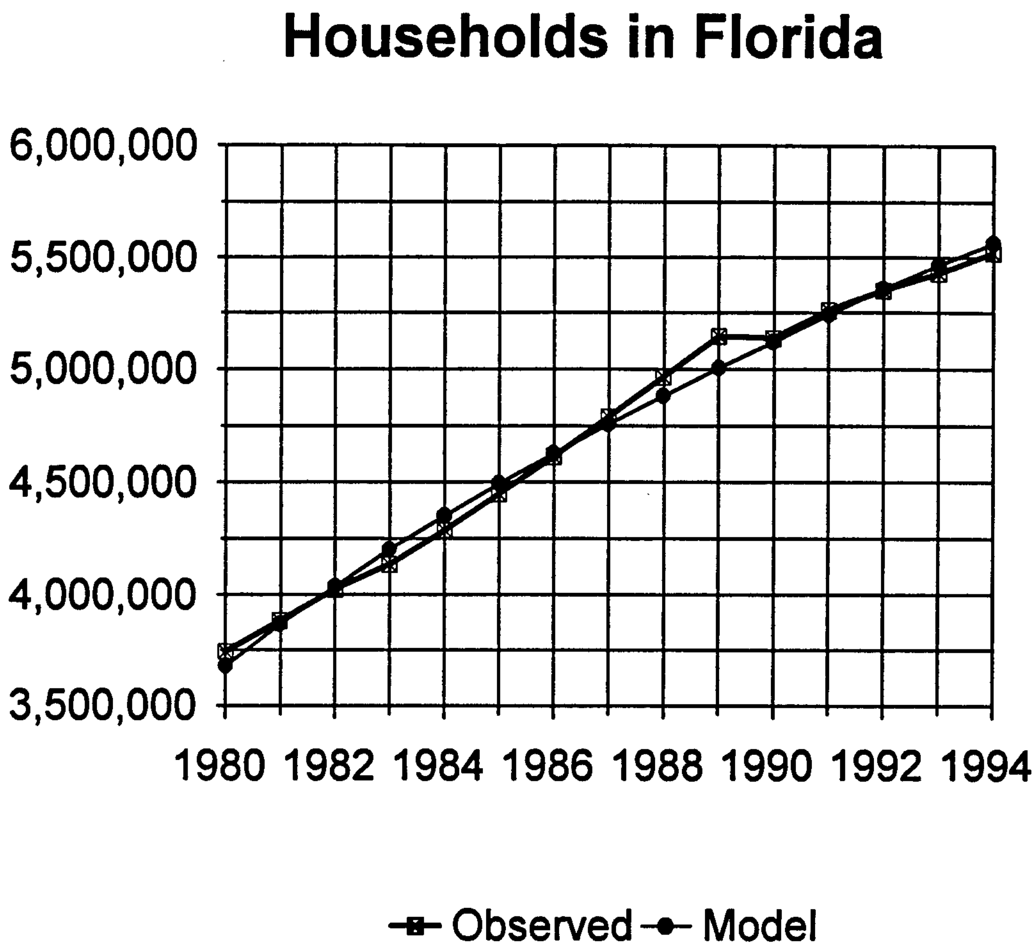

Figure 6.2 Observed and modeled households in Florida.

TAXES

The taxes in Florida is directly connected to the population. According to the Florida Statistical Abstract (FSA, series), there was a substantial increase in the taxes between 1980 and 1994. Taxes increased about 2.7 times in a 14 years period. Taxes are used to support the building of the infrastructure including highway constructions. The taxes in Florida is one of the considered variables to affect available funds and budgets used to construct and maintain highways and roads.

Based on the available past data, the taxes in Florida was modeled as a function of both old data, population and time. This taxes model is used as a independent variable in the consumption rate which will predict the future needs of raw materials, and to forecast for the future expenditures. Table 6.5 illustrates the taxes dada, Table 6.6 presents the selected model to forecast the future taxes in Florida, and Figure 6.3 presents a plot for the observed and the modeled data.

ROAD MILES

There is a significant correlation between the road miles and the population. Road miles were extracted from the Florida Statistical Abstract (FSA, series). Road miles has an influence on the FDOT construction activities. It was noted that the road miles are in increase due to the rapid grow of Florida. This expansion is translated to more road construction and maintenance activities.

Based on the available past data, the road miles in Florida was modeled as a function of both old data, population and time. This taxes model is used as a independent variable in the consumption rate model. Table 6.7 illustrates the observed road miles data, Table 6.8 presents the selected model to forecast the future miles of roads, and Figure 6.4 presents a plot for the observed and the modeled data.

Table 6.5 Taxes in Florida

Year	Observed (Millions)	Model (Millions)
80	$10,852	*$8,963*
81	$9,335	*$10,938*
82	$12,573	*$12,794*
83	$13,365	*$14,579*
84	$15,842	*$16,242*
85	$17,310	*$17,877*
86	$20,901	*$19,431*
87	$20,737	*$20,952*
88	$23,849	*$22,438*
89	$25,035	*$23,888*
90	$25,643	*$25,300*
91	$25,504	*$26,727*
92	$27,732	*$28,115*
93	$29,539	*$29,459*

Table 6.6 Model for taxes in Florida

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	3	561932047.59	187310682.53	139.655	0.0001
Error	10	13412427.629	1341242.7629		
C Total	13	575344475.21			

Root MSE	1158.12036	R-square	0.9767
Dep Mean	19872.64286	Adj R-sq	0.9697
C.V.	5.82771		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter = 0	Prob > |T|
INTERCEP	1	-33678	36185.367808	-0.931	0.3739
TIME	1	779.083583	2467.6652110	0.316	0.7587
POPUL	1	0.004354	0.00389184	1.119	0.2894
TIME2	1	-302.828398	924.76882055	-0.327	0.7501

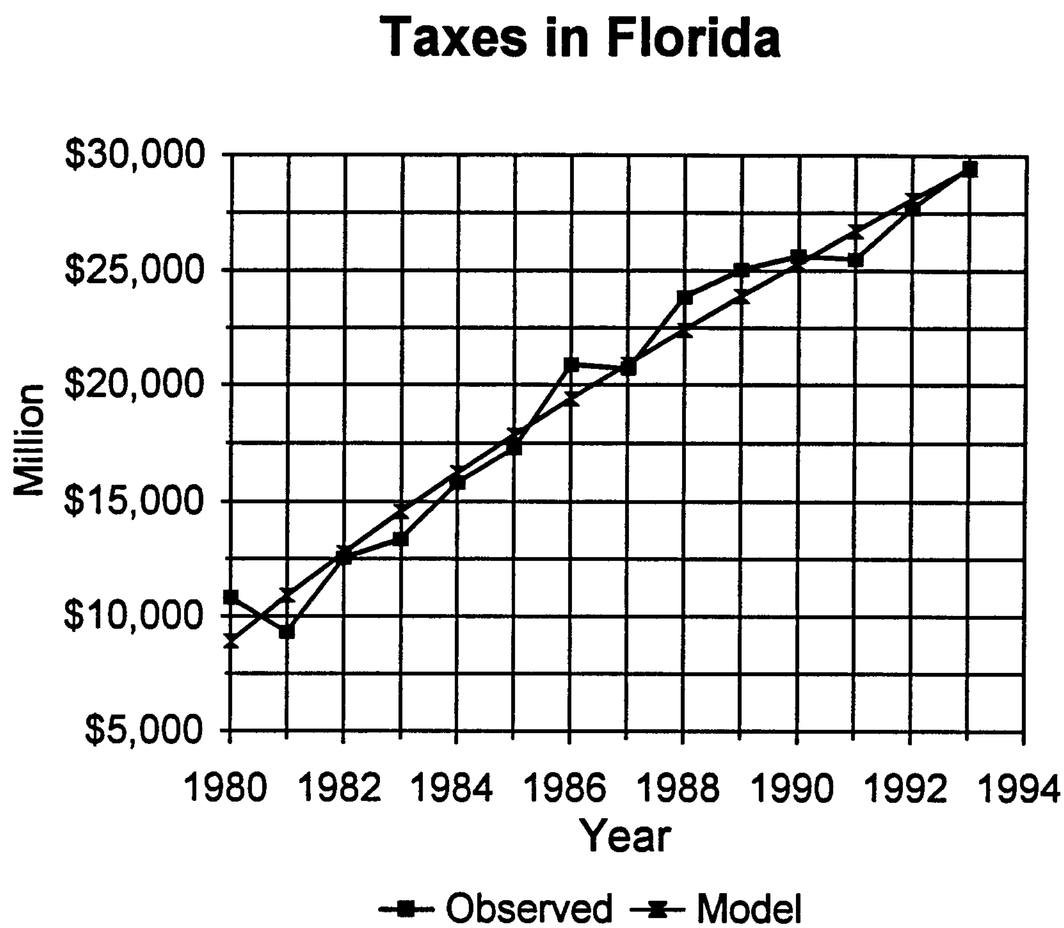

Figure 6.3 Observed and modeled taxes in Florida.

Table 6.7 Road miles in Florida

Year	Observed	Model
1980	93,582	91,699
1981	97,186	93,388
1982	93,797	95,039
1983	93,074	96,668
1984	98,984	98,249
1985	99,071	99,824
1986	99,074	101,368
1987	100,423	102,902
1988	104,589	104,426
1989	107,589	105,937
1990	108,095	107,435
1991	109,374	108,947
1992	110,640	110,443
1993	112,808	111,922
1994	113,478	113,382

Table 6.8 Model for road miles in Florida.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	668155191.87	334077595.94	139.655	0.0001
Error	12	45014093.058	3751174.4215		
C Total	14	713169284.93			

Root MSE	1936.79488	R-square	0.9369
Dep Mean	102784.26667	Adj R-sq	0.9264
C.V.	1.88433		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter = 0	Prob > |T|
INTERCEP	1	69312	48709.318267	1.423	0.1802
POPUL	1	0.002221	0.00511999	0.434	0.6722
TIME	1	878.654639	1538.3054868	0.571	0.5784

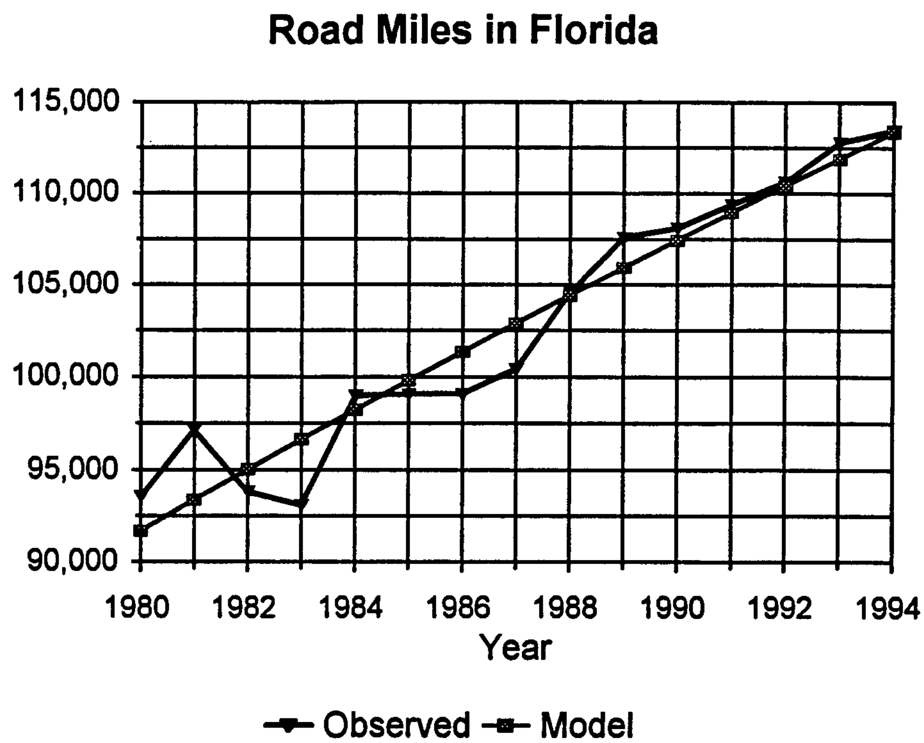

Figure 6.4 Road miles in Florida

CONSUMPTION MODEL DEVELOPMENT

The consumption model was developed with the assistance of the SAS PROC REG procedure. This procedure produces advanced regression operation.

Preliminary model selection was made on the basis of engaging the previous discussed variables to obtain the final model. This selection was based on taking the best value of the coefficient of determination, R-Squared, into consideration as well as consistent future forecasting quantities.

The development of the quantities model was based on the past collected data. For the purpose of model validation and verification, not all the observed data was applied. The quantities for seven years out of the available ten years data were used in the model development, while the rest three years data were excluded for the purpose of model verification and validation.

Table 6.9 is a summary of some attempts to achieve the best fit. This model is a simulation for the past data, and capable predict the future consumed limestone needed to support the FDOT construction activities. It was noted that the model that has the highest confidence to simulate the past data is model number 9 with R-Squared values of 0.9512. The chosen model represents the limestone quantities as a function of population, taxes, households, road miles and time.

The final step in the regression and the model development was to calculate the parameter estimates for the final model variables. Table 6.10 represents the regression analysis for the final model that can predict for the future consumption. Figure 6.5 presents the final model to simulate the past, present, and forecast the future limestone quantities that will be used in highway construction.

FORECASTING FOR FUTURE EXPENDITURES

The total expenditure for FDOT is around one billion dollar. Analyzing the past expenditures and material quantities will support the prediction for future sustainability.

To forecast for the future expenditures, the SAS PROC REG procedure was used as in the quantities model. The development of the a model to forecast the future expenditures was based on the past collected data, as well as independent variables such as the population, taxes, road miles, and time variables.

The calculation of the parameter estimates for the final model variables is the final step in the regression and the model development. Table 6.11 is a presentation for some trials to achieve the best data fit. Table 6.12 is the statistical analysis output for the final model that can predict the future expenditures. Figure 6.6 present the final model to simulate the past, present, and forecast the future expenditures in highway construction. The highest R^2 obtained was 0.9953 for model number 6. The final model is having the population, roads miles, taxes, and time as independent variables.

Table 6.9 Listing of some models used in the quantities model.

Model Number	Number of Parameters	Parameters	Coefficient of Determination R^2
1	1	Population	0.1294
2	1	Pop. Variation	0.6835
3	2	Expenditure Time	0.3370
4	2	Population Time	0.7591
5	2	Pop. Variation Time	0.7626
6	3	Population Roads Time	0.8413
7	4	Population Roads Tax Time	0.8413
8	5	Population Roads Tax Miles Driven Time	0.8512
9	5	Population Roads Tax Houses Time	0.9512

Table 6.10 Final model for limestone quantities.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	5	2.4700193E12	494003863167	3.896	0.3660
Error	1	126794156035	126794156035		
C Total	6	2.5968135E12			

Root MSE	356081.67046	R-square	0.9512
Dep Mean	4230557.14286	Adj R-sq	0.7070
C.V.	8.41690		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter = 0	Prob >|T|
INTERCEP	1	55981549	18728858.409	2.989	0.2055
POPUL	1	-2.766358	2.11377311	-1.309	0.4154
ROAD	1	188.033129	325.98126275	0.577	0.6669
TAX	1	0.000301	0.00028004	1.075	0.4770
HOUS	1	-9.928699	6.61785013	1.500	0.3743
TIME	1	1435939	476668.07970	3.012	0.2040

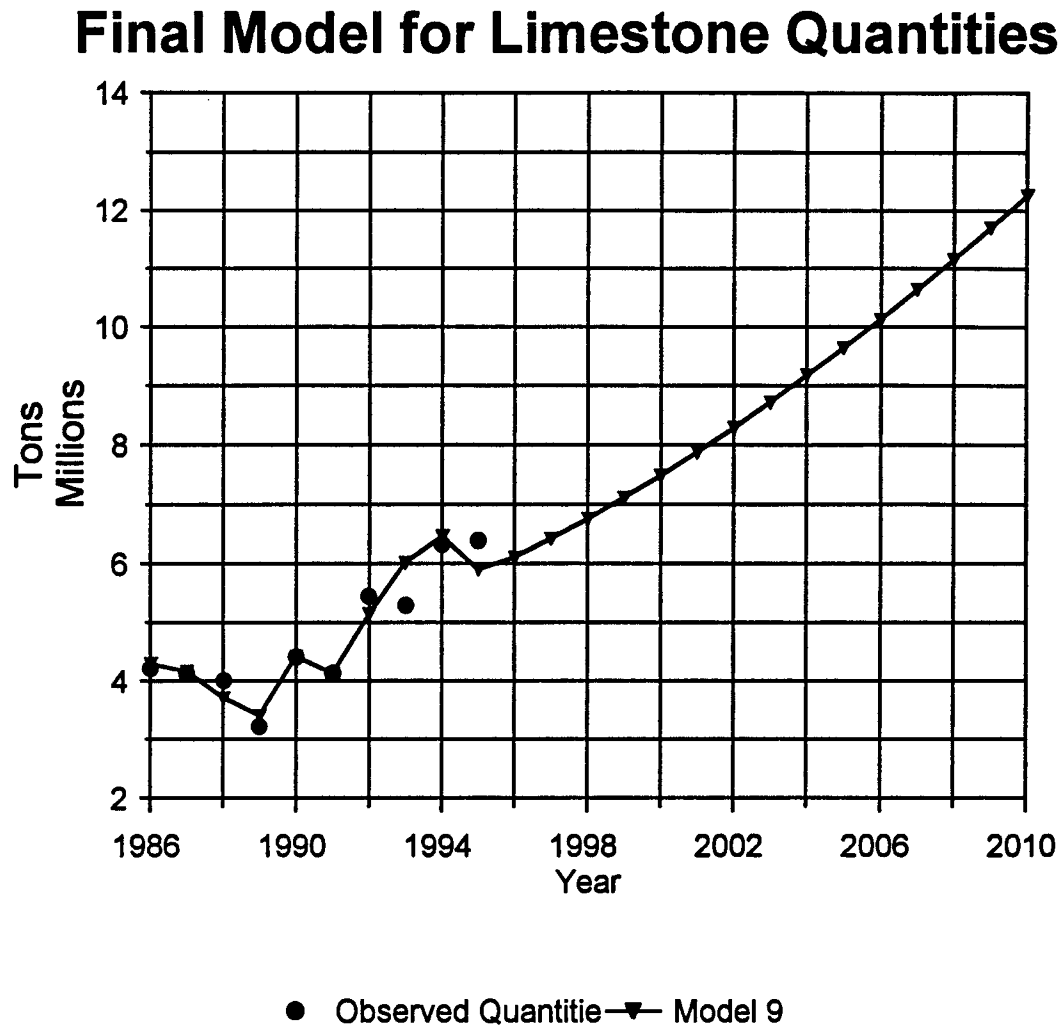

Figure 6.5 Final model represents the future consumed limestone quantities.

Table 6.11 Listing of some models used in the Expenditures model.

Model Number	Number of Parameters	Parameters	Coefficient of Determination R^2
1	1	Population	0.8365
2	2	Pop. Variation	0.1969
3	3	Population Time	0.8548
4	4	Pop. Variation Time	0.8684
5	4	Population Roads Time	0.8723
6	4	Population Roads Taxes Time	0.9953
7	4	Population Roads Taxes Vehicles Number	0.9847
8	5	Population Roads Taxes Vehicles Number Houses	0.9848
9	6	Population Roads Taxes Vehicles Number Houses Miles Driven	0.8951

Table 6.12 Statistical analysis for the final expenditures model.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	4	3.4636529E17	8.6591323E16	158.189	0.0008
Error	3	1.6421791E15	5.4739303E14		
C Total	7	3.4800747E17			

Root MSE	23396431.9870	R-square	0.9953
Dep Mean	654985440.250	Adj R-sq	0.9890
C.V.	3.57205		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter = 0	Prob >|T|
INTERCEP	1	5691347945	1191912903.9	4.775	0.0175
POPUL	1	231.182407	137.19243217	1.685	0.1906
ROAD	1	-65613	11353.328087	-5.779	0.0103
TAX	1	-0.081658	0.01153018	-6.909	0.0062
TIME	1	229257136	31165291.066	7.356	0.0052

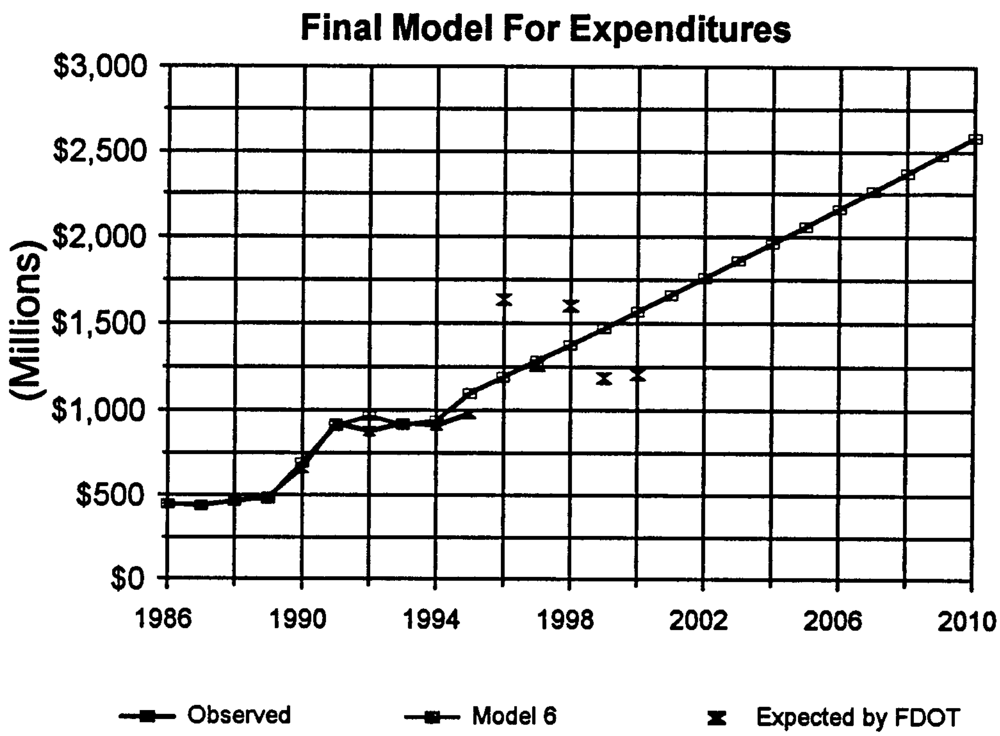

Figure 6.6 Expected future expenditure by the FDOT.

CHAPTER 7

CONCLUSIONS

Managing the supply and demand of natural resources while waste reduction is the key factor for a successful sustainable program.

RECYCLING AND SAVINGS

Technological advances, economic hard times and environmental awareness are paving the way for significantly greater recycling and use old materials in the United States' road construction, repair, and maintenance.

The quantities and percentages of recycling, adding waste materials and by-product to substitute the conventional materials are according to the Florida Department of Transportation standard Specifications for Road and Bridge Construction (SS, 1991). The following section of this chapter demonstrates examples for Portland cement, asphalt cement, and limestone savings. Portland cement savings is an indirect indication for limestone savings.

USING OF FLY ASH

Section 345-2.2 of the FDOT Standard Specifications permits the use of fly ash to replace up to 20 percent by weight of cement content in concrete classes used in structures. In addition, fly ash may be used to replace not more than 20 percent by weight of the cement used in concrete pavement.

Fly ash can substitute up to 93.6 lbs of cement used in concrete, which yield to 2.53 percent of saving in limestone material per each ton of concrete. The FDOT contract history was used to calculate the total quantities for concrete that were used in structures and pavement.

USING RECLAIMED ASPHALT CONCRETE PAVEMENT

According to section 331-2.2.4 of FDOT standard Specifications, reclaimed asphalt pavement RAP shall not exceed 60 percent by weight of total aggregates for asphalt base course nor more than

50 percent by weight of total aggregates for structural and leveling course. Reclaimed asphalt pavement shall not be used in friction courses.

The total saved limestone quantities were calculated between 28 and 31 percent of the total quantities when using reclaimed asphalt concrete. Using RAP not only save the limestone material but also save asphalt cement binder materials, and saved materials for the years 1986 to 1995.

Economic and energy analyses were conducted on a project in Florida to determine the cost and energy savings attained by using RAP in hot mix recycling (Schweyer, R., 1980). The project is described as an overlaying for a 33.3 miles of one lane road. The cost for recycling is about 75 percent of the cost for conventional hot mix overlay. The 25 percent savings incurred by recycling was achieved by 35 percent savings in asphalt cement, and 53 percent saving in materials and operating costs to produce asphalt concrete hot mix. The total savings would provide approximately 13 lane miles of additional recycled pavement for the equivalent cost of conventional paving.

The summary of energy savings is presented in Table 7.1, indicating that the recycling project consumed only 45.8 percent of energy required for conventional hot mix overlay. Approximately 50 percent of the energy savings was attributed to the reduction in new aggregate and asphalt cement.

USING GROUND TIRE RUBBER

Section 336-3 of the FDOT Standard Specifications mentioned that ground rubber shall be thoroughly mixed and reacted with percentage up to 20 percent by weight of asphalt cement depending on friction course type.

Ground rubber can substitute up to 24 lbs of asphalt cement used for each ton of concrete pavement. The FDOT contract history was used to calculate the total quantities of asphalt cement that were used in pavement.

The next section of this chapter demonstrates the previous analysis to visualize and monitor the consumption and savings in the non-renewable resources.

Table 7.1 Energy savings when using RAP.

Operation	Using Conventional Materials		Using Recycled Materials	
	BTU/Ton	Percent Energy Requirement	BTU/Ton	Percent Energy Requirement
Milling	--	--	32,178	9.2
Materials	203,600	33.5	37,765	10.7
Plant Operation	358,120	58.9	260,824	74.2
Field Operations	20,260	3.3	20,813	5.9
Shoulder Work	--	4.3	--	--
Total	***581,980***	***100.0***	***351,580***	***100.0***

ESTIMATED FUTURE SAVINGS

The developed model was used to forecast the future consumption of limestone. The median of saved quantity for the years 1986 to 1995 was calculated as 29.45 percent of the total limestone quantities for the activities included in this research. This percentage is assumed to be constant, if not increasing, to calculate the limestone quantities saved in the future.

The savings in asphalt cement was calculated for the years 1986 to 1995. The average of savings is approximately 2.72 percent. This value is assumed to be constant to calculate the future savings in asphalt cement. Table 7.2 demonstrates the forecasted consumed quantities in both limestone and asphalt cement. It is noted that the total forecasted quantities, based on the current management system used nowadays, will be approaching 12.5 million tons of used limestone by the year 2010. When using the recycling approach, an average gain of 29.45 percent is achieved. This leads to a huge reduction in the consumption of limestone as a representative to the non-renewable natural resources. Table 7.3 and Figure 7.1 show the used and saved amounts in the future. Accumulation procedure was performed to the used quantities in both cases of not recycling and involving recycling. Table 7.4 and Figure 7.2 illustrate these quantities showing that the total used limestone quantities

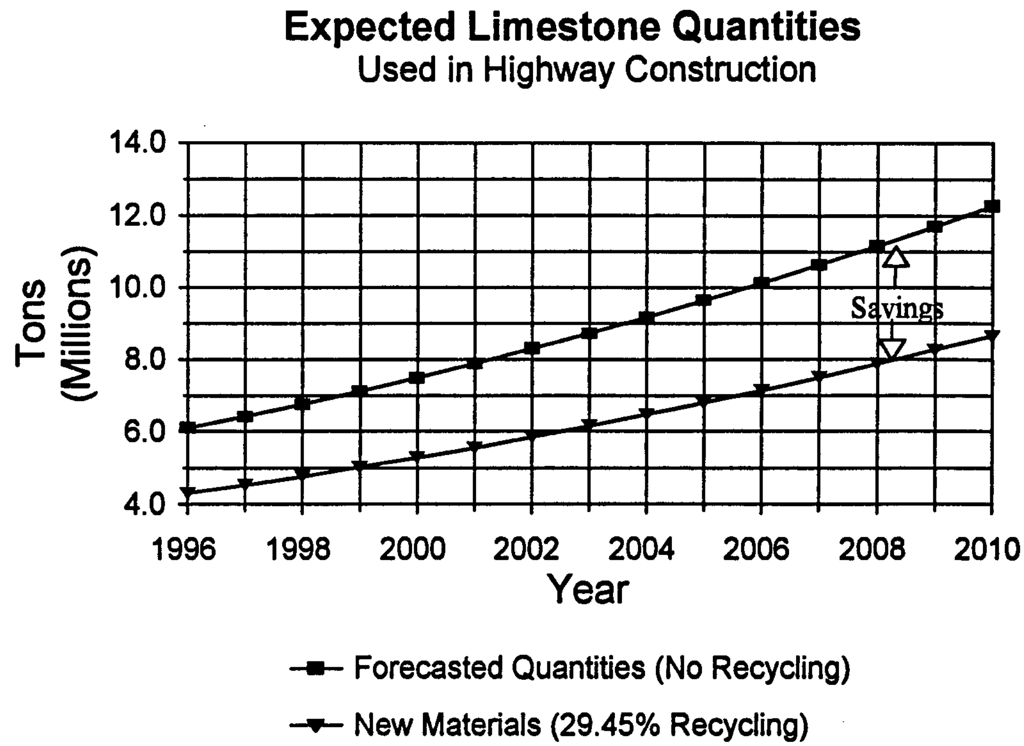

Figure 7.1 Expected consumed limestone materials and savings associated with recycling.

Table 7.2 Expected consumed and saved materials quantities.

Year	Forecasted Quantities	New Lime Materials	Limestone Saved	Asph. Cement Saved	Percent Lime Saved	% Asph Cem. Saved
1996	6,107,930	4,309,144	1,798,785	166,104	29.45%	2.72%
1997	6,424,355	4,532,382	1,891,973	174,709		
1998	6,760,348	4,769,425	1,990,922	183,846		
1999	7,115,611	5,020,063	2,095,547	193,507		
2000	7,489,923	5,284,140	2,205,782	203,687		
2001	7,883,126	5,561,545	2,321,581	214,380		
2002	8,295,116	5,852,204	2,442,912	225,584		
2003	8,725,832	6,156,075	2,569,758	237,297		
2004	9,175,251	6,473,140	2,702,111	249,519		
2005	9,643,379	6,803,404	2,839,975	262,249		
2006	10,130,247	7,146,890	2,983,358	275,490		
2007	10,635,911	7,503,636	3,132,276	289,241		
2008	11,160,442	7,873,692	3,286,750	303,506		
2009	11,703,926	8,257,120	3,446,806	318,286		
2010	12,266,460	8,653,988	3,612,473	333,584		

Table 7.3 Accumulated quantities used when invoking no recycling versus that of recycling.

Accumulated Quantities - No Recycling versus Recycling				
Year	No Recycling (Forecasted)	New Limestone Materials	Limestone Saved	Asph. Cement Saved
1996	6,107,930	4,309,144	1,798,785	166,104
1997	12,532,284	8,841,527	3,690,758	340,813
1998	19,292,632	13,610,952	5,681,680	524,659
1999	26,408,243	18,631,016	7,777,228	718,166
2000	33,898,166	23,915,156	9,983,010	921,853
2001	41,781,292	29,476,701	12,304,590	1,136,233
2002	50,076,408	35,328,906	14,747,502	1,361,816
2003	58,802,240	41,484,981	17,317,260	1,599,113
2004	67,977,491	47,958,120	20,019,371	1,848,632
2005	77,620,870	54,761,524	22,859,346	2,110,882
2006	87,751,117	61,908,413	25,842,704	2,386,371
2007	98,387,029	69,412,049	28,974,980	2,675,612
2008	109,547,471	77,285,741	32,261,730	2,979,118
2009	121,251,397	85,542,860	35,708,536	3,297,404
2010	133,517,857	94,196,848	39,321,009	3,630,987

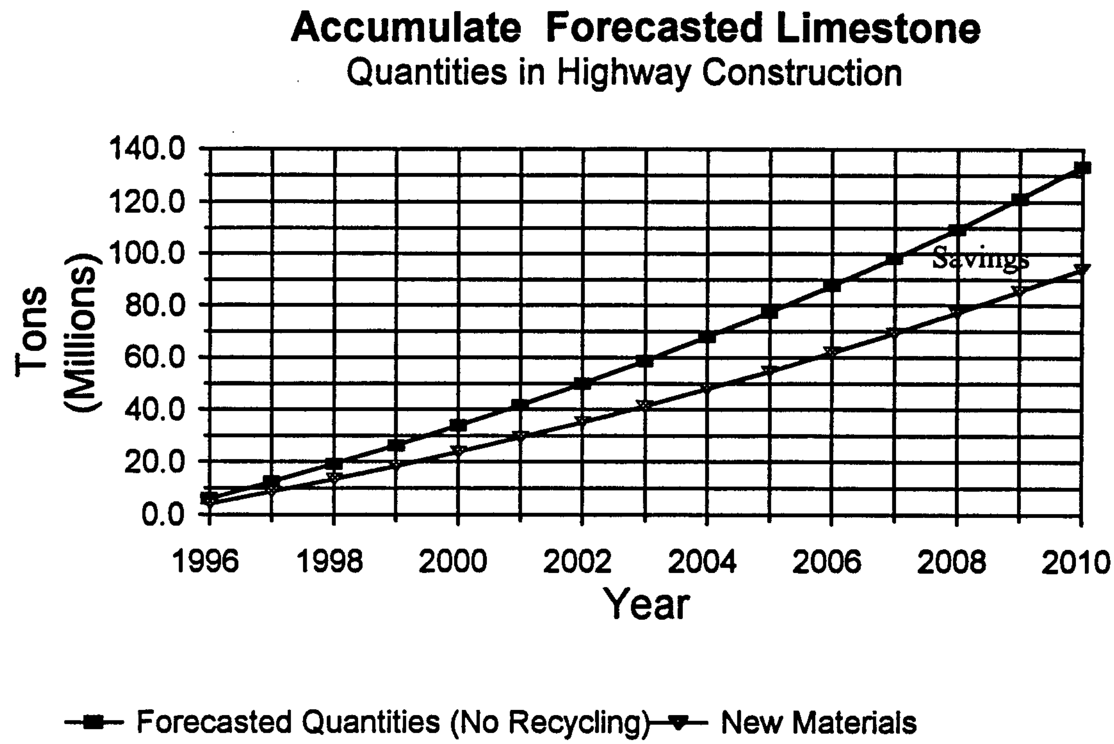

Figure 7.2 Accumulated future limestone quantities.

Table 7.4 Future cost savings associated with RAP.

Year	$ for Resurfacing	RAP Savings	Expend. After Savings
1996	$262,949,124	$65,737,281	$1,034,004,995
1997	$282,972,197	$70,743,049	$1,124,480,240
1998	$317,090,919	$79,272,730	$1,206,964,528
1999	$338,661,307	$84,665,327	$1,293,990,843
2000	$360,537,890	$90,134,473	$1,382,305,992
2001	$382,713,887	$95,678,472	$1,471,877,573
2002	$405,183,419	$101,295,855	$1,562,677,569
2003	$427,941,377	$106,985,344	$1,654,681,694
2004	$450,983,317	$112,745,829	$1,747,868,853
2005	$474,305,366	$118,576,341	$1,842,220,689
2006	$497,904,145	$124,476,036	$1,937,721,205
2007	$521,776,707	$130,444,177	$2,034,356,453
2008	$545,920,476	$136,480,119	$2,132,114,257
2009	$570,333,206	$142,583,302	$2,230,983,987
2010	$595,012,933	$148,753,233	$2,330,956,359

are approximately 134 million tons for the years 1996 to 2010. When applying recycling, the accumulated quantities in 2010 yielded to 93 million tons of used limestone. A saving of 39 million tons occurred by recycling. This savings could be translated to savings in asphalt cement used in highway construction, and consequentially, saving in funds. The saving is assumed to be 3.6 million tons in asphalt cement.

The recycling not only has effect on the consumed quantities of construction materials but also on the cost savings. The FDOT estimated that about 23% of the annual budgets are assigned to the resurfacing activities[1]. According to Schweyer (Schweyer, R., 1980), approximately 25% cost savings are achieved when using RAP in hot mix asphalt overlaying. Table 7.5 and Figure 7.3 illustrate the cost savings when incorporating RAP. It is noticed that using RAP can save up to $90 million in the year 2000, and approximately $150 million in 2010.

CONCLUSIONS

The Survey of Highway Agencies SHA indicated that all the states highway agencies are considering RAP as a first place candidate, followed by the fly ash by-product in their recycling program. The SHA portrayed that 91 percent of the responded states are using RAP in structural concrete course. About 31 percent showed its suitability in friction course of the asphalt concrete pavement. The RAP is a competitive to the conventional materials because of its less cost and equal performances. The fly ash was used by 80 percent of the total responded states. The survey showed that 90 percent of these states are using fly ash as a substitution for the Portland cement material in the Portland cement concrete pavement. The Scrap tires were used by 42 percent of the responded states as an additive to replace the asphalt cement in both the friction and structural courses. About 14 percent of the states are using scrap tires in the subgrade. The SHA indicated that furnace slag is used

[1] Fax transmission receive from Mr. William R. Kynoch--FDOT budget officer.

Table 7.5 Savings when using RAP in construction program.

Year	$ for Resurfacing	RAP Savings	Total Expenditures After Savings
1996	$262,949,124	$65,737,281	$1,034,004,995
1997	$282,972,197	$70,743,049	$1,124,480,240
1998	$317,090,919	$79,272,730	$1,206,964,528
1999	$338,661,307	$84,665,327	$1,293,990,843
2000	$360,537,890	$90,134,473	$1,382,305,992
2001	$382,713,887	$95,678,472	$1,471,877,573
2002	$405,183,419	$101,295,855	$1,562,677,569
2003	$427,941,377	$106,985,344	$1,654,681,694
2004	$450,983,317	$112,745,829	$1,747,868,853
2005	$474,305,366	$118,576,341	$1,842,220,689
2006	$497,904,145	$124,476,036	$1,937,721,205
2007	$521,776,707	$130,444,177	$2,034,356,453
2008	$545,920,476	$136,480,119	$2,132,114,257
2009	$570,333,206	$142,583,302	$2,230,983,987
2010	$595,012,933	$148,753,233	$2,330,956,359

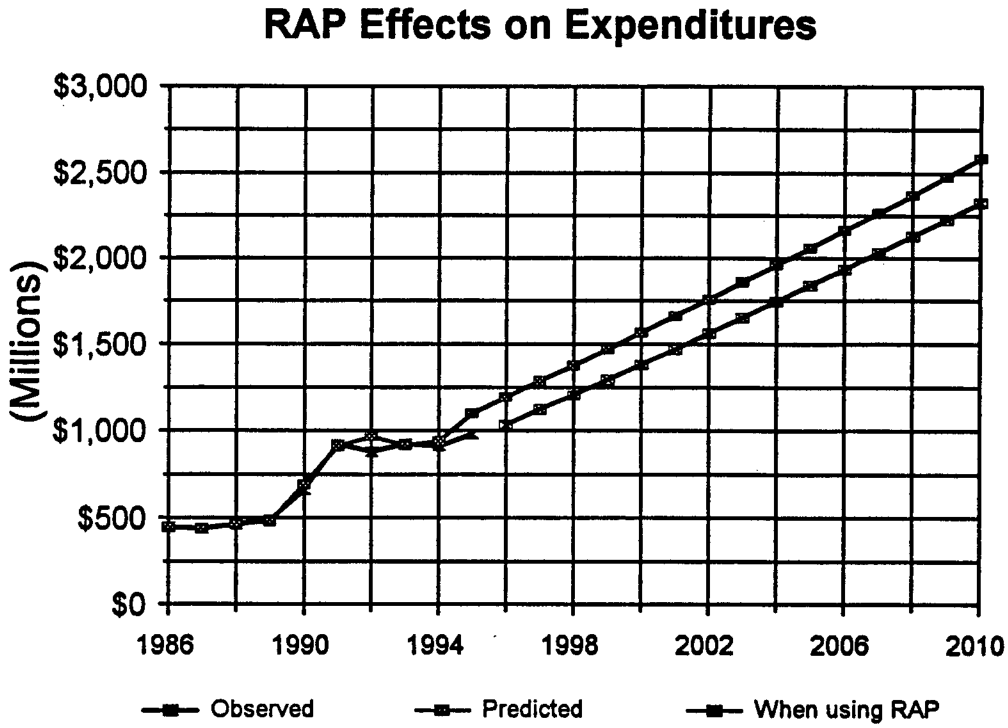

Figure 7.3 Using RAP and future savings.

as course aggregates in all pavement courses. At least 42 percent of the responded states are using slag in their construction program. Of these states, 73 percent indicated that it is equal cost, and 60 percent indicated that it has equal performance, when compared to the conventional materials.

Considering the total responds of recycling for all pavement courses, 27 percent of the states agencies are performing some kind of recycling in the structural course, 22 percent are performing recycling in pavement base, 17.5 percent in friction course, 17 percent in Portland cement pavement, and 16.5 percent are performing recycling in pavement subgrade.

Some major factors that could affect the suitability of using wastes in highway construction are the engineering characteristics and economical competition with the conventional materials.

The consumed limestone quantities indicated that the demand for this natural resources is on increase. The FDOT consumed 6.4 million tons of limestone in 1995, an increase of 21 percent of that of 1993, and 51 percent of that of 1986. This increase is due to the expansion of the construction and maintenance activities.

At this stage, after quantifying the past consumed limestone quantities, the model that simulate the past data and could forecast for future consumed limestone quantities is developed. The variables that have the most effects on the model behavior are the population, miles of roads, the annual taxes, and household numbers as functions of time. The chosen model to represent the past quantities and to forecast for the future ones has a Coefficient of Determination, R^2, value of 0.9512. The model demonstrates that the limestone consumption will approach 12.5 million tons by 2010 if the same concept of construction is used. The multiple regression procedure demonstrated that it is a valid and useful approach to simulate and forecast the future consumption.

Modeling for the future expenditures showed a high confidence when compared to the expected expenditures for the next 5 years that were conducted by the FDOT. The variables that showed the greatest influence on the model formulation were: population, road miles, and taxes as functions of time. The coefficient of determination for the expenditures model is 0.9953.

When using recycling, a total saving of 39 million tons of limestone and 3.6 million tones of asphalt cement, are expected in 2010.

Using RAP can provide approximately $90 million in cost savings in the year 2000. This saving is expected to be up to $150 million in the year 2010.

CHAPTER 8

IMPLEMENTATION PLAN

A sustainable construction program means that our current consumption of non-renewable resources is managed so that in the future we will be able to continue to maintain the infrastructure and quality of life which we desire. We all share in this responsibility. The Florida Department of Transportation (FDOT) currently manages the largest construction program in the State of Florida. The FDOT has been a leader in establishing standards in many areas such as safety, quality and environmental management. Clearly there is an opportunity here for the FDOT to also be a leader in Sustainable Construction Management.

ESTABLISHING GOALS

A working group should be established within the Department to develop reuse and recycle goals for the FDOT work program. These should include both short term and long term goals. Non-renewable materials which are heavily used should be given a priority. Planning and Design functions should routinely include a review of sustainability considerations. Specification changes should also include a review of the sustainability impact of the change.

MONITORING PERFORMANCE

The FDOT should establish an information management system for collecting and reporting information concerning its management of the resources utilized in the construction program. This should include (as a start) the asphalt and mineral materials which compose the major portion of materials consumed. Consumption, reuse and recycling quantities should be reported. An annual report summarizing the results of the FDOT's progress should be produced.

RESEARCH EFFORTS

The FDOT should continue to support research initiatives which focus on the subject of efficient management of our construction materials and processes.

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