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INVESTIGATION OF HIERARCHICAL CLASSIFICATION FOR LIFE CYCLE ANALYSES

By

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ABSTRACT

INVESTIGATION OF HIERARCHICAL CLASSIFICATION FOR LIFE CYCLE ANALYSES

By

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Today, landfills are overflowing with valuable and misdirected material. Life Cycle Analysis (LCA) is a tool which can provide environmental impact-information to improve products to utilize their entire life potential and prevent premature burial in landfills. Wide acceptance has been limited, however, for several reasons, such as: cost, data aggregation, and data limitation. The purpose here is to investigate the development of an Expert System for LCAs which can provide Life Cycle services. This Expert System, a Hierarchical Classifier (HC), can be used to initiate LCAs by identifying the processes involved in a products life cycle. Currently, this classification system cannot provide the impact information for an entire Life Cycle Analysis. This classification system was constructed using a simplified LCA for paper, which indicated the feasibility of using the HC if several modifications are added. These are: 1) an ability to quantify environmental impacts, 2) a knowledge acquisition module, and 3) an End-User Interface.

To Biika and Isaac.

ACKNOWLEDGMENTS

I would like to thank my Mom and Dad, and my brothers, Steve (and his wife, Ann), and Karl (and his wife, Diane). Through whom, I have received repeated assistance, without which, this work would have been an impossibility.

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LIST OF SYMBOLS, ABBREVIATIONS AND NOMENCLATURE

ADL	Arthur D. Little
AI	Artificial Intelligence
APA	American Pulpwood Association
API	American Paper Industries
CL	Carl Lehrberger
CSA	Canadian Standards Association
EPA	Environmental Protection Agency
ES	Expert Systems
HC	Hierarchical Classification
ISO	International Standards Organization
KBS	Knowledge Based System
LCA	Life Cycle Analysis
MSW	Municipal Solid Waste
OOP	Object Oriented Programming
PLA	Product Lifecycle Analysis
RDF	Refuse Derived Fuel
REPA	Resource Environmental and Profile Analysis
SETAC	Society of Environmental Toxicology and Chemistry
$\wedge$	Logical And
$\vee$	Logical Or
[1]	Reference number 1

INTRODUCTION

The goal of this research is to obtain a better understanding of Life Cycle Analysis (LCA), its application along with its difficulties, and to determine the feasibility of using a Knowledge-based systems approach to carry out these analyses. This task was accomplished by investigation of Life Cycle Analysis methods, a case study of paper, and an experimental implementation of this study with Hierarchical Classification. Currently, problmes associated with Life Cycle Analyses has made them difficult to use. The ease and power of todays computers could be used to help eleviate problems generally associated with LCAs. The first Chapter of this Thesis is a study of Life Cycle Analysis. This section discusses the general character of LCAs, and the problems associated with them. The second Chapter is a simplified LCA of paper to better understand the process of conducting LCAs. This section is an LCA essentially done by hand. The third Chapter entails the study of Expert Systems, and more specifically, Hierarchical Classification. The fourth Chapter describes the experimental LCA classification for paper. The final Chapter is a compilation of conclusions along with recommendations for future work.

CHAPTER 1: LIFE CYCLE ANALYSIS

INTRODUCTION

This Chapter introduces the concept of Life Cycle Analyses (LCA) and presents the general character along with the associated problems in these LCA implementations. The need for LCAs is also presented.

1.1 CHARACTERISTICS

The first LCA of products was undertaken in 1969[21]. The concept is attributed to Harry Teasley with The Coca-Cola Company. The purpose of his study was to determine which of several different beverage containers produced the least effects on natural resources and the environment. Since that time much work has been done to

develop LCAs, but as of yet their potential applicability and technique of application is still unclear.

LCA is essentially an environmental and energy audit (accounting procedure) that focuses on the entire life cycle of a product from raw material acquisition to final product disposal, rather than on a single manufacturing step or environmental emission. According to Franklin Associates, Ltd., LCA is a quantified inventory of resources used and releases to the environment in the entire life cycle of a product; "cradle to grave." LCAs are analyses that can identify opportunities to reduce environmental impact. The key is in defining the system boundary and the assumptions that are involved in defining this boundary. Much work has been done by Franklin Associates in developing the research protocol and underlying assumptions in LCA [17,18,19,21,24]. Figure 1 is a generalized stage flow diagram for a complete Life Cycle Analysis.

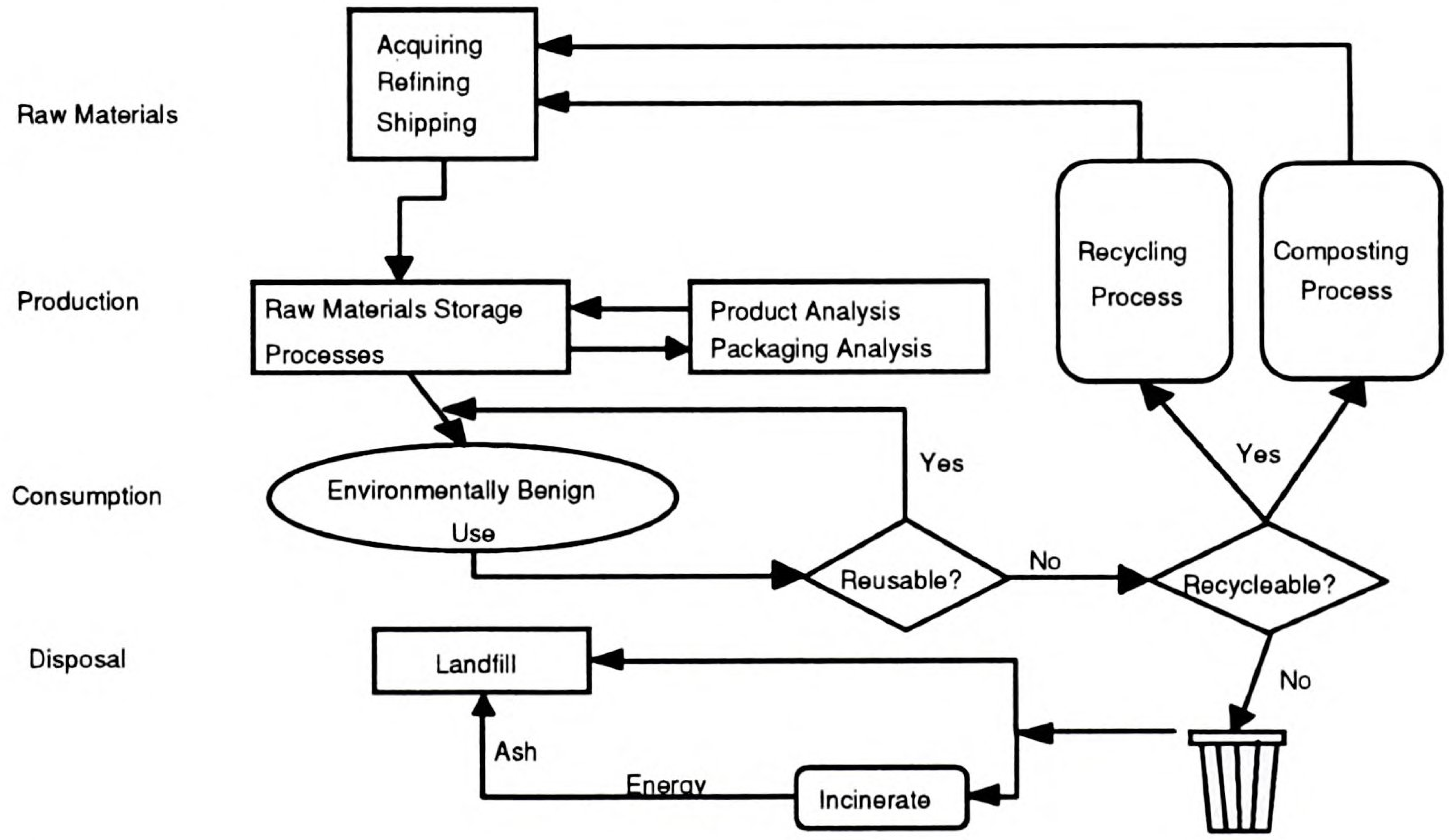

Figure 1: Stages of Life Cycle Analysis[12]

Where the analysis consists of each step being monitored for materials and energy flows is as in Figure 2.

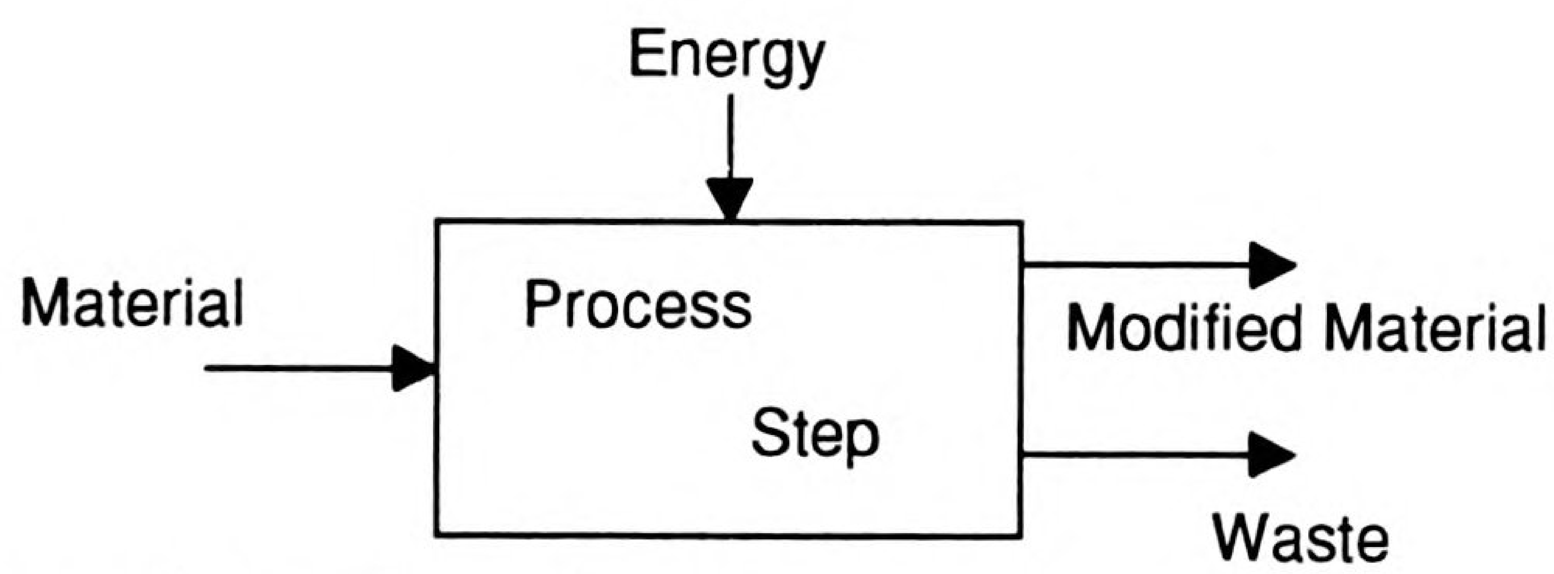

Figure 2: Micro-Analysis Boundary

Such an analysis consists of five major sections:

1. Raw Materials Acquisition
2. Product Manufacturing / Packaging Manufacturing
3. Consumer Use
4. Recycle, Compost
5. Final Disposal.

LCAs are useful for product designs. For example, in order to reduce the volume of waste (municipal solid waste - MSW) a plan could be designed to collect and recycle a particular product or the product could be redesigned to biodegrade in an appropriate waste management infrastructure. However, these changes often result in the overall process consuming more energy or producing wastes/emissions in some step. The net result of the change towards recycling or biodegradation, then, may do more harm than good to the environment. Although recycling is thought of as the "green thing to do", there is associated risks. The risk of recycling needs to be examined to determine if risk reduction is also needed

for recycling. [36, page 3]. LCA helps quantify all these effects and permits informed decision-making on the proposed change. LCAs would also help in identifying significant areas for improvement in energy usage and waste reduction throughout the entire process.

Franklin Associates, Ltd. claim [19] Life Cycle Analyses can provide:

1) Quantitative profiles of environmental impact - baseline data,
2) Comprehensive report on environmental issues,
3) Analysis of alternatives for dealing with environmental issues,
4) Comparison of alternative improvement strategies, and
5) Comprehensive analysis of product, packaging, and processes from cradle to grave.

LCAs can also provide information to evaluate waste management options, can help reformulate products and can provide an overall view of the process such that environmental decisions can be made. LCAs are sometimes viewed as one input into a broader decision making process such as corporate decision making to [19]:

1) Support strategic planning,
2) Support corporate policy and product planning,
3) Guide public relations policy and action,
4) Identify opportunities for suppliers and customers to reduce environmental impact.

1.2 THE NEED FOR LIFE CYCLE ANALYSES

In order to develop new technologies, modify existing ones, or redesign products to meet the new environmental criteria, Life Cycle Analysis (LCA) or Cradle to Grave Analysis of the technology has to be performed. In today's rush by industry to make changes in product design that would enable their products to meet requirements for their ultimate disposability or recyclability, LCA assumes great importance.

Environmental product planning and design have become a necessity. All processes produce wastes, thus, the characteristics of the wastes and their impacts on the environment must be one of the basis to determine alternate designs of products and processes. A recent EPA report Characterization of Municipal Solid Waste in the United States[36], presents EPA's stated goal of managing 25% of America's municipal solid waste through source reduction and recycling by 1992 (now updated to 1995). Composting will play a key role in attaining this goal.

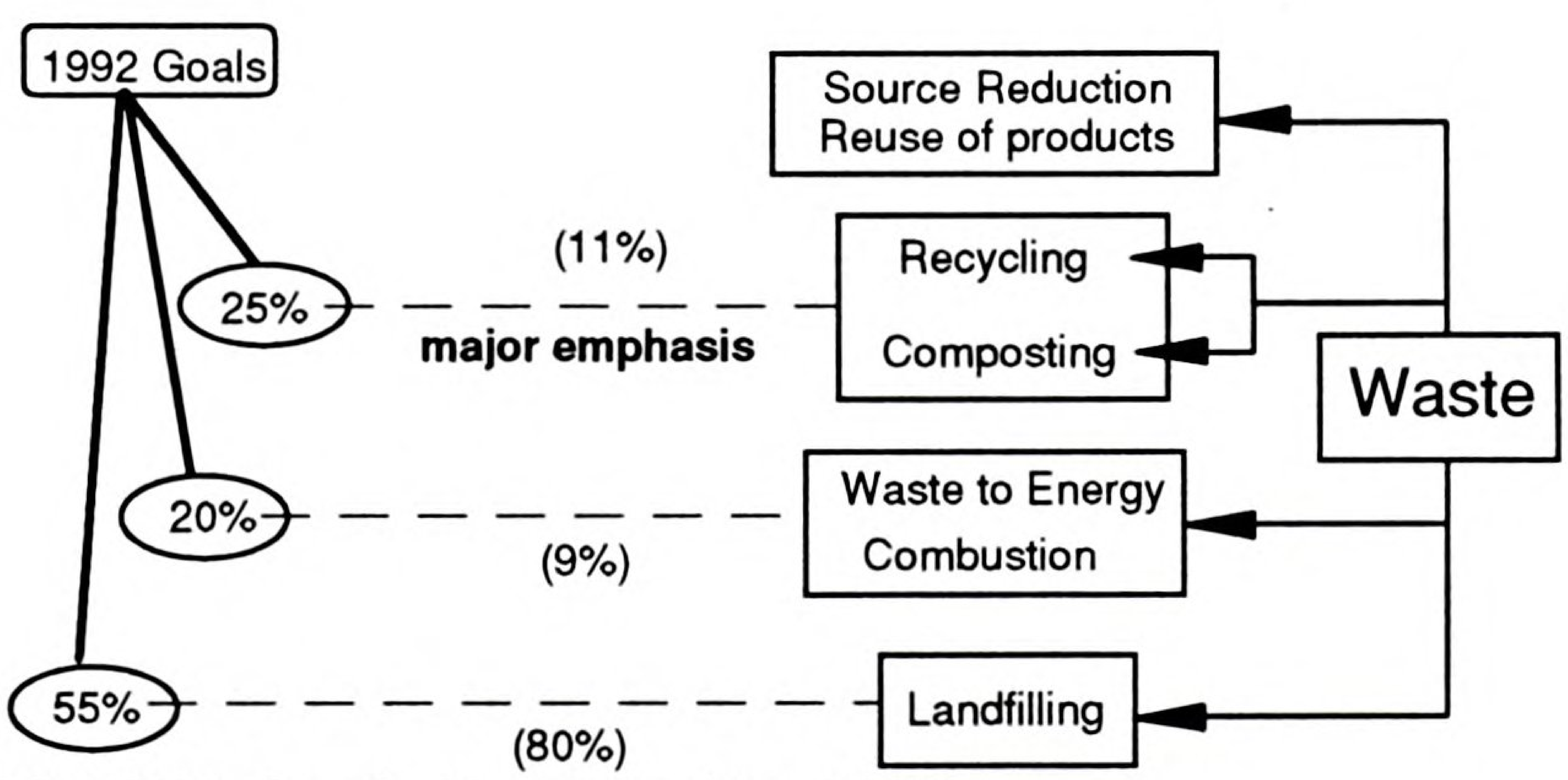

Figure 3: 1992 EPA Goals Extended to 1995

With the majority of a landfill occupied by materials that should not be there (40% paper, for example), planning is necessary on the front-end design of products to keep them out of the landfill. This is especially true in the paper industry, where planning today will be essential to increasing domestic paper recycling in the mid 1990's.

Another EPA publication The Solid Waste Dilemma: An Agenda for Action[26] has hit upon the need for LCAs.

> As a nation, we generated about 160 million tons of solid waste last year; by the year 2000, we are projected to generate 190 million tons. This deluge of garbage is growing steadily and we must find ways to manage it safely and effectively. Eighty percent of garbage is landfilled.

Until recently, little or no thought had been taken of the final disposability of the product during the product design process. Industry is starting to respond to environmental and economic pressures. Manufacturers of products have had, as of yet, no direct incentive to design products for waste management because they usually are not directly responsible for the ultimate costs of waste management[36]. The way business is conducted is starting to change. With that change comes the need for LCAs. Soon, every manufacturer will need to do LCAs of their products. If not due to governmental laws then due to economic pressure. The diaper

industry has seen good examples of the latter. If an opponent does an LCA and claims their product superior, the only way to disclaim the results is to conduct an LCA to try to repudiate the first results.

1.2.1 Legislation Promoting Life Cycle Analysis

Governments are moving towards promoting the concept and implementation of LCAs. The ISO 9000 series, which promotes environmental decision-making, is being accepted internationally. Canada is developing a standard specifically for Life Cycle Analyses. And an example of the US trend is seen from CONEG (Coalition of Northeastern Governors) Source Reduction Task Force, which has recently published this "Model Legislation"[24]:

> It is the intent of this Act to: 1) assist the state in its goal of promoting effective and efficient solid waste reduction, reuse, and recycling programs that maximize public and private sector cooperation; 2) encourage the use of packages and packaging components that are source reduced, reusable, made of recycled materials or are recyclable while also minimizing the potential dislocation of manufacturing, wholesale and retail companies engaged in or dependent on the packaging industry that distribute their products in (insert state name); and 3) control the extent to which packages and packaging components contribute to the decline in local landfill disposal capacity.

The EPA will foster workshops for manufacturers and educators to promote the design of products and packaging for effective waste

management, and will identify economic, regulatory and possibly legislative incentives for decreasing the volume and toxicity of waste. The EPA will also take steps to facilitate Federal procurement of products with source reduction attributes. Industry should conduct waste audits, and determine ways to decrease the volume and toxicity of materials used in manufacturing[26].

1.3 DIFFICULTIES WITH LIFE CYCLE ANALYSES

A proposed LCA system will have to face and overcome a number of challenges in the domain of product development/assessment. A number of problems exist in the application of LCAs that have prevented universal acceptance and application.

1.3.1 Problems Associated with LCAs

The problems generally associated with LCAs are 1) Data Limitation, 2) Assumptions, 3) Lack of a Standard, 4) Cost, 5) Lack of a Common Currency, 6) Boundary Definitions, 7) Weighting Factors, and 8) Aggregation.

1) Data Limitation. Data are not always available as in the case where manufacturers have proprietary equipment or processes.

This information is essential for the most correct and up-to-date solutions. The problem of data limitation has been noted in a number of articles [10,32 e.g.]. The lack of manufacturers' input has been a major problem for current LCAs due to the manufacturers' fear of divulging proprietary information. This problem may be remedied in one of two ways (or both). The first is that the governments (EPA, CSA, etc.) could require disclosure of relevant information to be used solely for the construction of the data bases required to run an LCA. The government would not have to explicitly make such a requirement, but could, in their usual way, make it uneconomical not to cooperate in such a capacity. Second, perhaps in combination with the first is that proprietary information could remain locked/hidden in the data base, where the providing manufacturers are not at risk. This lack of information availability, however, remains a major stumbling block for most analyses. The EPA is making strides towards an accessible database needed to increase the applicability of LCAs[26].

2) <u>Assumptions.</u> Another problem in this domain is the representation of the allowable assumptions. For some processes, the quantitative data is known and attainable while for others a best guess is as far as can be done. It is often easy to assume a case out of reality, which makes the assessment no longer useful. Generally, these oversimplifying assumptions have plagued LCAs in the past, since there are many external forces acting on a products life cycle. This can be overcome by an extensive knowledge base on

the processes themselves and the components involved. With this information, a product manufacturer can interactively 'see' the impact a design will have on the environment and can interactively judge whether assumptions are necessary or viable.

3. Lack of a Standard. One of the greatest difficulties is the lack of a standard for LCAs. Marketing people have used this fact to their advantage, claiming green superiority over other products in the same class, only to be rebuffed by another LCA determining completely opposite results. In this sense, LCAs can currently be manipulated for any purpose. Some feel this to be a benefit for LCAs, but it merely serves to injure the integrity of such studies. According to Dr. Baumgartner of the Ecological Economic Research Institute in Germany (Institut fuer Oekologishe Wirtshaftsforshung -IOW)[11]:

> ...marketing products might become interesting exactly because their does not exist unanimity about the quality of results. This is the stuff of advertisement. If need be one can always find somebody who produces an LCA where one's own product comes out on top. The freedom they now have to make these definitions allows them to fulfill their clients' frequent expectation that an LCA will show their product to be best.

Not only does this render LCAs untrustworthy, but it also points out that without a standard, LCAs are just another marketing weapon. An example of opposing results of two studies considering the life cycle of both single-use and reusable diapers shows how the analyses of the same products can differ (see Section 1.3.2).

4) Cost.[16] The workhours required to carry out an LCA currently costs time and money. This cost has made LCAs unattractive to some.

5) Lack of a Common Currency.[16] According to Norman Dean, there exists no common unit for comparing different environmental impacts. He claims that it is difficult, for example, to compare the impacts of a ton of carbon dioxide with a ton of benzene, much less compare the loss of an endangered species with human exposure to a carcinogen. But the purpose of an LCA is not to compare, but to present. The final decision lies on the user. This difficulty is indirectly associated with the lack of a standard problem, but deals more with the comparability of products.

6) Boundary Definitions[12] Altering the boundary of a problem will change the results of a problem. The study may still be termed an LCA (there is no standard), but may omit certain steps which dramatically affect the outcome.

7) Weighting Factors. A very large problem also exists in weighting factors from other media using LCA[16]. For example, should ozone-depleting chemical release be weighted against global-warming-contributing-gases release?

8) Aggregation. Both ecological and environmental assessment instruments have to deal with the problem of aggregation, that is, the reduction of the potentially large number of impacts to a number that is manageable by decision-makers[10].

1.3.2 Diaper Example

Two seemingly contradictory reports on reusable vs. disposable diapers were issued [9,23]. Table 1 summarizes the data from the two reports.

	Reusable Diapers		Disposable Diapers	
Raw Materials	ADL	CL	ADL	CL
*Renewable	0.0047 lbs	0.0046 lbs	0.254 lbs	0.216 lbs
*Non-renewable	0.038 lbs			
Water Consumption	14.05 lbs		2.3 lbs	
	1.69 gal	3.779 gal	0.278 gal	5.986 gal
Energy	(Btu)		(Btu)	
*Renewable sources	175.2		43.8	
*Non-ren. sources	752.9		230.2	
Total	928.1	2,030.6	274.0	3,455.5
Atmospheric Emissions	(*10^3)	(*10^3)	(*10^3)	(*10^3)
* Particulate Matter	3.0 lbs	0.45 lbs	0.035 lbs	1.28 lbs
* Nitrogen Oxides	1.8 lbs	1.32 lbs	0.071 lbs	1.18 lbs
* Sulfur Oxides	3.8 lbs	2.29 lbs	0.082 lbs	2.29 lbs
* Carbon Monoxide	0.4 lbs	0.81 lbs	0.094 lbs	2.76 lbs
* Hydrocarbons	1.2 lbs	0.74 lbs	0.080 lbs	1.01 lbs
Total	10.2 lbs	5.61 lbs	1.082 lbs	8.82 lbs
Waste Water Effluents	(*10^3)	(*10^3)	(*10^3)	(*10^3)
* Total Sus. Solids	0.152 lbs	1.796 lbs	0.082 lbs	1.939 lbs
* Chemical Oxy. Dmd.	0.047 lbs	4.226 lbs	----------	1.227 lbs
* Biological Oxy. Dmd.	0.141 lbs	1.887 lbs	0.035 lbs	1.5 lbs
Process Solid Waste	0.0369 lbs	0.0040 lbs	0.024 lbs	0.014 lbs
Post Consumer Waste	0.0028 lbs	0.055 lbs	0.261 lbs	0.428 lbs

Table 1: Environmental Impacts of Diaper Usage (Arthur D. Little and Carl Lehrburger)

(ADL numbers compiled by Arthur D. Little and Associates and were per 85 diaper changes but have been normalized to per single diaper use; CL numbers are from Carl Lehrberger et. al. and were per 1000 diaper changes, but have been normalized also).

Direct comparison of results show contradictions, even though both research teams evaluated the same products, reusable and disposable diapers:

1) A 300% Energy difference-
   CL: single-use diapers use 70+% more energy
   ADL: reusables use 230% more energy
2) An 800% Water-usage difference (per diaper change basis)-
   CL: single-use diapers use greater volumes of water: reusable, ~3.8 gal, disposable, ~6.0 gal
   ADL: reusable, ~1.78 gal, disposable, ~0.27 gal
3) A 14% Materials difference
   CL: reusables use 72% fewer raw materials
   ADL: reusables use 86% fewer raw materials

Thus, different studies of the same subject may arrive at contradictory conclusions as a result of varying assumptions and boundary conditions set for LCA. The results are not always black and white[31]. As stated earlier, the key is in defining the system boundary and the assumptions that go into this boundary. A report in Germany[32] about the same comparisons also talks of several other reports along the same line that differ. There is thus a need for a standard, an analyzing technique broad based enough to allow applicability to a wide spectrum of products within their Life Cycle boundary. The analyzing tool needs to judge the en-

vironmental merits/demerits of a product or process. This tool would be capable of drawing together reports such as those used in the above example and provide practical, sound environmental product and process information.

1.4 CURRENT WORK

Life Cycle Analyses have been attempted under many names, but are essentially LCAs. Some of these include: Environmental Audits, Cradle-to-Grave Analysis, Life Cycle Analysis, REPA (Resource Environmental Profile Analysis), Eco-Balance, PLA (Product Lifecycle Analysis), among others; publications range near 130 [10].

To facilitate the need for LCAs and overcome the difficulties associated with LCAs, a standard system should be developed. Currently, a number of attempts at such a standard exist. These next two sections touch upon groups carrying out research in this area. Some believe that LCAs should be left mainly to human judgment or subjective evaluation, citing that even a cursory review of the existing LCA documents show them to contain many subjective judgments[16]. Until recently, LCAs have been used to study and as of yet not to predict the environmental impact of products to aid in design decision-making.

Several EPA reports talk of using "integrated waste management"[3,26].

> In this approach, systems are designed so that some or all of the four waste management options (source reduction, recycling, combustion and landfills) are used as a complement to one another to safely and efficiently manage municipal solid waste. Recycling (including composting) is the preferred waste management option to further reduce potential risks to human health and the environment, divert waste from landfills and combustors, conserve energy, and slow the depletion of nonrenewable natural resources.

Franklin Associates, Ltd., The European Community, Canada, Batelle Institute, Ecological Economics Research Institute, Sweden, Recycling Algorithm for the Development of Strategy, are some of the groups helping to develop an LCA characterization and standardization.

1.4.1 Franklin Associates, Ltd.

Franklin Associates, Ltd. have done extensive research into developing the protocol for Life Cycle Analyses[17,18,19,21,24]. William Franklin was one of the pioneers of the subject back in the early 70's while working for Midwest Research Institute. He then started working on Resource and Environmental Profile Analysis (REPA). Currently, Franklin Associates, Ltd., are known

for their work in LCAs. A detailed description of their approach can be found in their reports cited earlier.

1.4.2 Canadian Standards Association

Canada is currently working towards an LCA Standard [Environmental Life Cycle Assessment, CSA-Z760, Draft # 5B]. CSA views the life cycle assessment process as an iterative process, consisting of four interrelated stages: 1) Initiation, 2) Inventory, 3) Impact Analysis/Assessment, and 4) Improvement Analysis. The standard CSA-Z760 is a generic life cycle model to facilitate system formulation and boundary definition, and is based on the technical contributions of the Society of Environmental Toxicology and Chemistry (SETAC) and the on-going work carried out by the US EPA.

1.4.3 RADS group

RADS[25,55,56], Recycling Algorithm for the Development of Strategy (working with SEPA-Systems Engineering for Pollution Avoidance). The work being done is to develop a model that will be an input-output model similar to that used for assessing the industrial output of the US industrial sector including such things as: inventory or landfill accumulation options, economic and

logistical subroutines, and suggestions on future efforts. This work is to create a more or less materials and energy flow diagram for all products. Although, this does not deal directly with LCAs, the work is related and useful.

1.4.4 European Community

The European Community is working out an Eco labeling standardization. A part of the criteria will be a Life Cycle Analysis. They are working to develop the standards for such an analysis. One benefit of having a single standard is that companies will not be afraid of being audited continually by different groups doing similar but different tests. Hence, the European Community as well as the European Chemical industry is promoting the concept of ISO 9000 certification of health, safety, and environmental (HSE) management systems, of which Life Cycle Analysis (Eco-Balances) plays a role.

In the near future, an LCA audit will be required for every product and process, if not due to government regulation then due to the markets (consumers) demand. Life Cycle Analysis can provide the essential information necessary to improve each product and

process environmentally and economically. However, due to the difficulties listed in section 1.3, LCAs should not be used to compare the environmental merits or demerits of competing products, but to present information regarding the impacts of the individual products.

The characteristics of an Expert System, which are explained in chapter 3, can be exploited to provide a tool to perform such analyses.

CHAPTER 2: PAPER LIFE CYCLE ANALYSIS

INTRODUCTION

The purpose of this chapter is to gain understanding of a Life Cycle Analysis by applying a sample analysis to paper, and to have a sample product line with which to run the Expert System evaluation. Paper was chosen due to its high environmental profile. Municipal Solid Waste consists of more than 40% paper/paperboard products. These products are presented in this chapter along with the energy requirements and releases for their manufacturing. The difficulties with such LCAs are presented in Section 1.3.

2.1 PAPER PRODUCTS

Paper can be broken down into a myriad of sub-categories[54]

1) Printing and Writing Papers
   - NewsPapers
   - Groundwood Paper
   - Coated Printing and Converting Paper
   - Book Paper
   - Bleached Paper
   - Writing and Related Papers
2) Packaging and industrial converting paper
   - Wrapping Paper
   - Shipping Paper
   - Bag Sack Paper
   - Other Converting Paper
   - Glassine Greaseproof Paper
3) Tissue and other creped paper
   - Sanitary Paper
   - Tissue Paper
4) Paperboard
   - Linerboard
   - Corrugating Medium
   - Folding Carton
   - Tube, Can, and Drum Paperboard
   - Other Bleached Kraft
   - Other Bleached Paperboard
   - Container Chip Fill Paperboard
   - Combination Paperboard
   - Combination Nonbendable Paperboard
   - Special Combination Paperboard
5) Wet Machine board
6) Construction paper and board

2.2 PAPER LIFE CYCLE

The manufacture of paper in its life cycle runs along the somewhat generic life cycle from raw materials acquisition to disposal is illustrated in Figure 3:

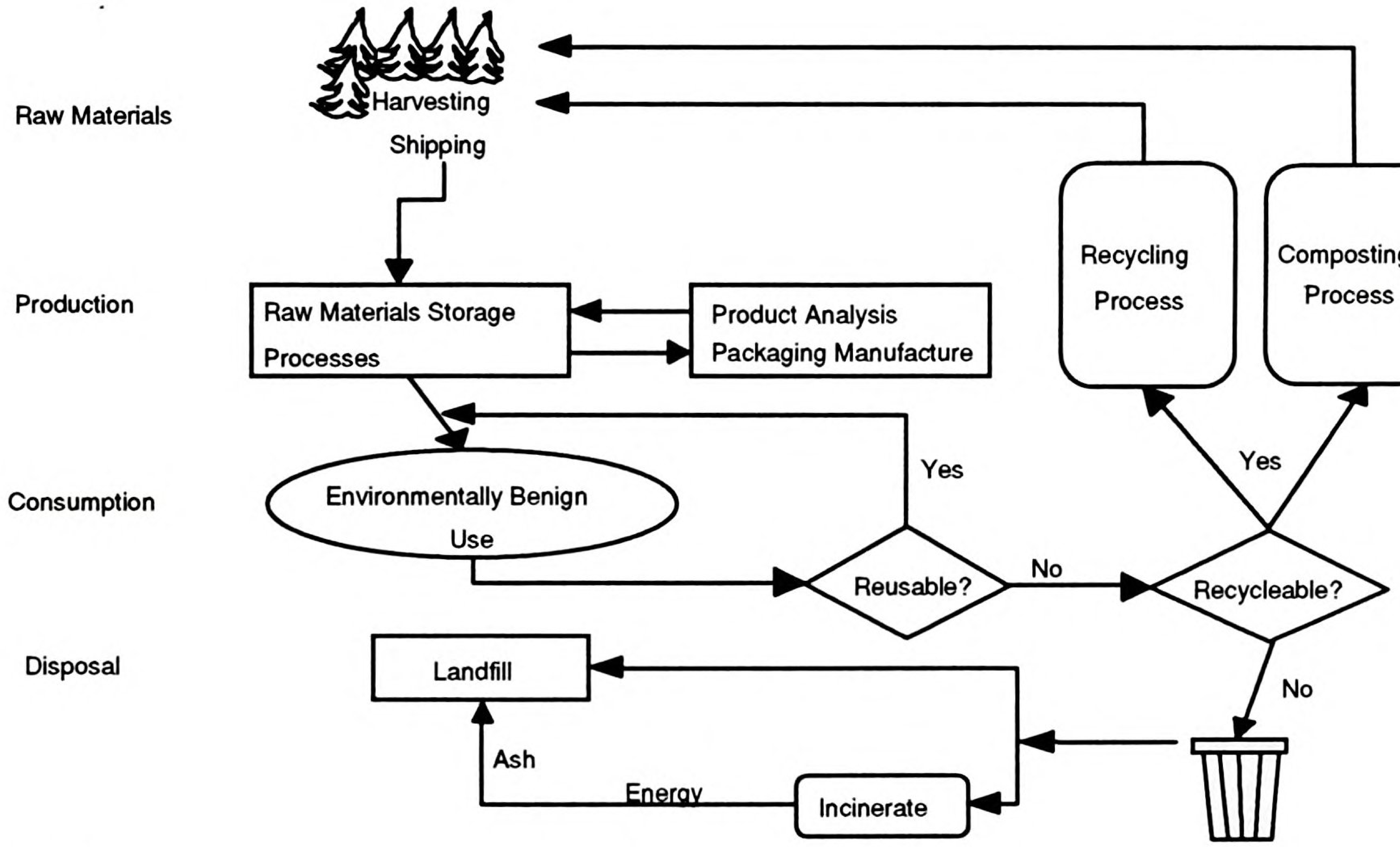

Figure 4: Stages of Paper Life Cycle Analysis

Paper is first harvested, shipped to production where any of the various products listed in Sect. 2.1 are produced. The packaging is made, if necessary (whether purchased or manufactured on site). The final product is sent to the market/consumption stage where it serves its useful purpose. It is either reused, recycled or thrown away. Depending on which choice has been made, the paper will either be transported to the landfills, whether via incinerators or directly, or be shipped to be recycling facility to start back into some

products raw materials. Section 2.6 shows the recycling rates for 1990, and the utilization for each waste stream.

2.3 PAPER RAW MATERIALS

The raw materials acquisition is mainly derived from the forest trade along with recycled paper and other wastes from the lumber industry:

	41.4%	Round Logs from private forests.
	29.0%	Waste Paper
	26.0%	Chips, sawdust, and other waste products from lumber operations including public and private lands.
	3.3%*	Round logs from public forests.
	0.3%	Misc., cotton, linens, etc.
Total	100%	

* Estimated between 2% and 3.3%

Table 2: Sources of Paper Pulp for US Paper Mills, 1992 estimates[55]

2.4 PAPER PRODUCTION

The total paper manufactured for 1990 was 78.78 million tons. (39.36 million tons paper, 39.42 million tons paperboard) [63].
The manufacture of paper products is essentially generic for most of the paper grades, but differs nearing the final production stage in the web modification and converting.

The five steps to make paper as shown in Figure 4 are:

1) Pulping
2) Stock Preparation
3) Paper Making
4) Web Modification
6) Converting

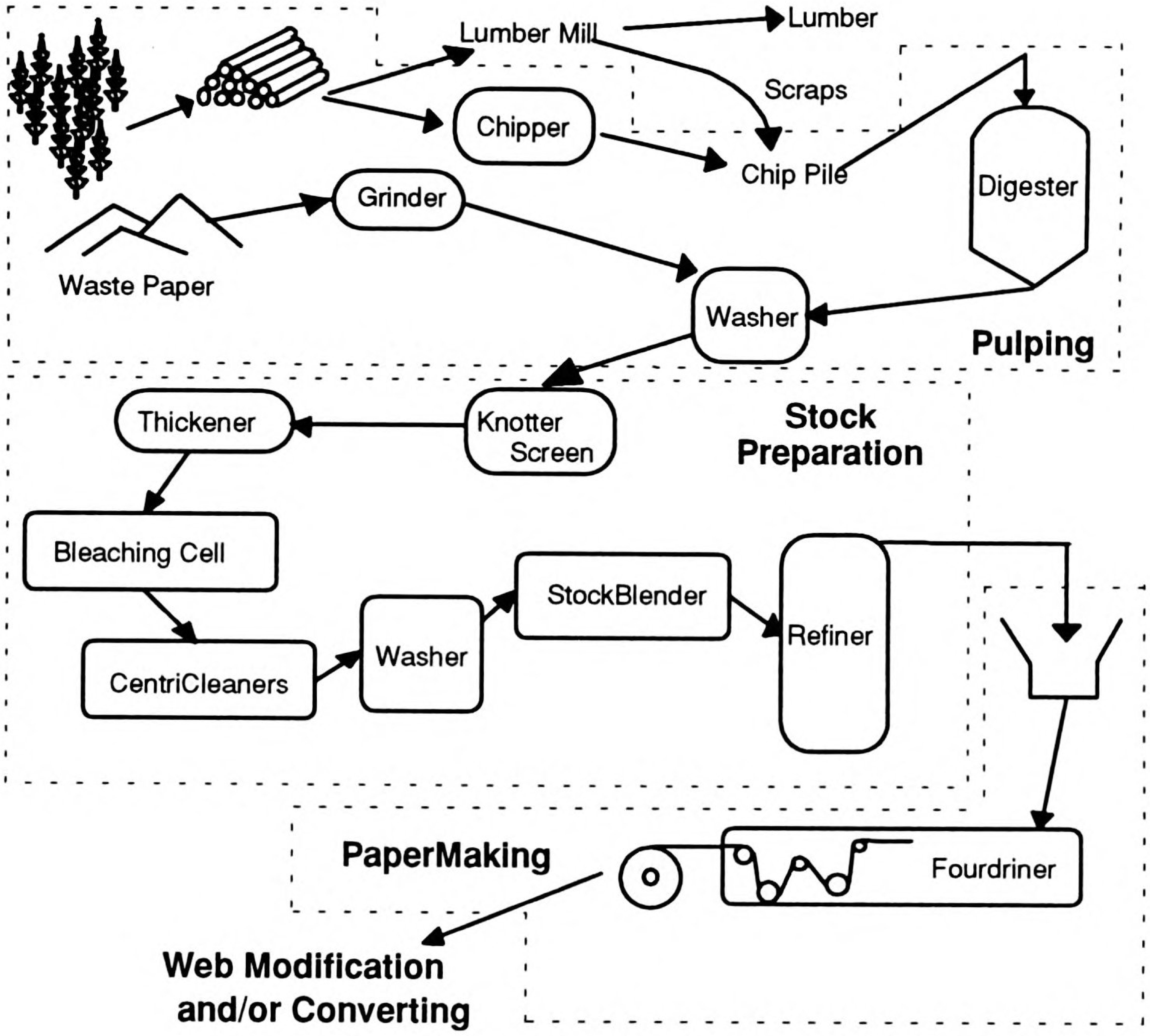

Figure 5: Paper Production Layout (For process descriptions see [38,54])

2.4.1 Energy Use

The Energy utilized by the Paper as a whole consists of 44% from outside sources and 56% from self generated sources. The Energy use is for the entire Paper industry.

Source	Est. Use	(Units)	Billion Btu's	% of Total
Purch. Electricity	46,673.0	MMKWH	158,772.5	6.5%
Purch. Steam	17,490.1	MM lbs	19,085.4	0.8%
Coal	13,969.4	M tons	338,051.6	13.7%
Residual Fuel Oil	23,963.8	M 42 gal	150,854.7	6.1%
Distillate Fuel Oil	1427.1	M 42 gal	6898.2	0.3%
Liquid Propane Gas	34,575.6	M gal	3350.1	0.1%
Natural Gas	393,419.6	MMCF	401,682.9	16.3%
Other Purchased Energy			5413.9	0.2%
Energy Sold			(-33,581.1)	
Total Purchased Fossil Fuel and Energy			1,050,528.2	44.0%
Hogged Fuel	29,702.2	M tons	2247,578.3	10.1%
Bark(50% moist)	15,065.7	M tons	130,694.4	5.3%
Spent Liquor	77,977.3	M tons	967,036.5	39.4%
HydroPwr	3938.3	MMKWH	17,240.0	0.7%
Other Self-Generated Energy		12,984.0	0.5%	
Total Self Generated & Waste Fuels			1,375,533.2	56.0%
Total Energy			2,476,061.4	100.0%

Table 3: US Pulp, Paper, and Paperboard Industry Estimated Fuel and Energy Use [37]

2.4.2 Releases for Paper

The total releases for the Paper manufacturing industry are presented in Table 4.

Air Releases:	194,029,676.9 lbs
Surface Water Releases:	42,164,020.8 lbs
Public Sewage Releases:	45,985,722.6 lbs
Off-Site Releases:	21,144,661.3 lbs
Land Releases:	9,930,159.4 lbs
Underground Releases:	0 lbs

Table 4: Total Media Releases for Paper Industry[49]

The specific chemical releases are listed in Table 5.

Carcinogenic chemicals:		
	Dichloromethane	717,000 lbs
	Styrene	41 200 lbs
	Tetrachloroethylene	204,000 lbs
	Formaldehyde	1,130,000 lbs
	Chloroform	20,500,000 lbs
	Chromium	36,189 lbs
	Asbestos (friable)	1,425,729 lbs
	Isopropyl alcohol (manufacturing)	473,000 lbs
	polychlorinated biphenyls (PCBs)	764,000 lbs
	Di-(2-ethylhexyl) phthalate	26,000 lbs
	Ethylene Oxide	31,400 lbs
Other Chemicals:		
	Methanol	118,334,484 lbs
	Toluene	36,055,332 lbs
	Hydrochloric Acid	27,038,003 lbs
	Sulfuric Acid	23,312,163 lbs
	Acetone	17,751,587 lbs
	Ammonium sulfate (solution)	13,064,014 lbs
	Chlorine	10,024,514 lbs
	Methyl ethyl ketone	8,244,205 lbs
	Chlorine dioxide	6,137,251 lbs

Table 5: Specific Chemical Releases for Paper Industry[49]

2.4.3 Releases for Printing

The total releases for the printing industry are listed in table 6.

Air Releases:	55,349,146.0 lbs
Off-Site Releases:	4,819,061.6 lbs
Public Sewage Releases:	749,361.0 lbs
Surface Water Releases:	6092.4 lbs
Land Releases:	0 lbs
Underground Releases:	0 lbs

Table 6: Total Media Releases for Printing [49]

The specific chemical releases for the printing industry are listed in Table 7.

Carcinogenic Releases:	
Dichloromethane	352,000 lbs
Styrene	28,800 lbs
Tetrachloroethylene	195,380 lbs
Lead	5,960 lbs
Chromium	2,680 lbs
Isopropyl alcohol (manufacturing)	1,241,000 lbs
polychlorinated biphenyls (PCBs)	24,100 lbs
Di-(2-ethylhexyl) phthalate	4,080 lbs
Other Chemicals:	
Toluene	42,789,389 lbs
1,1,1-Trichloroethane	4,522,055 lbs
Methyl ethyl ketone	3,906,677 lbs
Xylene (mixed isomers)	2,004,817 lbs
Glycol ethers	1,893,662 lbs
Acetone	863,576 lbs
Methanol	822,857 lbs
Dichloromethane	351,262 lbs
Methyl isobutyl ketone	328,537 lbs

Table 7: Specific Chemical Releases for Printing Industry[49]

2.5 Paper Waste Management

The main waste management practice today is set for Landfill, Incineration, Composting, and Recycling.

Constituent	%H2O	%Volitile Matter	%Fixed Carbon	%Ash	HHV
Newsprint	23.0	68.5	6.93	1.54	6565
Corrugated	17.0	71.4	9.58	1.95	6594
Other Paper	30.6	58.8	6.80	3.8	5430

Chemical Analysis:

	%H2O	%C	%H	%N	%O	%S	%Cl	% Ash
Newsprint	23.0	37.0	3.53/6.11	<.10	34.8/55.2	0.16	-	1.54
Corrugated	17.1	39.0	4.98/6.90	<.10	36.7/51.9	0.25	-	1.95
Other Paper	30.6	30.7	4.26/7.69	<.10	30.4/57.5	0.12	0.12	3.80

Table 8: *Paper As Received Basis by Weight* [28]

Source reduction and recycling are the preferred options for managing solid waste. Combustion and landfilling should be used only when the preferred options are unavailable or insufficient. [3,26,56,57]

2.5.1 Landfill

A landfill essentially buries waste for posterity sake[62]. The landfill has been a last ditch effort to entomb waste for generations to come. The landfill is one of the greatest indicators of the need for

LCA's. Americans have been too generous in our waste production, and have been under zealous in waste recovery.

The landfill requires the least amount of preparatory work. Usually, waste will enter as is. This option should not be available for paper. Currently, of the 175 million tons of waste annually [2], 30-40% is paper [36].

2.5.2 Incineration

Incineration has gained importance due to the lack of or diminishing landfill space. Although burning waste can provide energy, the greatest benefit derived from incineration is the waste volume reduction. But along with these benefits came many negative aspects. In fact, an earlier study of Incineration Units by Michael Braungart (EPEA, FRG) stated that the construction of an Incineration plant produced more waste by volume than it would ever reduce over its useful lifetime (referred to in [44], unlike in Braungart's report, this thesis does not consider the environmental impacts of the capital equipment manufacture, though this may gain in importance later in the development of Life Cycle Analysis).

The characteristics of the Refuse Derived Fuel (RDF) are as follows[28]:

Higher Heating value	6100 BTU/lb (14,152 kJ/kg)
Ash content	10-12%
Moisture Content	18-22%
Particle Size	91% less than 3/4 in (1.9cm)

Percent RDF produced per ton of MSW 54%

If MSW enters an Incinerator without preparation, the energy value is much less. Usually, to increase the fuel value, the waste is separated, but this adds processing steps and decreases the overall energy benefit from incineration.

2.5.3 Recycling

The paper industry has always been known for its recycling practice. Now, American paper companies have set a goal of 40% paper recovery by 1995 [40]. Recycling waste paper is one of the oldest, and fastest growing segments of the recycling industry. Recycling one ton of paper conserves approximately 3 cubic yards of landfill space [54]. But, in order to understand the impacts that paper recycling has on the environment, we must be aware of the effects, both positive and negative of the paper recycling process.

When recycled paper leaves the recycling stage it enters the raw materials stage of either the same or a new product. The main impact of recycling lies in the acquisition of raw material where recycled fiber displaces raw fiber. Figures 6-10 illustrate where the recycled material is utilized.

2.6.3.1 Recycled Fibergrade

Each wastepaper grade has unique physical and chemical properties and contaminants[44]. In 1990, 29.28 Million tons of paper

was recycled. Totals for the various grades of recyclable paper are[42]:

Waste Paper Fibergrade	Amount Recycled
High Grade:	2,925,500 tons
Mixed Paper:	3,510,600 tons
Pulp Substitutes:	3,218,050 tons
Old NewsPapers:	6,143,550 tons
Old Corrugated Cardboard:	13,460,000 tons

This recycled fiber is utilized in various ways. Figures 5-9 show where each waste fiber is used.

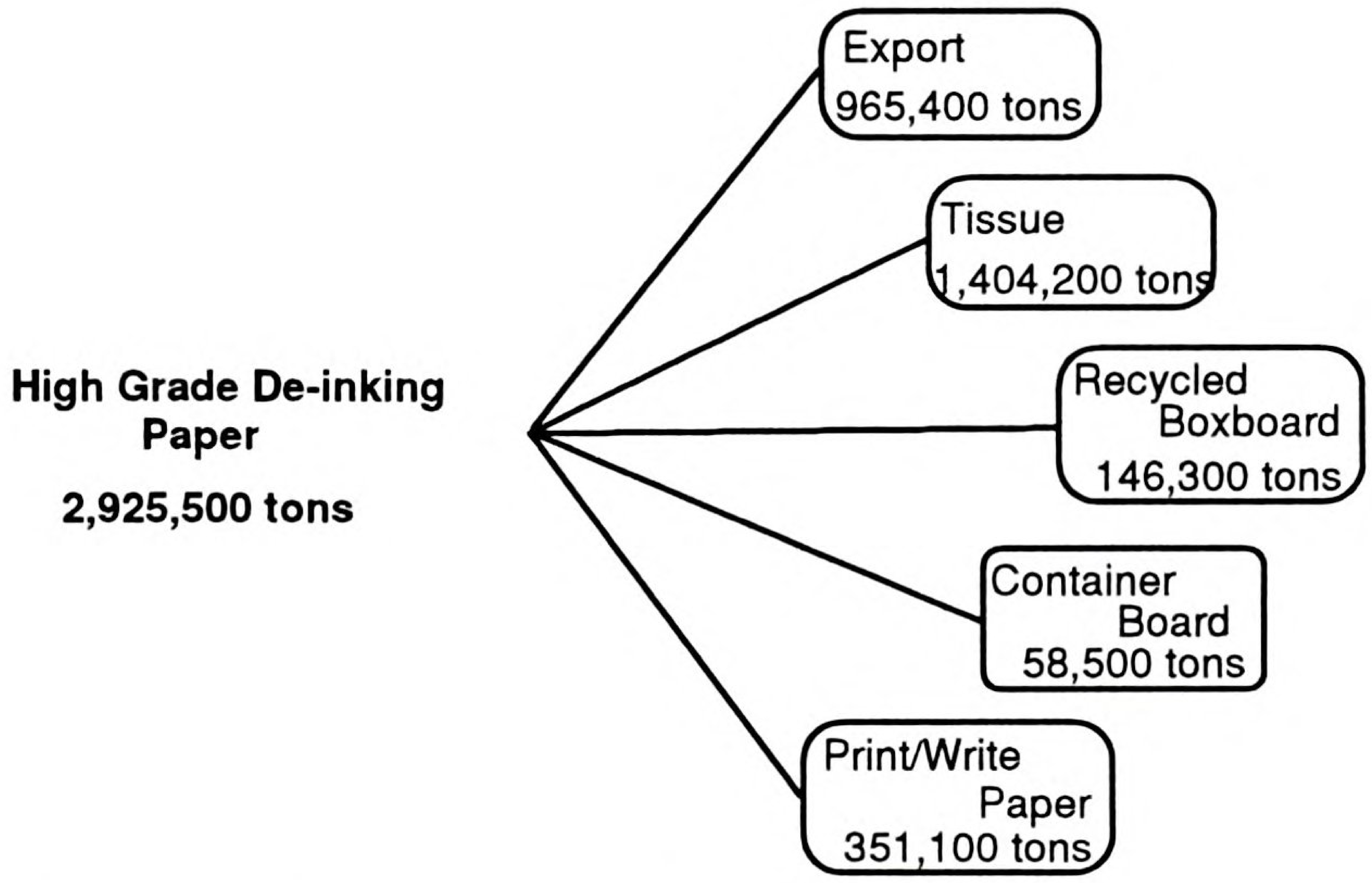

Figure 6: Recycled High Grade De-inking Paper Flow

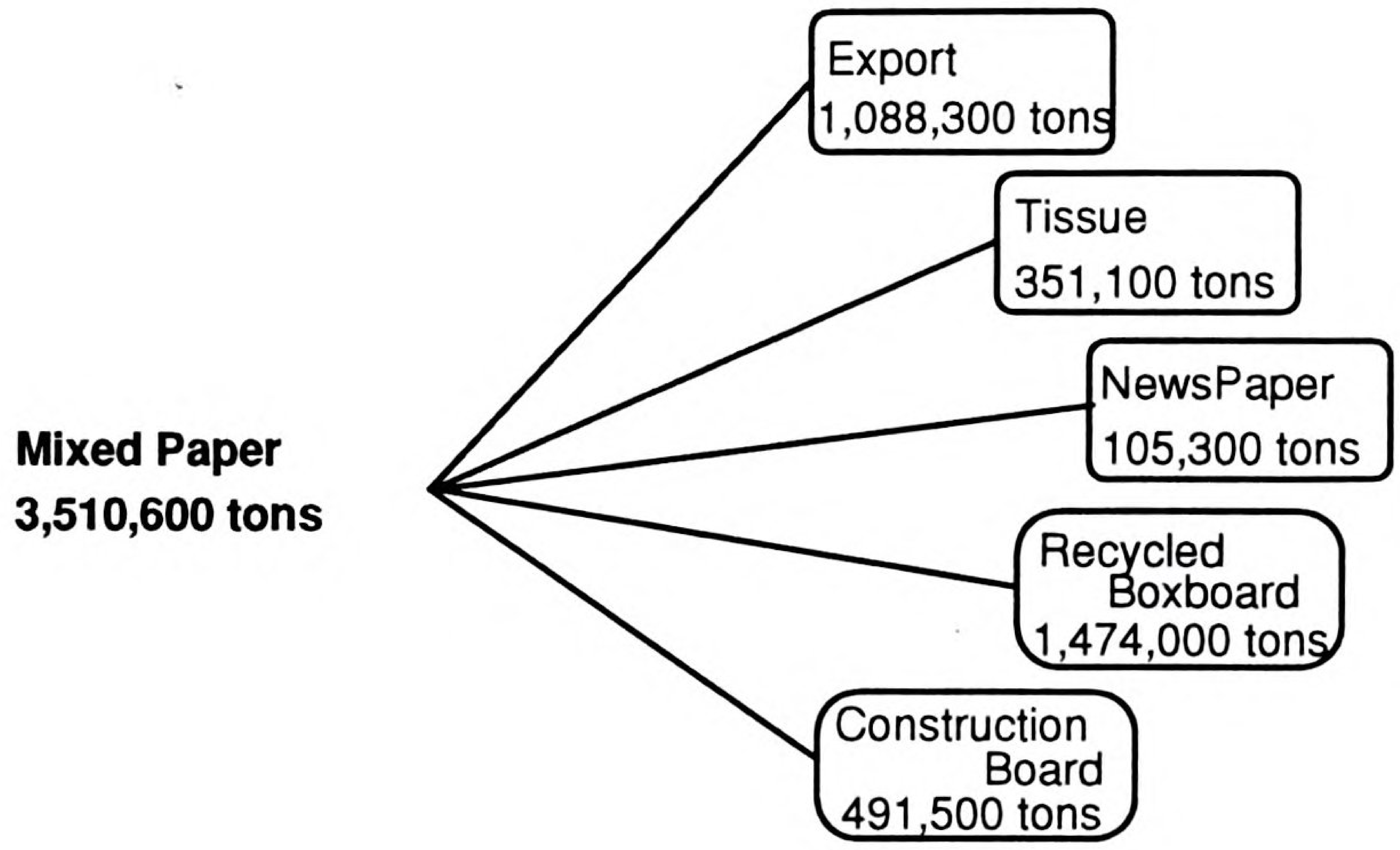

Figure 7: Recycled Mixed Paper Flow Diagram

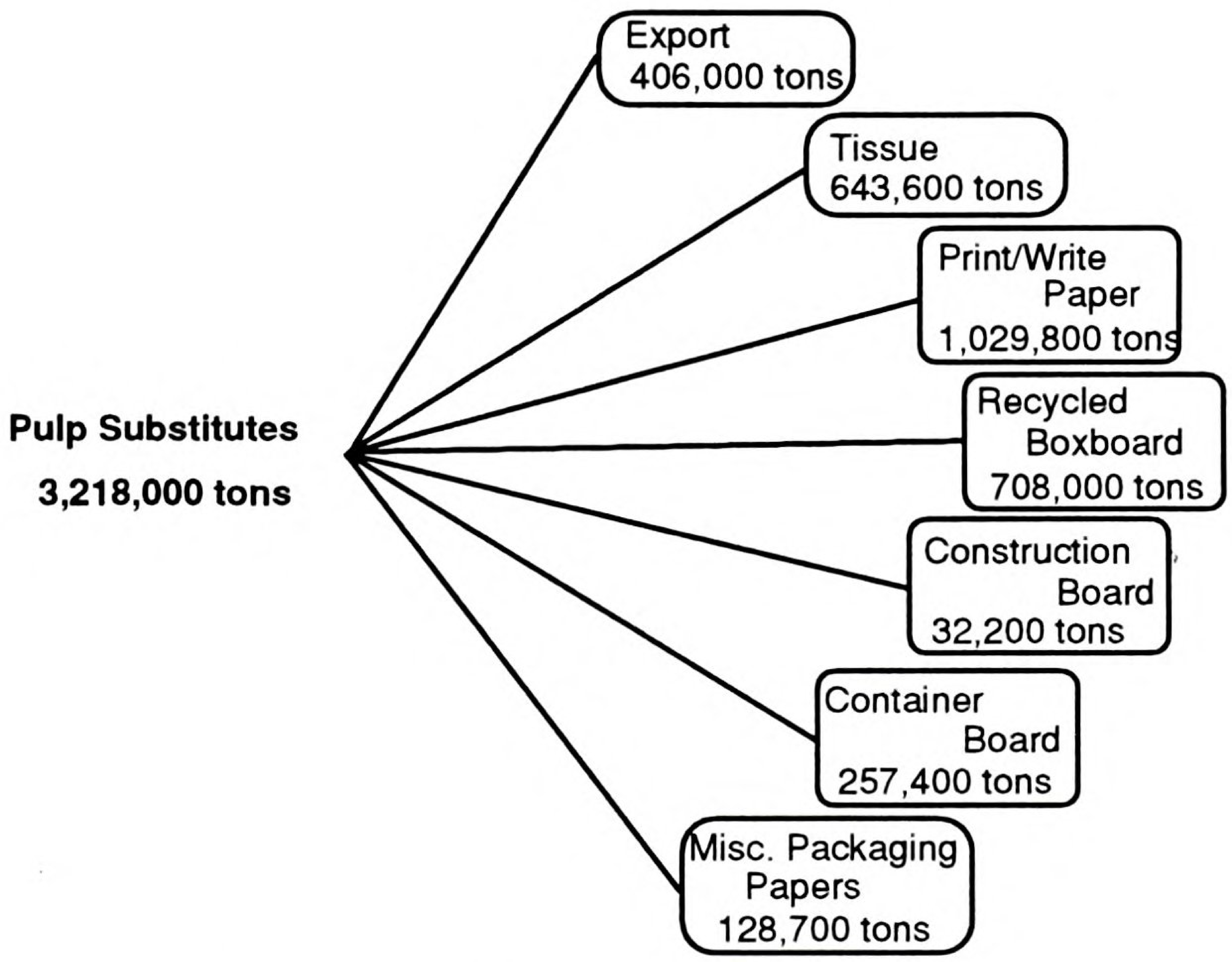

Figure 8: Recycled Pulp Substitutes use

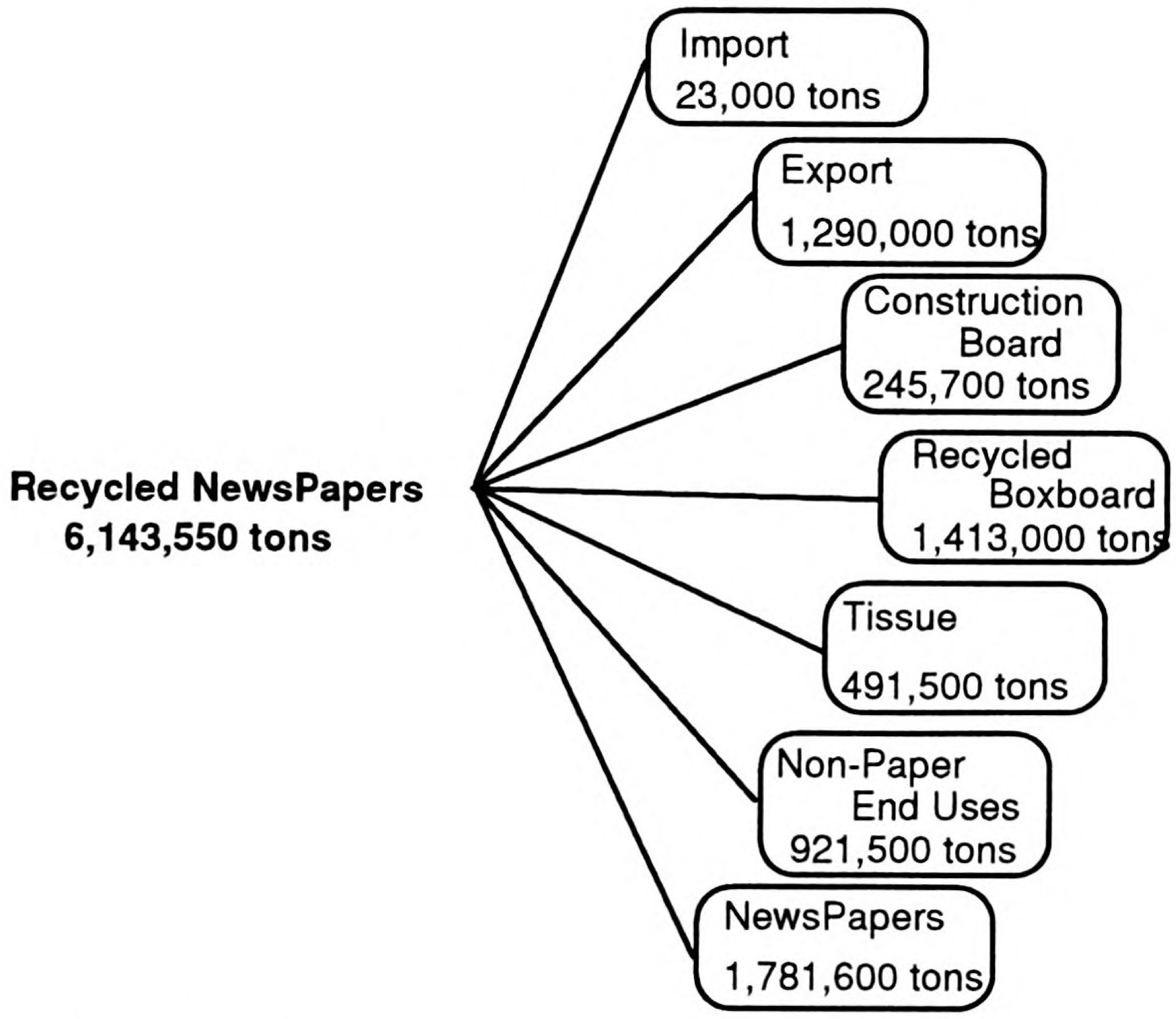

Figure 9: Where Old Newspapers are Used [also 41]

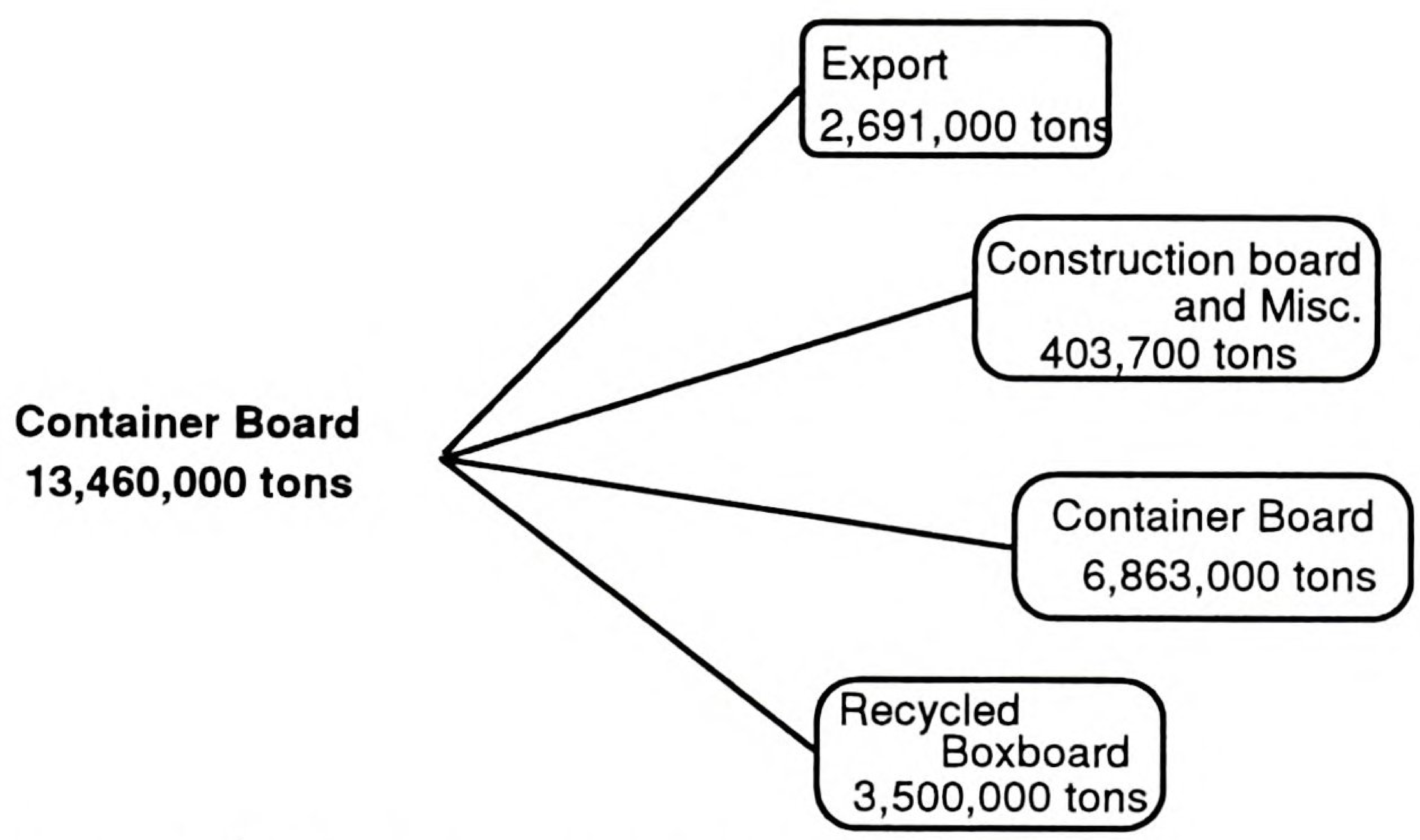

Figure 10: Recycled Old Corrugated Containers

2.5.3.2 De-inking

De-inking processes clean recycled paper. Simple repulping allows for a higher yield, but the cleaning process is not complete enough to allow the pulp to be used in many high quality papers.

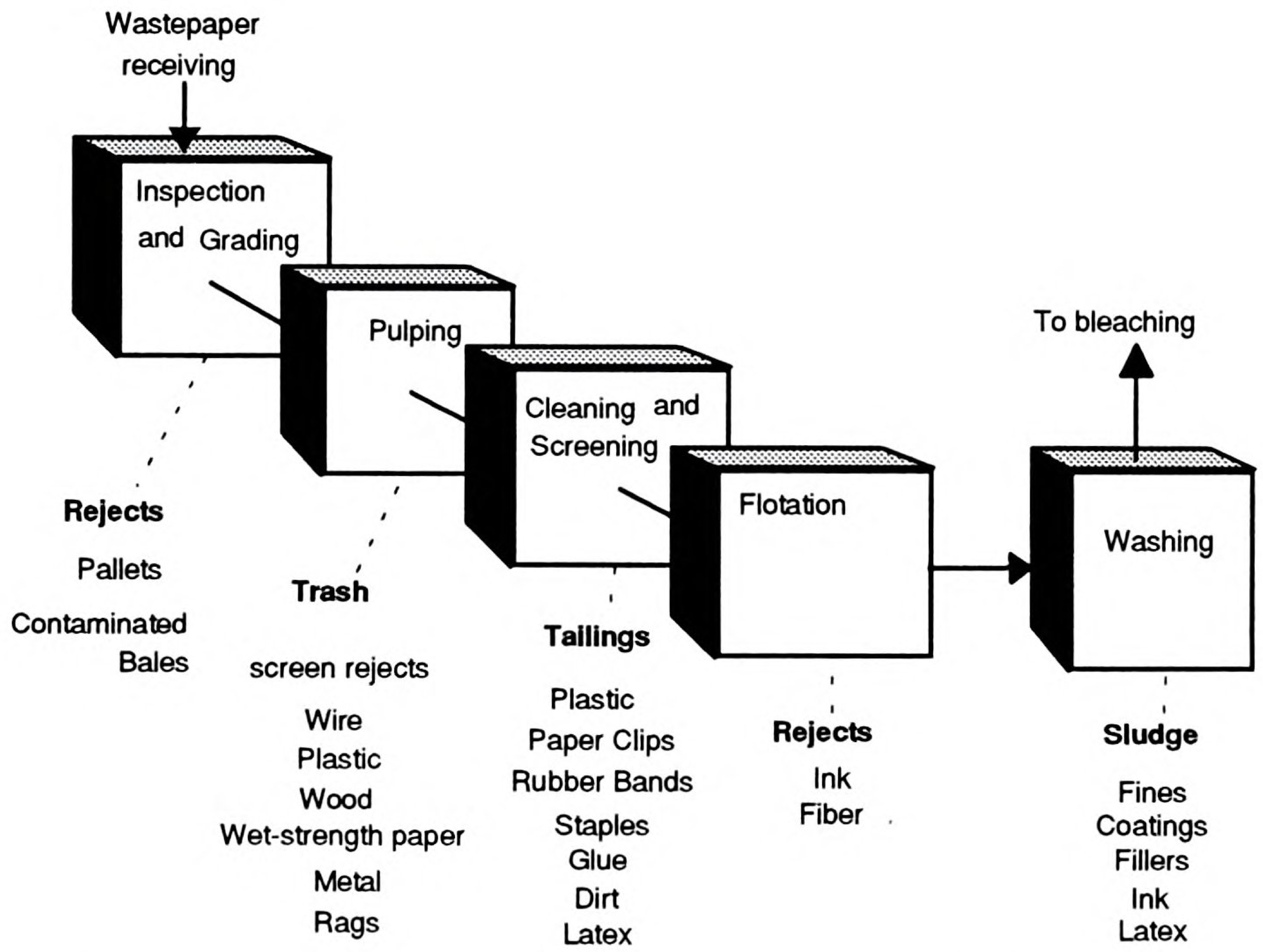

Figure 11: Sources of Solid Waste from De-inking (adapted from 45).

The Solid Waste generated at a De-inking plant [45]:

* Rejected Wastepaper. Unusable paper or contaminated paper.
* Screen Tailings. (rejects) can consist of fiber and water, plastic, glue, staples, rubber bands, paper clips, and other debris.
* Sludge. The de-inking sludge is generated in large quantities. It consists of the inks, fillers,

toners, coatings, adhesives and other materials washed out of the paper during the cleaning process. Sludge from newspaper de-inking usually consists of fiber and ink and is lower in ash since newsprint grades little fillers and clay (for specific chemical releases see [45,55,67]

* Misc. Solid Wastes. This is the solid waste generated in wastepaper receiving and handling: baling wire, pallets and boxes.

2.5.3.3 Energy Savings through Recycling

Many paper processes realize significant energy savings when waste paper is used. Bark, spent liquor, and other by-products, however, are consumed for fuel at many virgin fiber mills. For this reason, some recycling processes actually consume more energy from outside sources[55].

End Product	Virgin Fiber %	Change in Energy use
Tissue paper	0%	- 57%
Printing & Writing	16%	- 35.9%
Newsprint	0%	- 21.6%
Packaging Paper	70%	- 7.6%
Corrugated Board	0%	- 2.5%
Construction Board	65%	+ 1.7%
Box Board	0%	+ 39.6%
Liner Board	75%	+ 150.9%

Table 8: *Change in energy consumption due to recycling*

Source: US. EPA, Office of Technology Assessment. 1983 Study. Figures include only energy demand from outside sources. Energy supplied from by-products are not included. These figures do not include a full life cycle analysis. This only entails production Energy savings[55].

2.5.4 Composting

Composting is one of the oldest solid waste disposal methods known to man which converts solid organic material into a humus like mixture. This compost: (1) has a lower bulk volume than the original waste, (2) is stable and (3) has the potential of being recycled for a multitude of uses without destruction of its innate high energy value[53].

In the basic process, organisms break down the available biodegradable organics into simpler, more stable compounds and carbon dioxide. The organisms self-generate heat, which has been determined to kill possible pathogens [50]. Since during their processing period the anaerobes generate offensive odors that are difficult to control in a composter, the normal practice is to use aerobic composting. (An overview of considerations can be found in [8])

The difficulty associated with the de-inking process in not considered a problem for Composting [1]. Namely, the same chemicals are present but are not concentrated as is the case for recycling during the de-inking stage. Paper should not be composted alone, however, due to its lack of Nitrogen content, which is necessary for composting. Generally, paper is co-composted with other wastes;

paper can act as a bulking agent, as a dryer, or as a carbon-content contributor, the other wastes can supply the nitrogen content [53,47,1].

Composting Process description[28,8]:

(1) preparation of the feedstock,

sorting of organic and inorganic fractions and adjusting the feedstock if necessary, the carbon/nitrogen ratio should be adjusted to about 30:1.

(2) decomposition,

Windrow decomposition: prepared solid wastes are placed in windrows in an open field. The windrows are turned by mechanical means to insure uniform reaction, and aid in aeration for a period of about 5 weeks. (There are also controlled environment closed composters).

(3) curing, (stabilization of the material)

2-4 weeks to 2-3 months

and (4) finishing or product preparation.

may include screening to recover the bulking agent and fine grinding to remove oversize material, blending with various additives, granulation, bagging, storage, and shipping.

CHAPTER 3: THE EXPERT SYSTEM - HIERARCHICAL CLASSIFICATION

INTRODUCTION

The use of Hierarchical Classification as the Expert System to accomplish LCAs has been studied. The aim of this work is to better understand the applicability of using a hierarchical classifier to carry out life cycle analyses. This was accomplished by attempting to classify the life cycle of paper products. This chapter presents the necessary background of Hierarchical Classification and an introduction to the breakdown of the paper scenario, which chapter 4 will present in more detail.

3.1 EXPERT SYSTEMS

The Expert Systems (ES) area centers on the construction of problem solving in such areas as process design, fabrication control, plant trouble shooting, etc. In the engineering domains, these systems solve problems that would otherwise be solved by human 'experts' (hence, "Expert Systems") by drawing upon past experiences and 'back of the envelope calculations.' Thus, these systems must contain expertise such that they can mimic the performance, skill and robustness of a human expert [74].

For engineering problems, 'exact' answers are often unattainable, and when found are frequently 'over exact.' ES try to work their way around this problem by using heuristic 'rules of thumb' which an expert would have applied in the same situation were exact data unattainable, and thus provide a sufficient answer to tough problems. This is especially useful where exact answers are difficult or impossible to obtain, such as in LCA, due to various factors such as random inputs.

The development and use of an Expert System is shown in Figure 12.

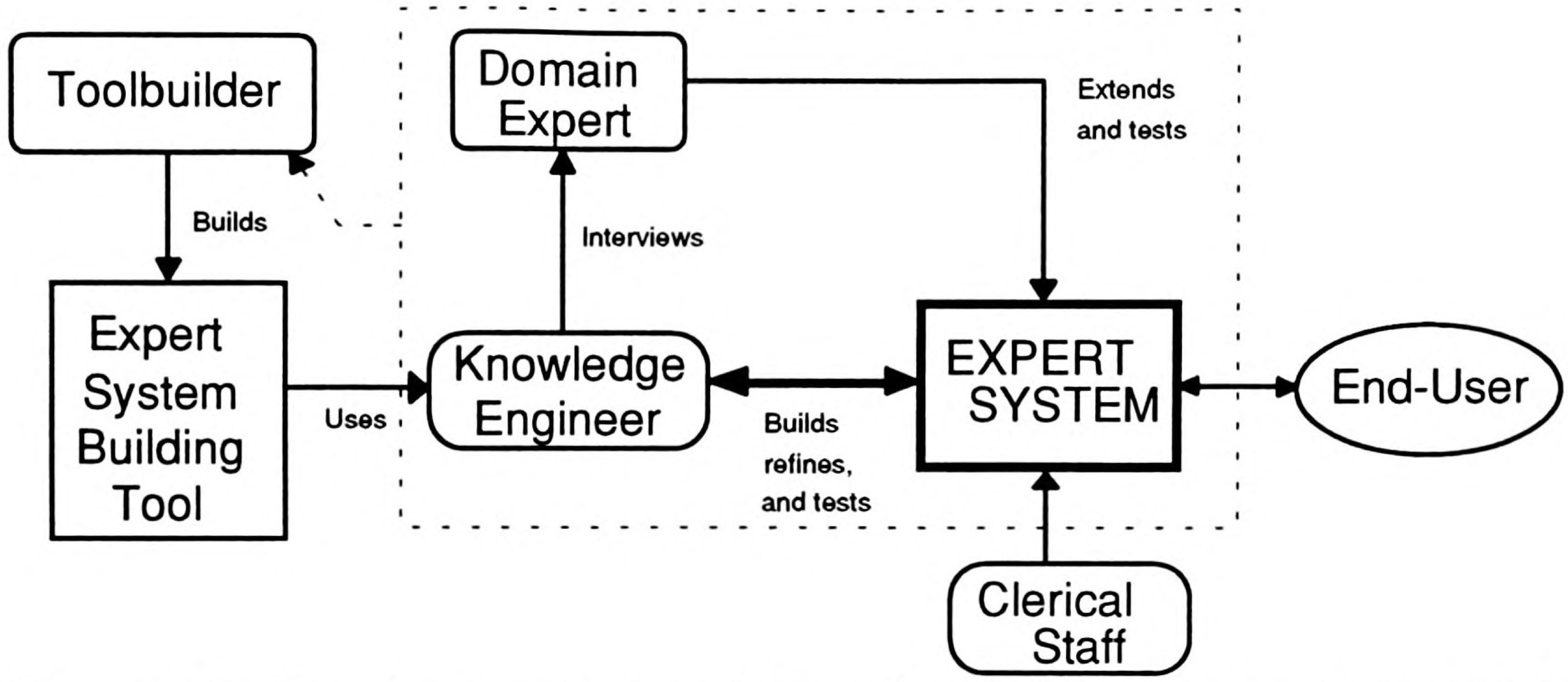

Figure 12: The development and Use of an Expert System (Adapted from [77]).

The Expert System has four main users. As a system, the most visible user is the End-User (hence the necessity of an explanatory interface). The system must not only be equipped with this usable interface, but should also be able to provide the reasoning behind a particular solution to demonstrate the basis for a decision.. This is one area that separates ES from conventional algorithms. Expert Systems contain the ability to explain how an answer was deduced. (As of yet, the Hierarchical Classifier cannot do this without going into the inner workings of the system). The Clerical Staff must also be able to use the system to input large amounts of data. If information (knowledge) is required to be input into the system, it must be provided in a 'computer-understandable' manner. They must update or complete the knowledge base in an accurate manner (this input stage is sometimes unnecessary due to the vast databases available, but whether working on the database or directly on the knowledge base, the clerical staff must provide correct information). Once the Building tool is available, the

knowledge engineer works most interactively with the ES. The Expert System is built through interviews with experts in the field of study, and is extended and tested. Feedback is given to the toolbuilder to aid in the further development of the system.

The basic elements of an expert system as described by Rich [73] are:

1) these systems derive their power from a great deal of domain specific knowledge, rather than a single powerful technique

2) in successful systems, the required knowledge is about a particular area and is well defined.

3) usually derived with the aid of one or more experts.

4) the transfer of knowledge takes place gradually through many interactions between the expert and the system.

5) the amount of knowledge required depends on the task.

Expert Systems are used for problem solving, which is a search through potential solutions, guided by heuristic rules. These should point to a destination without exhausting every possible avenue by eliminating the study of undesirable or unnecessary paths.

For the purposes here, the Expert System Building tool is the hierarchical classifier which has been built by Dr. Sticklen of the Computer Science AI/KBS department at MSU. This work has been focused on the knowledge Engineering, Expert System, Domain Expert loop, with a feedback to the Toolbuilder as to useability and wishes. (Enclosed in dotted box in Figure 12).

3.2 HIERARCHICAL CLASSIFICATION

Life Cycle Analysis (LCA) can be easily broken into a hierarchy, wherewith an Expert System could be applied. Expert Systems are particularly useful in complicated but routine problems. Hierarchical classification is a problem-solving technique that efficiently compares a set of pre-enumerated categories with a particular situation to find those categories that 'best' apply. As part of the conceptual LCA process, hierarchical classification can be used as a heuristic filter, pruning categories which are not appropriate for achieving the goals of the problem (determining the processes involved with the problem and the associated environmental loading). This is essential in accomplishing Life Cycle Analyses. As previously mentioned, one of the largest difficulties with LCAs is the vast number of directions in which an LCA can go. A hierarchical classifier can help reduce the number of paths one must investigate.

In hierarchical classification, the categories are organized into a hierarchy in which the children (the connected nodes at the next level down the hierarchy) represent a sub-category of the node and the parent (the connected node one level up the hierarchy) represents a super-category of the node (Figure 13 illustrates an abbreviated and greatly simplified hierarchy for a products life cycle).

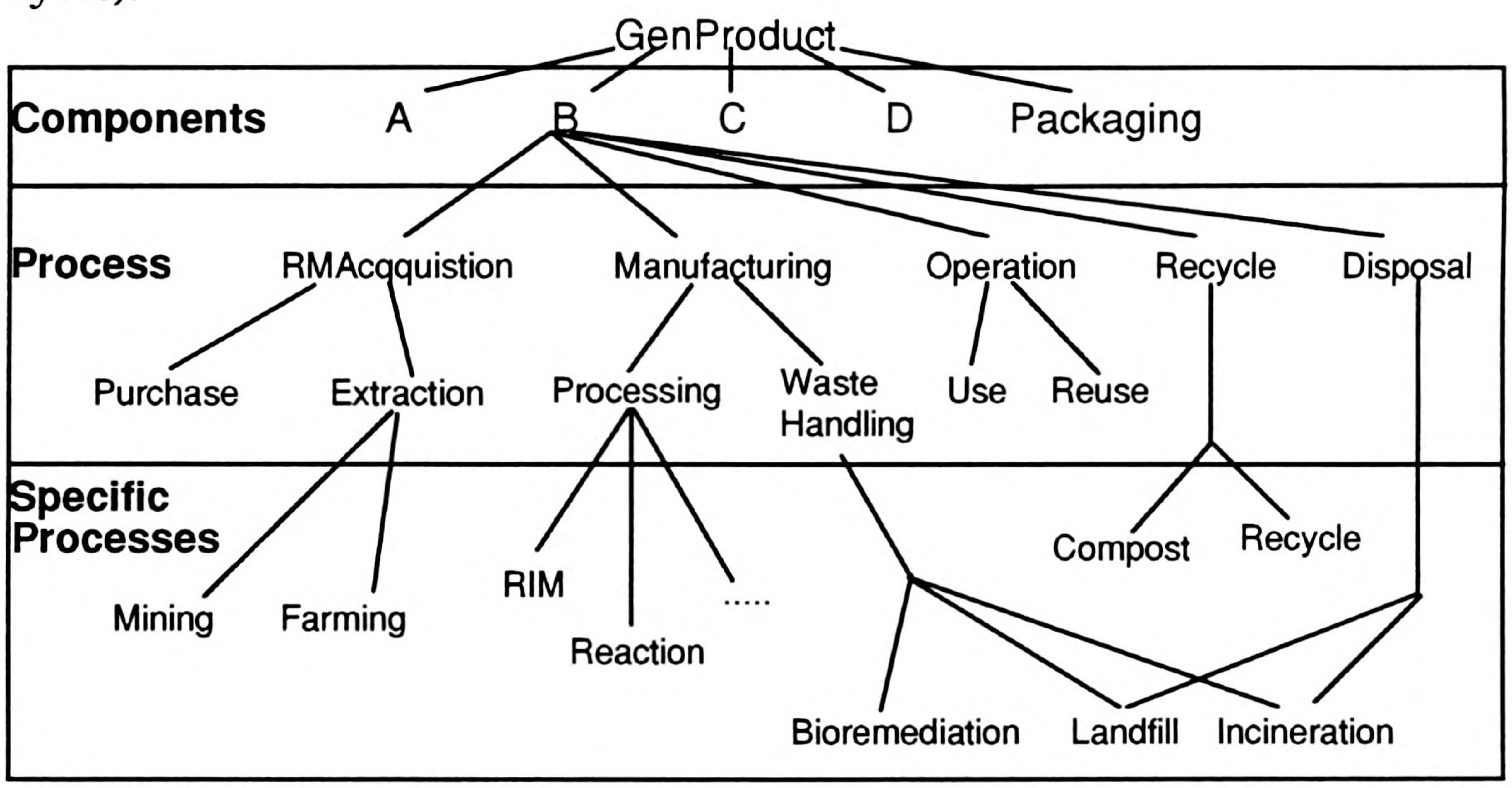

Figure 13: Example of a classification scheme for a products life cycle analysis.

As is shown in Figure 13, a generic product (GenProduct) can be made up of five (any number, say, cap, bottle, label etc.) separate components, A, B, C, D, and an associated (usually) packaging. Each one of these components has children nodes for processes: RM(Raw Materials) Acquisition, Manufacturing, Operation, Recycling, Disposal (Only component B is expanded in Figure 13 for the sake of clarity). Some of these first generation nodes will also

have children: i.e. the Recycling node has both Compost and Recycle as children. As can be seen, these categories become more specific as the hierarchy is traversed from the top towards the lower, more knowledge-specific nodes.

Each node in the hierarchy is responsible for determining the process steps involved for its category relating to the current problem. For example, the RMacquistion node in Figure 13 is responsible for determining the processes involved for acquiring raw materials for manufacture of component B of GenProduct. Each process node will likewise be queried for information about environmental impacts, as shown in Figure 14.

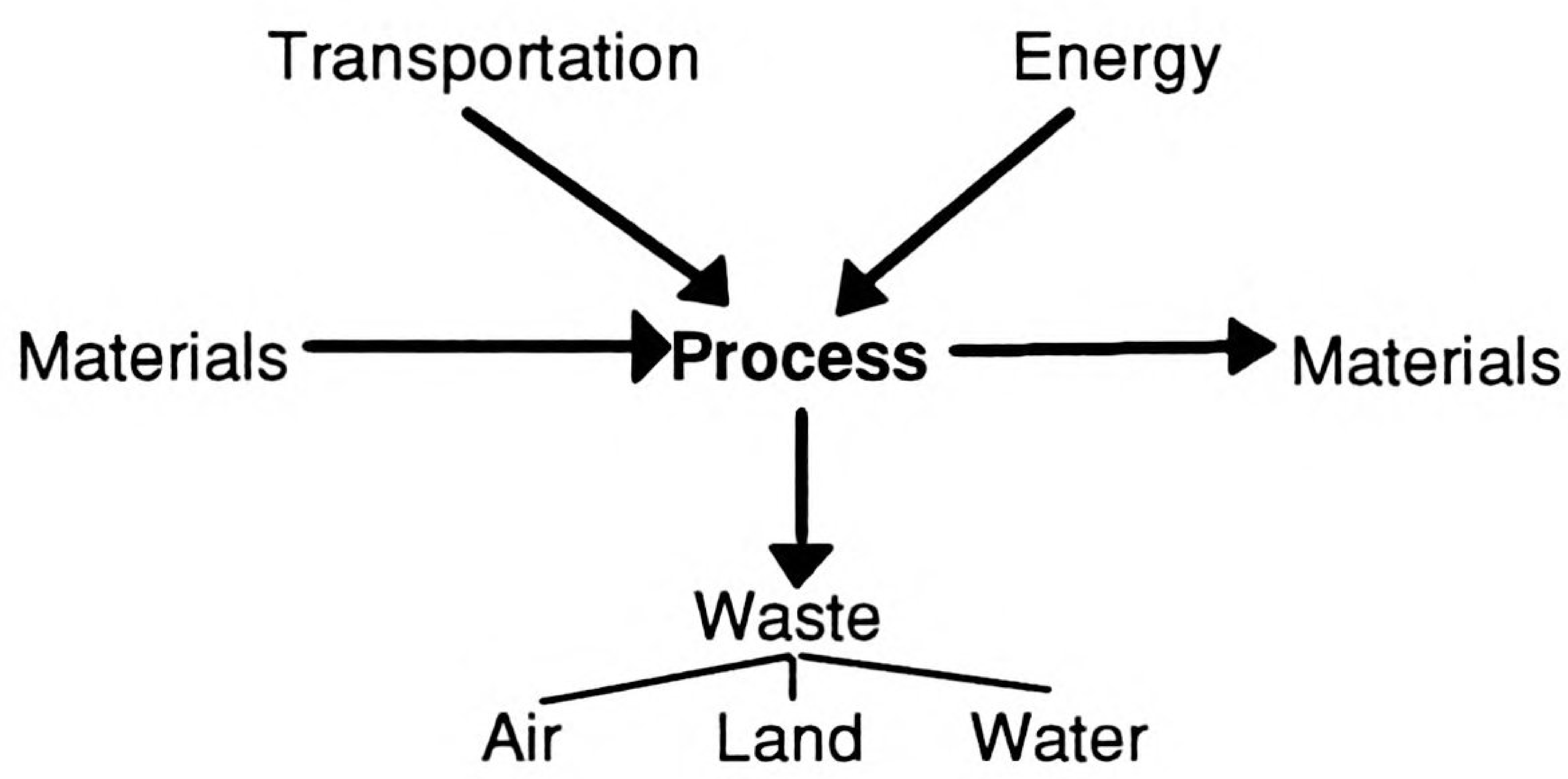

Figure 14: Filter for Process Steps

Each of these subprocesses or Flows have their own impacts which are imbedded in their respective filter. Such as Transportation and Energy:

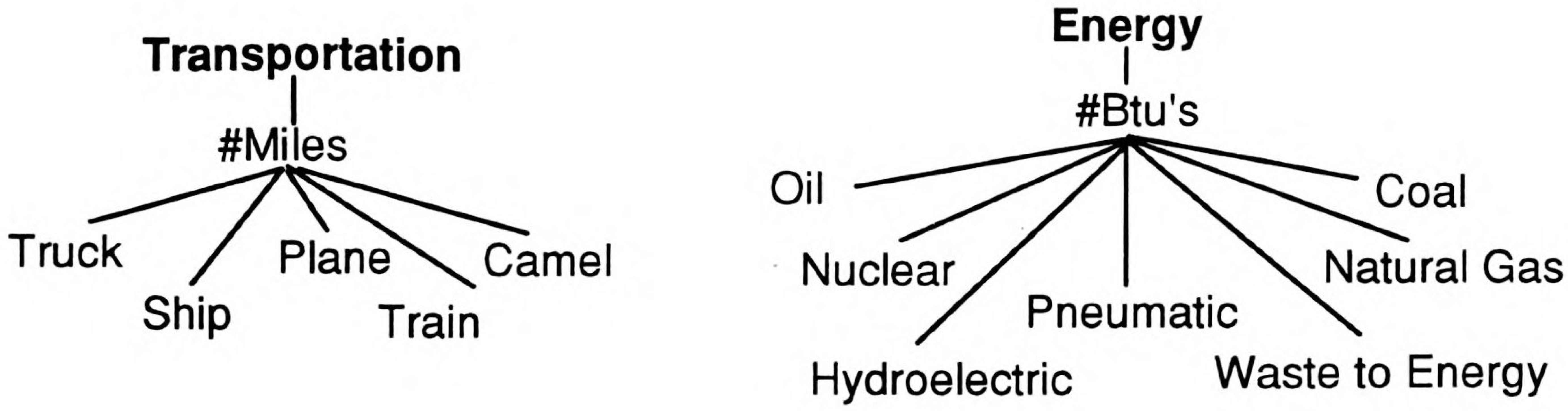

Figure 15: Transportation and Energy Filter

Each node can be thought of as a specialist in the field which the node represents (see [70]). Higher level nodes act as managers to the lower-level specialists. The RMacquistion knows nothing about farming or mining but can refine itself and essentially 'get' the information from the Extraction specialist. Not all nodes, however, are relevant to all components. In the Processing, Reaction Injection Molding(RIM), for instance, may be important for plastics, but will not be needed for cotton products. The general idea is that each node requires a list of features that are important in determining whether the category it represents is relevant to the present system or not, and a list of patterns that map combinations of features to confidence values. This essentially *classifies* the product with each node. For a given product, confidence values will depend on the physical properties of the product, the technologies normally used and other practical considerations. The output value will be a numerical value within some specified interval, for example, -3 to 3. Positive values would indicate confidence in the categories' applicability while values less than or equal to zero indicate a low level of confidence.

Consider the manufacture node in Figure 13. As previously noted, this node determines the process steps for product B for its manufacturing process. Each node includes a list of patterns that map to some confidence value. At the deepest level of the hierarchy specific confidence values are chosen and sent back up the hierarchy for the department's manager to report to the top node.

Before a manger sends the exploration down to its specialists it will use a technique called "establish-refine." A node will establish by applying its local pattern-match knowledge to determine that the confidence value is 'good-enough.' That is, in dealing with plastics, one can be fairly confident of the use of a RIM machine, so a confidence value is given of 2. Once established, a node will attempt to refine itself by asking its more detailed sub-categories (its direct children) to establish themselves. If later a match is found to conflict with the value of 2, that value will then be removed by the 'advice' of the specialists. In this way the most detailed categorical description can be determined. (In the HC used for this research, a value of 2 or greater Establishes, 1 or zero Suspends, any minus value is Rejected).

Pruning is a large advantage gained by the establish-refine technique. This prevents the system from wasting time. Whether or not a given node will establish depends upon the pattern-match knowledge encoded in the node. A category that rules out or rejects with a low degree of confidence does not ask its daughter nodes to

establish, thus pruning the search space or cutting down the search required. In order to solve tough problems efficiently, it is important to eliminate some of the details of the problem until a solution that addresses the main issues is found. Then an attempt can be made to fill in the appropriate details. This will become clearer in the paper products example.

3.3 Rationale for Use of Expert Systems

Expert Systems can offer depth and completeness to the LCAs. The general idea of the Expert System is that it can attempt to mimic the problem solving behavior of an expert. Since LCAs are based upon the availability of knowledge from many various experts, these systems can act as those experts. Research in LCAs using conventional algorithms exist [76,19]. A nice feature of using an ES, however, is the ability to more or less 'discuss' results with the user. The fact of being an Expert System does not preclude the exclusion of conventional algorithms, but rather adds a dimension to the software capability. An ES can utilize such algorithms if necessary and 'knows' when this necessity arises.

LCAs lead to complicated system of solutions, in determining all environmental impacts of a product and its processes. However, by breaking the solution search into sub-problems, such as the five parts of a products life cycle, one can then deal with each of these problems separately and more handily.

3.4 THE COMPUTER SYSTEM EXPERIMENTAL SET-UP

The Knowledge Based System Building Tool, a hierarchical classifier, has been constructed by Dr. Jon Sticklen at Michigan State University. The classifier is built using Tigre and SmallTalk version 4.0, object oriented programming. This section describes somewhat the set-up and the use of the system.

3.4.1 The Hierarchical Classifier

The operating system used was the Sun/OS, with the host "Pleiades" in the AI/KBS lab at Michigan State University. The basic building tool uses Tigre/SmallTalk to set up interfacing windows to facilitate the construction of the Expert System. Appendix A shows the working screens on X-windows, taken by snapshots. The individual windows will be discussed shortly.

3.4.2 Hierarchical Classifier Individual Window Descriptions

To work with the Hierarchical Classifier, there are essentially nine windows of importance: 1) The Launcher, 2) Classifier Window, 3) DataBase Window, 4) VariableDefine Window, 5) SubSpecialist-

Relation Window, 6) TableMatcher Window, 7) Table Editor, 8) Graphing Tree, and 9) The System Transcript.

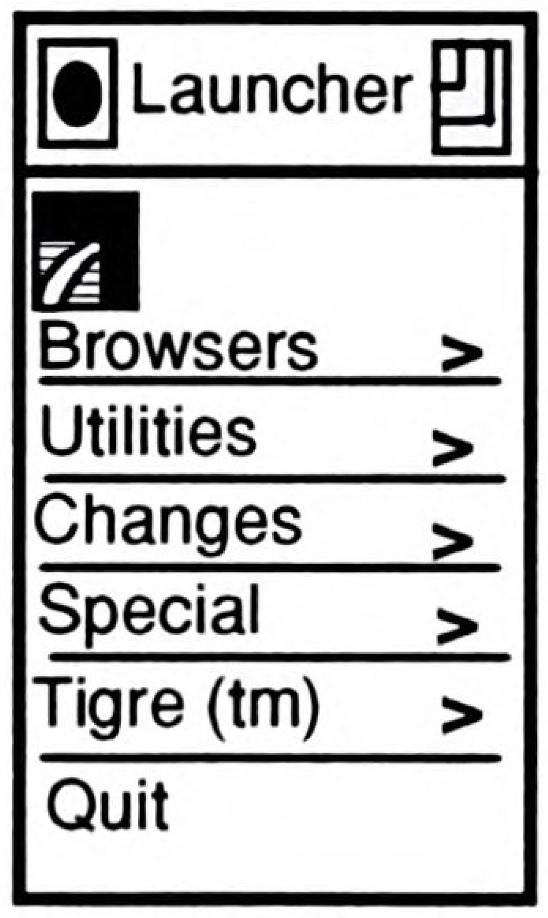

Figure 16: Launcher

Normally, when using Tigre/SmallTalk or programming in SmallTalk the Launcher is essential. For the use here, this was only needed to save the image. The save provided with the system proved to have difficulties, and hence to avoid problems the Launcher was used.

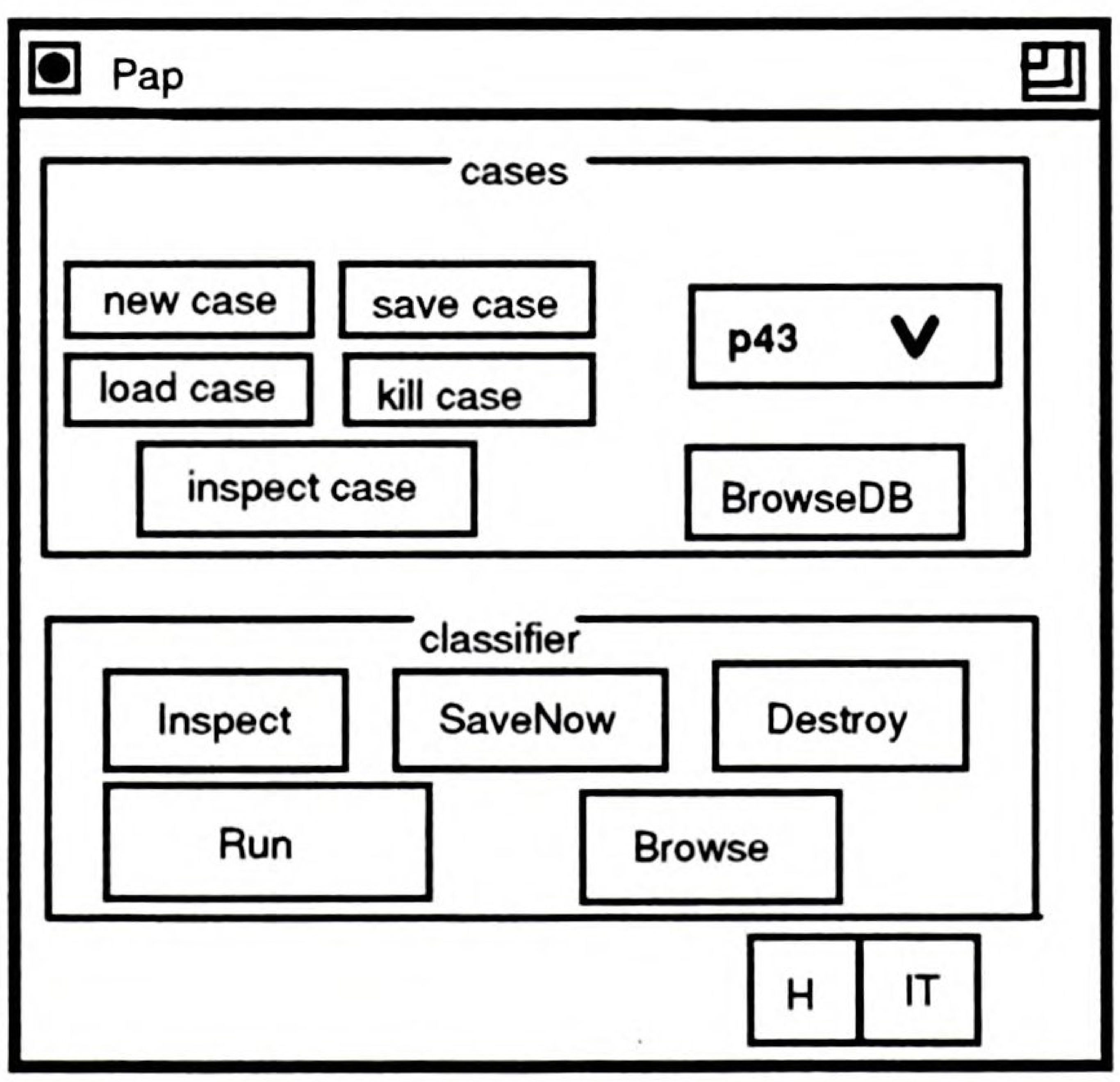

Figure 17: Classifier Window

This is the main classifier window. All other windows of the classifier are direct descendants. The database and SubSpecialists windows come directly from here; wherefrom all other sub-windows originate. A new case name must be entered for each new classification attempt.

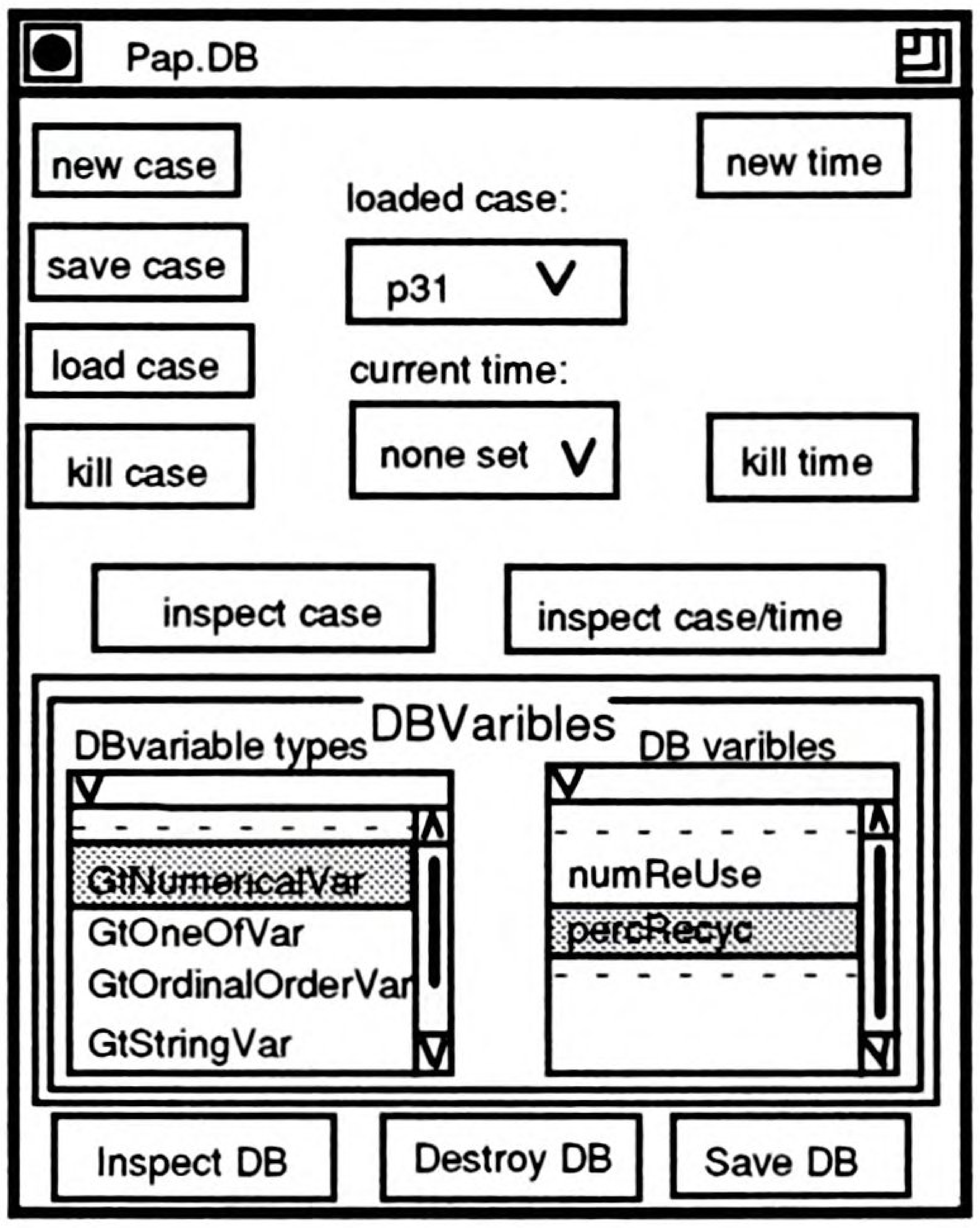

Figure 18: DataBase Window

The database stores all of the current values of the variables within the classifier. The variable type is defined here (Numerical, string, Yes/No, etc.). The database allows for the definition of the process variables. The choice define variable from the operate window brings up the Variable Define Window.

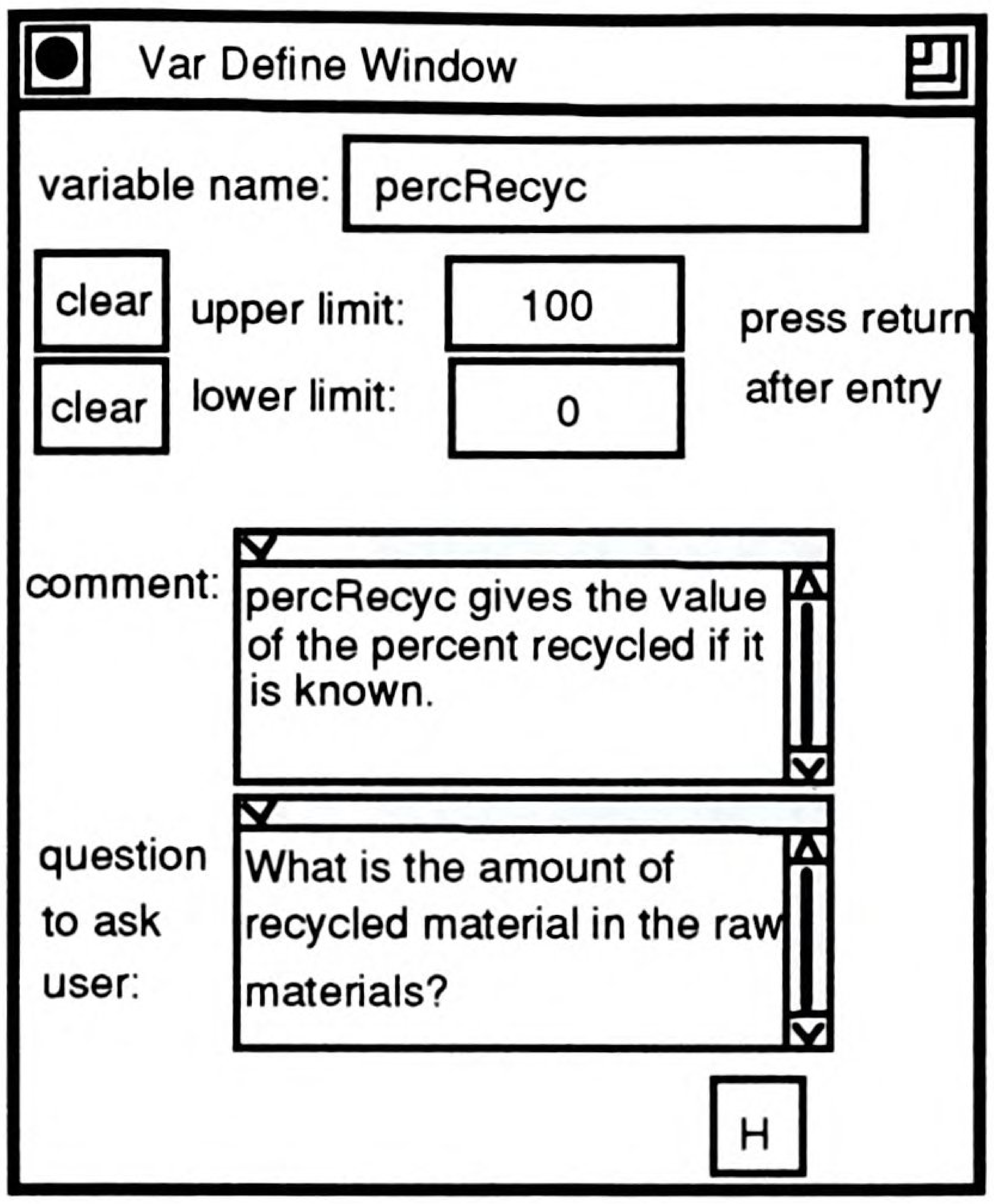

Figure 19: DataBase VariableDefine Window

The question which will prompt the user for a value (answer) is input (an example: What percent of the product is recycled?). All of the variables in the tables must be defined in order to be used by the system.

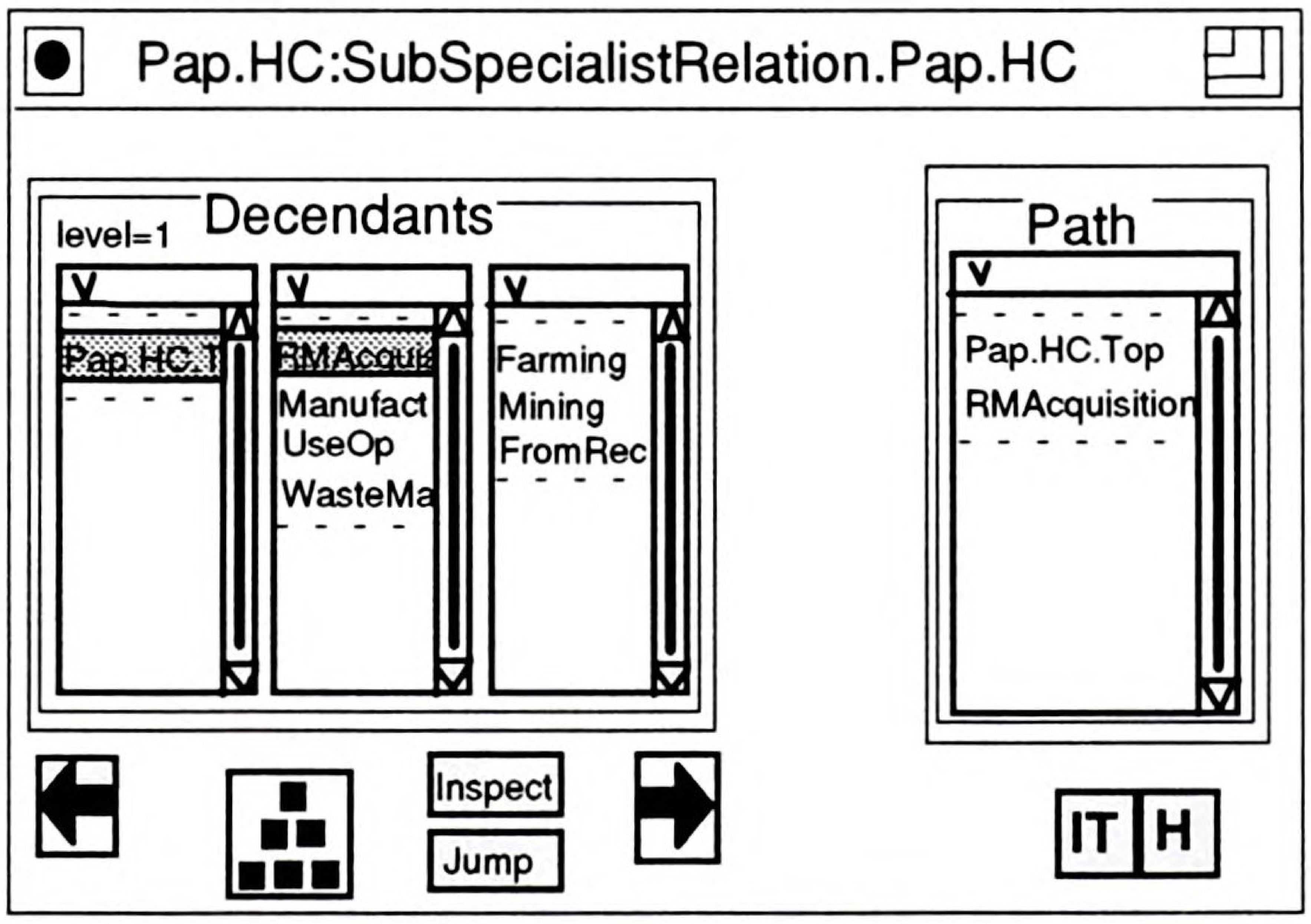

Figure 20: SubSpecialistRelation Window

This window is a sub-window of the classifier window and is a compilation of all of the nodes within the classifier. Highlighting a node (a name in the window drawn above) will call up the daughter nodes in the right-adjacent window. This highlighting can be done down to the lowest nodes. Highlighting a node also makes that node current such that its TableMatcher may be called upon from its operate menu (activate by selecting the menu located 'under' the arrow just above it). To initially run the classifier once a new case name has been chosen, the run-establish/refine option must be chosen in the operate menu while the highest level node is selected, in this case it is the Pap.HC.Top (shown).

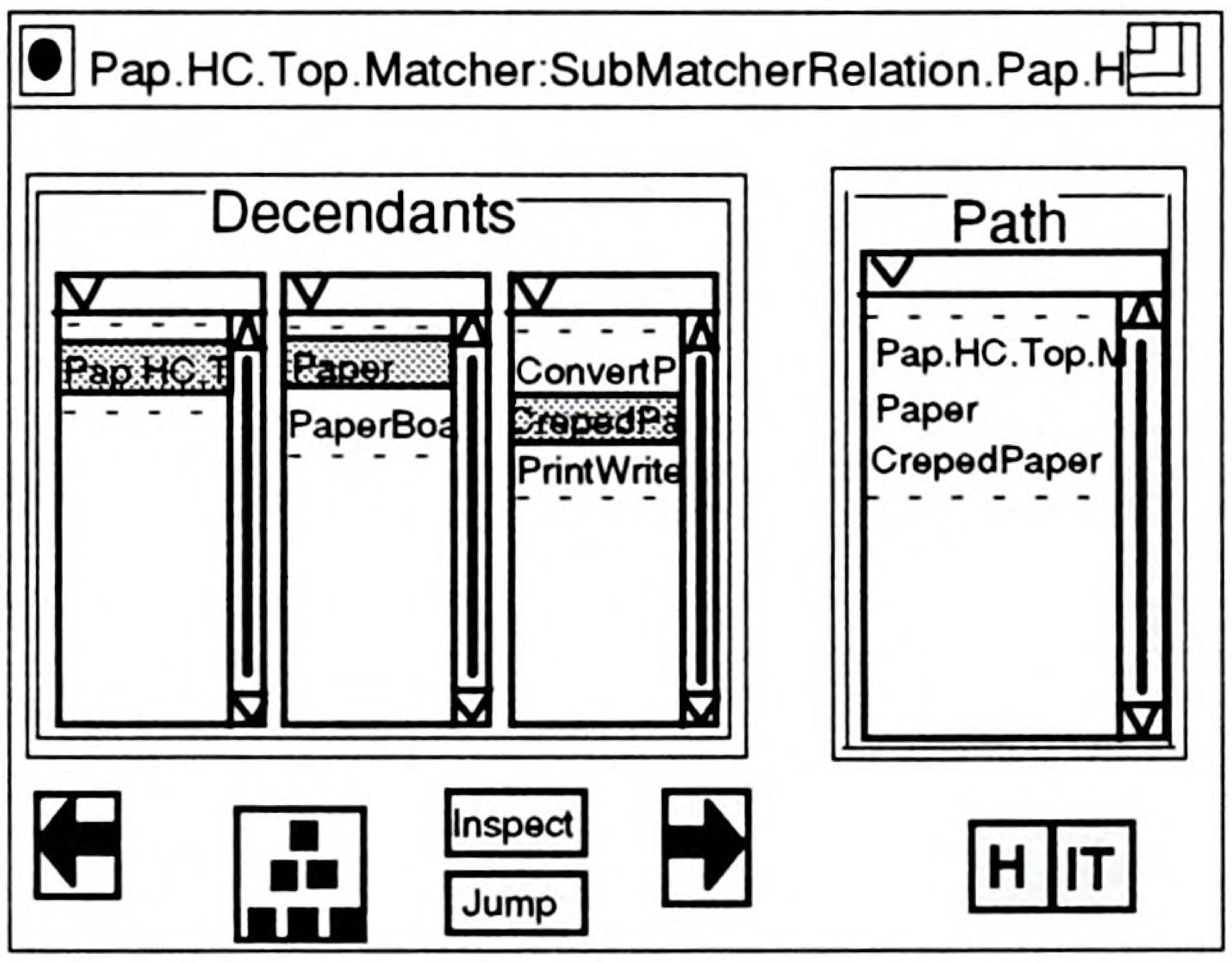

Figure 21: TableMatcher Window

The TableMatcher is a sub-window of the SubSpecialist window. When the classifier tries to establish at a node, it calls on its SubMatcher, or knowledge holder for that node. This Matcher has the information needed, or knows how to ask the user for the

necessary information to determine whether or not the node will establish or not.

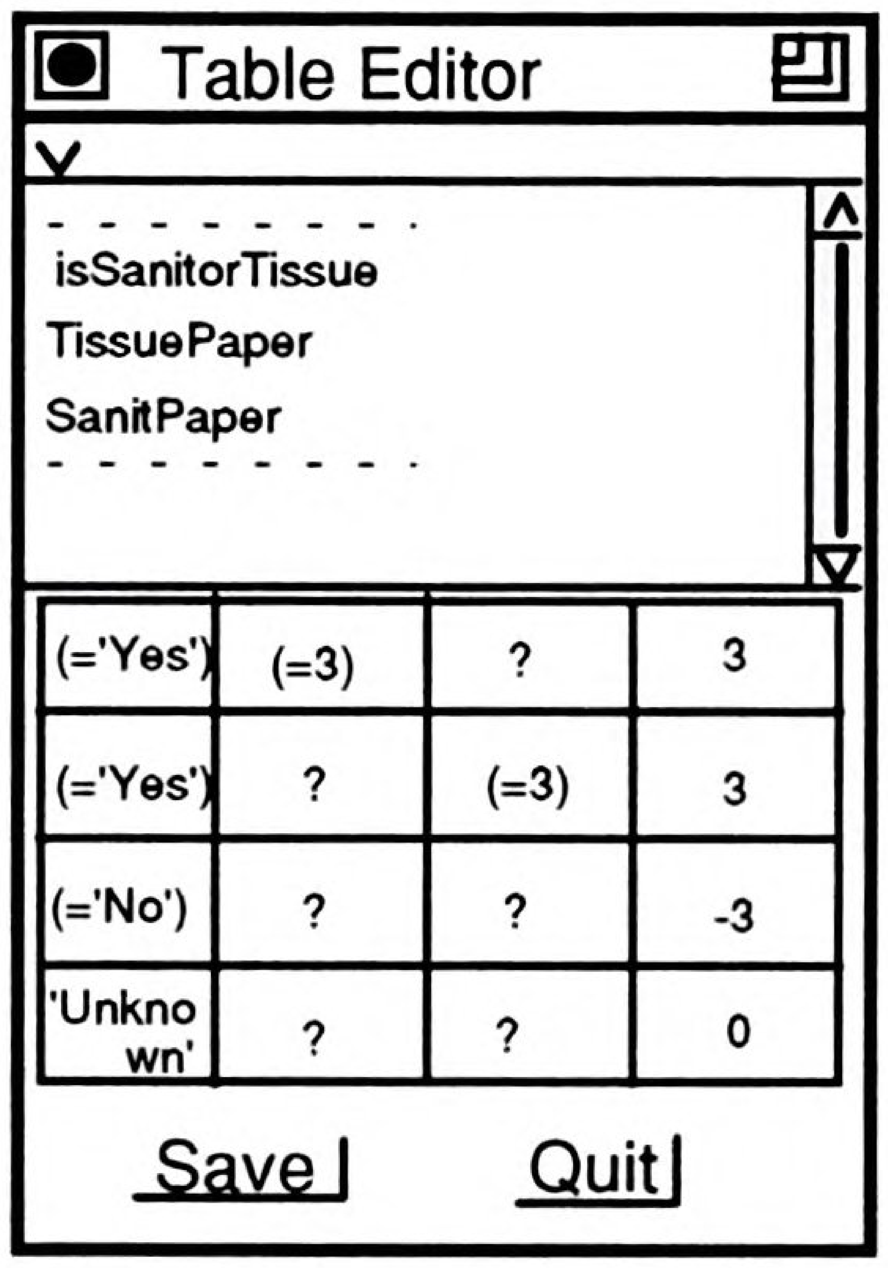

Figure 22: Table Editor

The Table is a sub-window of the SubMatcher. These tables contain the pattern-match knowledge for the system. This contains the rules of the system as a more or less weighted if then ruling. For example, in the above table, the first line says: "if {isSanitorTissue} = 'Yes' and TissuePaper has a confidence of 3, then the confidence is 3 (very high)." Since TissuePaper has a confidence value attached to it, the table has a sub-table which must be queried to determine its value and then return a confidence of 3 in order for this table's first line to return with a value of three. The order of the table is important. The sub-table will not be called unless it is either first or the previous rules have proven correct. Here, the classifier will enter the node on the SubMatcher and ask it to refine. The node checks its matching table to try to return a confidence value. When the problem solver enters the table, it will start with the first line

and solve from left to right. This is important in some cases to eleviate wasted search and refining. If, for example the first two boxes were switched in the above table, the problem solver would first try and find a confidence for TissuePaper (via its table information). The problem solver would have wasted that time in search if it comes back with a confidence of 3 but then finds out that the variable isSanitorTissue is 'No'.

Most of the difficulties in use came from the Table Editor(see 3.5: Difficulties in Use).

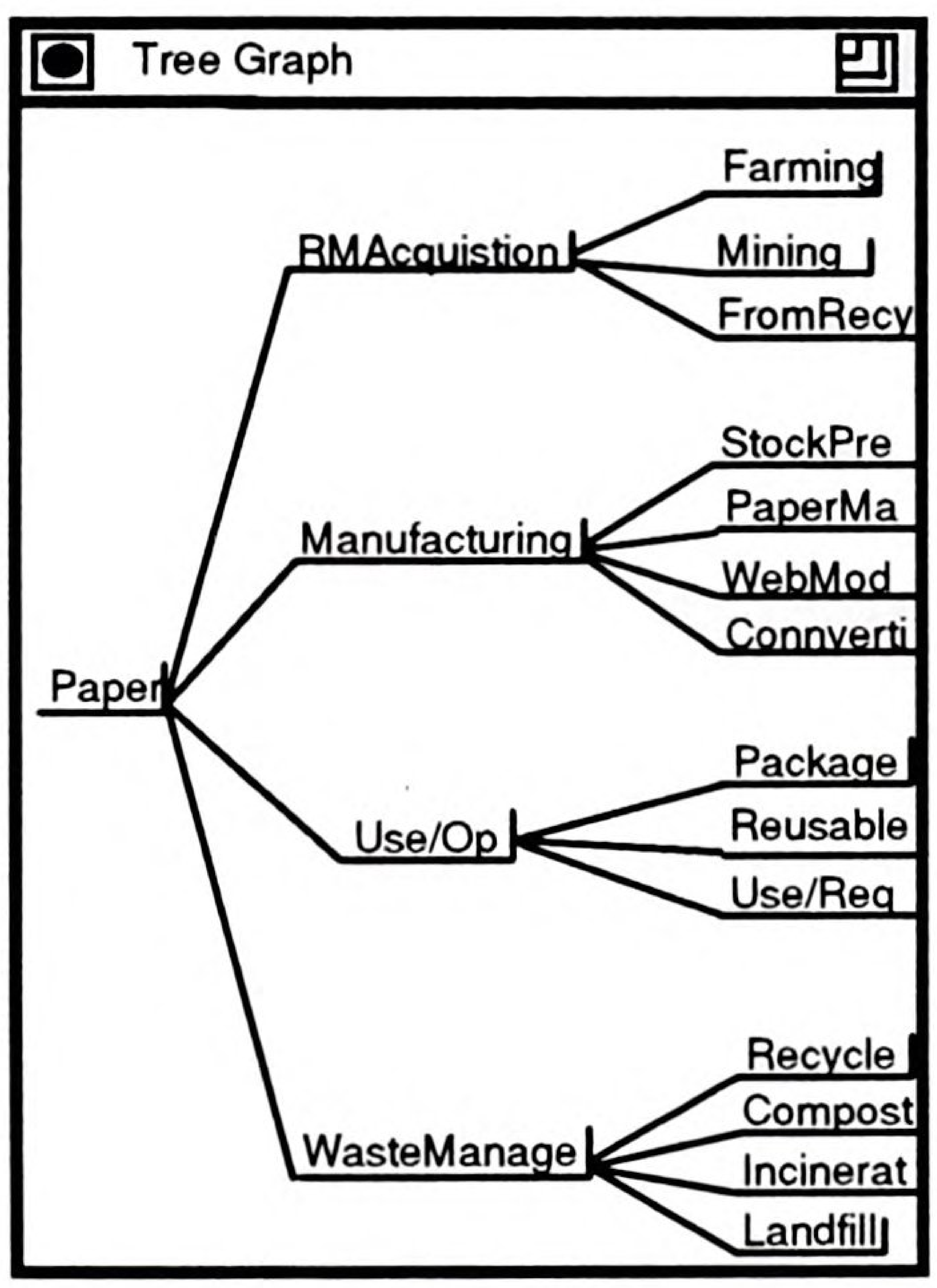

Figure 23: Graphing Capability

The graphing capability exists for both the table Matcher and the SubSpecialist relation. (Here, Figure 22 shows the SubSpecialist relation just down to the third level.) This window is brought up by depressing the tree button in the bottom of the Matcher or SubSpecialist windows (see Figures 19 and 20). This function is

particularly useful to prevent the knowledge engineer from becoming too lost while interactively building the Expert System. The nodes, however, do not update dynamically. That is, to see how changes have affected the set up, a new window has to be opened. Also, although the nodes are buttons (implemented with Tigre) they do nothing on depression. It would be particularly useful to have the SubSpecialist move to select (find and highlight) the appropriate node selected on the tree graph. This would save the steps required to locate that node when in the SubSpecialist alone.

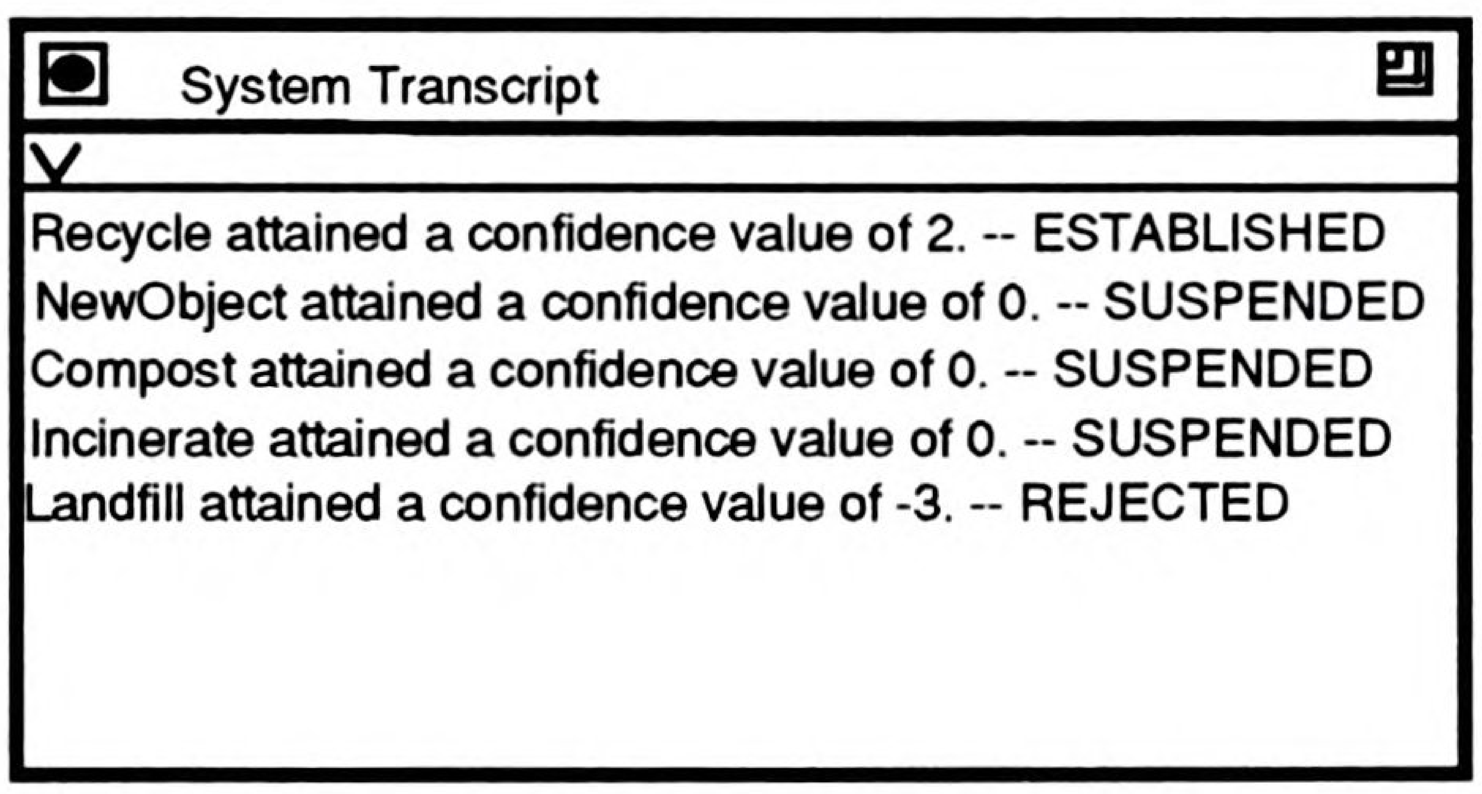

Figure 24: System Transcript

The System Transcript is mainly the output window for results. This window will dynamically indicate what value of confidence each node receives as the classifier runs through towards a solution.

3.4.3 Failure Handling

When conflicting knowledge is incomplete or inconsistent a node cannot establish and a failure occurs at the node. The Hierarchical Classifier identifies that failure as a confidence value of zero and

aborts continuing down the leg of that node. The problem solver will then jump back one level to the next highest node and try to establish one of its other children nodes.

3.4.4 Updating the knowledge base

Updating the system will be necessary as technology progresses. This will have to be done via the table Matchers. The rules will have to be checked periodically and altered accordingly. There is no easy way to update or check these data/rules. A recommended addition to the system is the Update/Check Data modules (Discussed in Section 3.5).

3.5 DIFFICULTIES IN USE; RECOMMENDATIONS FOR FURTHER DEVELOPMENT OF THE HIERARCHICAL CLASSIFIER

The current Hierarchical Classifier runs nicely but could use a few refinements.

1. It is difficult to run new cases. Currently, to run a new classification, a new case name has to be entered in Figure 16, the highest level node in Figure 19 must be highlighted, SupSpecialistRelation's operate menu must be activated, "run" highlighted, and finally "establish/refine" must be chosen.

2. A case cannot be edited. To run a similar case with but a few changes, the entire system has to be run again. The capability should exist such that the user could alter the information in one section and find global response.

3. The "Quit" button is ineffective or missing. It would be nice have a "Quit" button on windows. Some windows have "Quit" button already, but its function is as of yet limited. For example, in the table Matcher when the "Quit" button is selected, the system prompts the user to remind that the changes since the last save will be lost (even if no changes were made). Upon verification, the system does not leave the table, and the user has to use the window menu to close the window anyway. The DataBase define variable window needs a quit button.

4 Saving the database requires a lot of time due to all of the conformations.

5 The DataBase saves only with a direct data base save command. Upon simply choosing "Quit" in the Launcher, a prompt notifying that the DataBase has been updated since last save and would not be saved along with would be a helpful safety feature. Or, the save image could have the option to save the database.

6. The Matcher is a SortedCollection not an OrderedCollection which poses a problem in some instances. That is, if nodes would

like to be placed in a particular order, they cannot be, as SmallTalk sorts the list on input

7. In the Table Editor:

- the 'set condition' selection cancel leads to an error message

- when viewing the TableMatcher, if the mistake is made to select to edit a table, cancel is not one of the options (only: Simple Matcher or Data Attribute). After the mistake, a fake choice has to be made, the table must pop-up, and the it has to be closed. "Cancel" could be added to the pop-up menu.

- Need <OR> capability. Currently, the only way to do an <OR> statement is to create a new line. Thus, the table could end up looking like a diagonal array, with values along the diagonal, and question marks elsewhere. As an example ,

if (A Λ (B V C) then 3

could be entered instead of:

if (A Λ B) then 3

and if (A Λ C) then 3.

as is the case in Figure 21 where the first two lines could be consolidated as above. For small tables this is not a problem, but as the information base becomes larger, this will be a great hindrance.

8. No help has been installed for any of the windows. The help button is available, but it leads to a prompt indicating that no help is available.

9. The tree graph is a great visualization tool, however,

- it would be nice to have it selfUpdate, that is dynamically update from any changes in the SubSpecialist Relation.

- it would be nice to be able to click on a node and have the SubSpecialist relations window move to that node. As this tree graph shows all nodes, it would not be difficult to locate a particular node, instead of having to search the Matcher (as is currently necessary). This will be particularly useful as the size of the mapping becomes larger.

10. It is difficult to Update the knowledge of the system.

To update or add knowledge data/rules into the system, a previous understanding of the system is necessary in order to get into the workings of the classifier. A data acquisition /data check module could be developed as part of a user shell.

3.6 LIMITATIONS OF USING HIERARCHICAL CLASSIFICATION

Hierarchical Classification can be used mainly as the pruning method to consolidate a search. It cannot however, carry out the Life Cycle Analysis (LCA) alone. The pure classifying system simply classifies. It does not quantify impacts.

It cannot store variables, nor can it manipulate them. This capability will be essential for summing environmental impacts. To

allow this system to be suitable for Life Cycle Analyses, three changes/additions are needed.

1) An Explanatory capability is necessary.

This system could tell what to do, but not why. A higher level system should be capable of extracting the proper information at the level of specificity the user requires.

2) The end-user interface will need to be developed.

Currently, an end user needs to have prior knowledge of the building of the system to be in position to use it effectively. The final product should allow a user-friendly atmosphere.

3) A knowledge Acquisition Module is needed

This module is essential to allow the ease and accuracy of the knowledge base construction.

CHAPTER 4: PAPER PRODUCT CLASSIFICATION SYSTEM

INTRODUCTION

The experimental set-up of the classification system for paper is presented. A simplified system is shown as an example. The decision process is shown for one case to illustrate the operation of the Hierarchical Classifier throughout the problem solving.

4.1 The System

The simplified Classification system for paper is as follows:

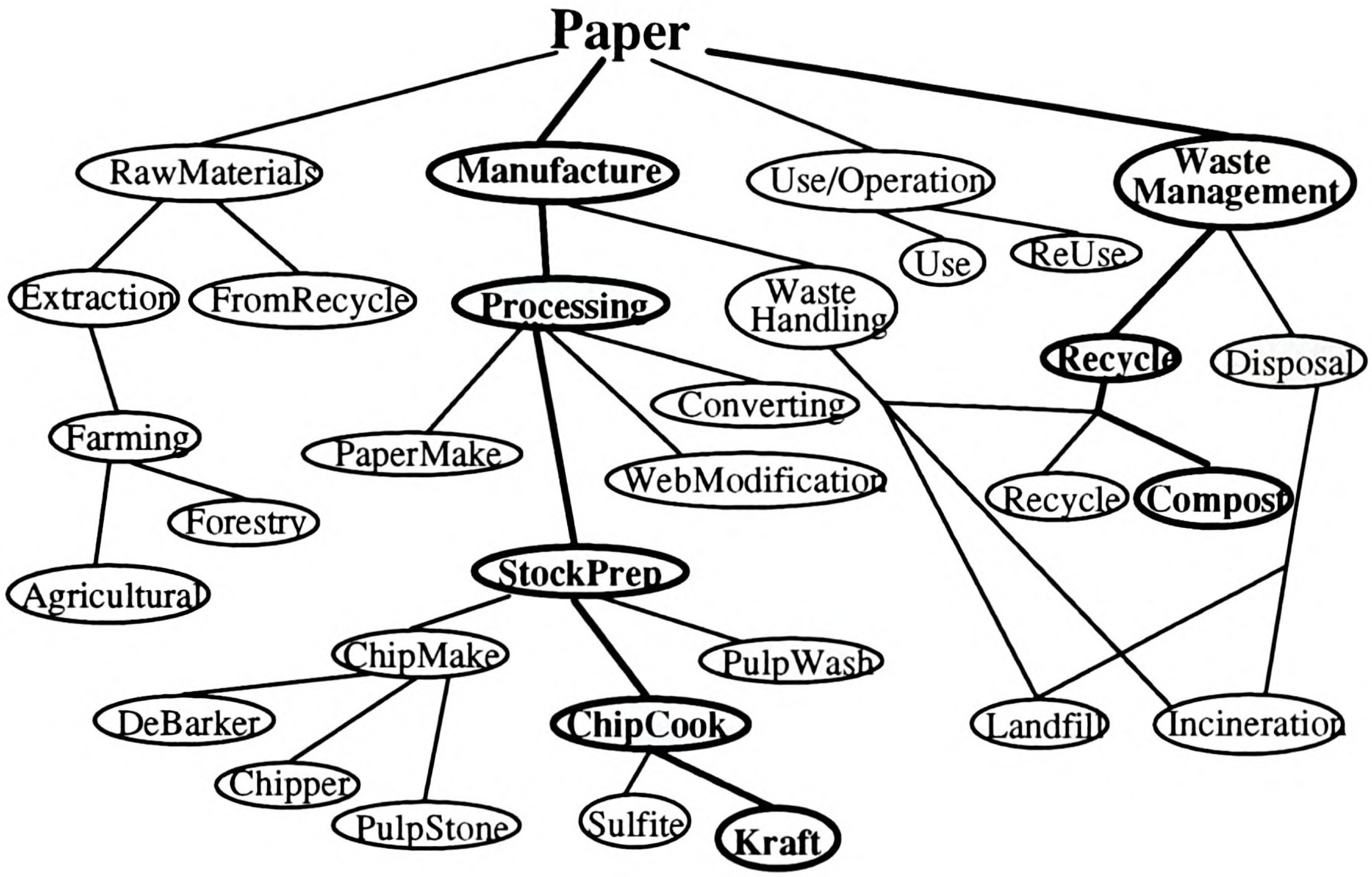

Figure 25: Classification System for Paper

Where Paper is the highest level node and the first descendants are the nodes which represent the main breakdown of a life cycle. This abbreviated hierarchy for paper is to illustrate the type of network an LCA must deal with. The highlighted portion shows a classification example traverse through a network of nodes. The first node in bold print here is Manufacture. The true classifier has been set up to start with RawMaterials, but this is just an example layout. To traverse through the network to the 'lowest' node (lowest in the tree shown in Figure 24, but highest in regard to specificity), the top agent, Paper, queries for a description of a product. The first answer it must establish is that the system is for a paper product. In this system, this answer is trivial, but when this system is expanded to include other higher level nodes and other

types of products, it will need to establish itself as being paper, as opposed to tin, say. Once paper is established, the query is made to determine what type of paper product: Paper or Paperboard? Then further refine to the specific type of paper product (while still in the top node). The table Matcher is set up as follows:

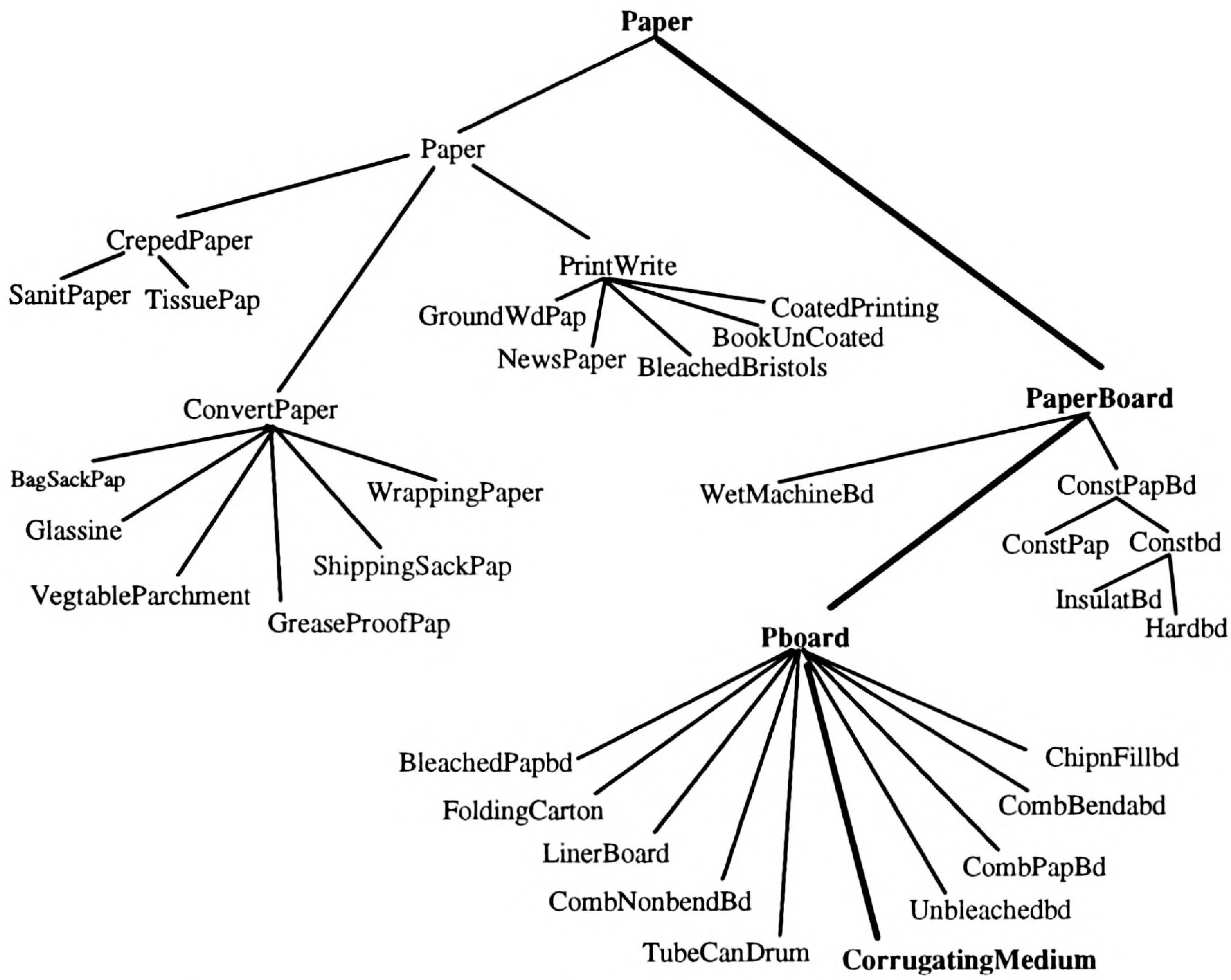

Figure 26: Table Matcher Example

As can be seen in Figure 25, the table Matcher not only establishes, it refines as well. The outcome of this node will not only be that the system is paper, but also what kind of paper. In Figure 25, the darkened lines follow the determination that the system is dealing

with CorrugatingMedium. Each one of these nodes have a table associated with them to determine the confidence value for that product. All of these 'nodes' are associated with the refinement of the top classifier node Paper.

This continues down until a leaf node (the lowest level) establishes. The system will then halt and query the user if it should continue. In the case of the LCA, at least four leaf nodes need to establish before completion (one for each main branch: RMAcquisition, Manufacturing, Use/Operation, and WasteManagement). The system has been set up such that each of these nodes will establish (as it is assumed that all products have at least these processes involved). Hence, once it is done establishing the processes involved with the acquisition of raw materials the system will then instruct the user that a leaf node has established, and the option remains whether or not to continue. In order to complete the classification, at least three other nodes will also have to refine and establish. This system, then, is made up of essentially four separate, but similar and interlinked, sub-classification systems.

4.2 Table Matchers

It has been attempted to wherever possible, establish the rules for the table Matchers from information in the literature. Where no specific rules were located, rules of thumb were sought out. An example of such is shown in Table 10 abbreviated from the Solid Waste Handbook [28]:

Reuse Potential	Recycling Suitability	Suitability for land storage	Suitability as Incinerator fuel	Suitability for Landfilling
Low	High/Variable	Not Suitable	High/Variable	Not Suitable

Table 10: Sample Basis for Waste Management Rules

With this information, the Landfill node was set with the condition: if the component is paper, then the confidence of using a landfill is -3, hence the Landfill node will be rejected every time paper is involved [see also 49]. Whereas, Recycling and Incineration would establish with a high value of confidence. Where such information was unattainable a best hypothesis was set for this experimental system.

4.3 Sample Results

As a whole, the results obtained seemed fair. Three sample results are provided to demonstrate the classification runs. The first example is a walk through the interactive procedure to complete an analysis. The next two examples simply state the waste management outcomes, as they are the most interesting (the other nodes simply establish the leafs of RawMaterials, Manufacturing and Use/Op, which are relatively generic). In an entirely built system, the specific processes involved in each step would be explicitly identified.

4.3.1 Corrugated Medium Example

The following is a sample of a classification run. The first item is the question asked by the system, with possible responses in "< >". The second (in italics) is the user-response given to identify this example as Corrugated Medium: The unindented lines are the responses of the computer after user-entry of the answer to the question just asked.

<u>SAMPLE CLASSIFICATION</u>

1) Is this system to classify Paper? <Yes, No, Unknown>

    Yes.

2) Is this Paper or PaperBoard? <Enter a String or Unknown>

    PaperBoard.

3) What type of PaperBoard? <choose from a list>

    CorrugatingMedium.

Paper.HC.Top attains a confidence of 3 - ESTABLISHED

RMacquistion attains a confidence of 3 - ESTABLISHED

Farming attained a confidence of 3 - ESTABLISHED

Forestry attained a confidence of 2 - ESTABLISHED

Timber attained a confidence of 2 - ESTABLISHED

4) A Leaf Node has Established. Is the classification complete?<Yes, No>

    No

5) How much of Raw Material is from Recycled Paper?

80%

FromRecycle attained a confidence of 3 - ESTABLISHED

6) Is the waste stream presorted? <Yes, No, Unknown>

Yes.

{PreSort Establishes}

7) A Leaf Node has Established. Is the classification complete?<Yes, No>

No.

{Manufacturing nodes establish}

8) A Leaf Node has Established. Is the classification complete?<Yes, No>

No.

9) How many times can the consumer reuse it? <value>

5.

{Use/Op nodes establish}

10) A Leaf Node has Established. Is the classification complete?<Yes, No>

No.

WasteManagement attained a confidence of 3 - ESTABLISHED

Recycle attained a confidence of 2 - ESTABLISHED

NewObject attained a confidence of 0 - SUSPENDED

ToRawMat attained a confidence of 2 - ESTABLISHED

11) A Leaf Node has Established. Is the classification complete?<Yes, No>

No.

Compost attained a confidence of 2 - ESTABLISHED

Incineration attained a confidence of 1 - SUSPENDED

Landfill attained a confidence value of -3 - REJECTED

4.3.2 Other Example Results

These results seem fair estimations of what could be done with the products (only the waste management node results are shown for the following two examples):

<u>For NewsPaper:</u>

WasteManagement attained a confidence of 3 - ESTABLISHED

Recycle attained a confidence of 3 - ESTABLISHED

NewObject attained a confidence of 1 - SUSPENDED

ToRawMat attained a confidence of 2 - ESTABLISHED

Compost attained a confidence of 2 - ESTABLISHED

Incineration attained a confidence of 1 - SUSPENDED

Landfill attained a confidence value of -3 - REJECTED

Which is essentially the same as for the CorrugatingMedium.

<u>For Tissue Paper</u>

WasteManagement attained a confidence of 2 - ESTABLISHED

Recycle attained a confidence of -2 - REJECTED

Compost attained a confidence of 2 - ESTABLISHED

Incineration attained a confidence of 0 - SUSPENDED

Landfill attained a confidence value of -3 - REJECTED

CHAPTER 5.0 CONCLUSIONS/FUTURE RESEARCH RECOMMENDATIONS

In the near future, an environmental audit will be required for every product and process, if not due to government regulation then due to the markets (consumers) demand. Life Cycle Analysis can provide the essential information necessary to improve each product and process environmentally and economically. With further development, the characteristics of an Expert System can be exploited to provide a tool to perform such analyses.

5.1 BENEFITS OF USING HIERARCHICAL CLASSIFICATION FOR LIFE CYCLE ANALYSES

Hierarchical Classification (HC) can help solve some of the problems associated with Life Cycle Analyses (LCA).

1) Data Limitation. Although this has been a major stumbling block in the past, HCs can help to circumvent it. Proprietary data need not be viewable or reachable within a system. Also, if the information is unattainable, the Expert Systems will provide the 'best' answer with incomplete information.

2) Lack of a Standard. The developed system can aid in providing the standard for carrying out LCAs. This system will then have to be tested completely by the governing bodies to implement such a standard, and in the long run, through interactive development - this system could be the LCA standard.

3) Cost. An LCA done using an HC utilizes the information of thousands of experts for the cost of one: the Expert System.

4) There exists no common currency. This is lesser tackled by the HC, than it is by the nature of LCAs. LCAs are not to criticize, but to present environmental impacts.

5 and 6) Boundary Conditions and Aggregation. Boundary Conditions are sometimes set to simplify the problem. With the aid of computing power and methods used by the HC to reduce computing time, the complexity of a problem is not a problem.

7) Fuzzy Rules Some experts cannot give precise quantitative data about processes, but can give estimates and rules of thumb which

govern the operation of these processes. This fuzzy, non-precise type of data is generally implementable in Expert Systems.

5.2 LIMITATIONS OF USING HIERARCHICAL CLASSIFICATION FOR LIFE CYCLE ANALYSIS

Hierarchical Classification can be used mainly as the pruning method to consolidate a search. It cannot however, carry out the LCA alone. The pure classifying system simply classifies. It does not quantify impacts. Ultimately, the goal of an LCA is to do just that, quantify impacts.

5.3 FUTURE WORK RECOMMENDATIONS

A system needs to be developed such that exploits the characteristics of a knowledge rich system and can provide the user with appropriate life cycle information.

5.3.1 Higher Level System

A final package should consist of a user-shell which will provide a simple interface for the user. One that could conduct an LCA by only asking pertinent questions. This systems LCA algorithm could be based on the best available methods, such as from CSA Z760, or

form Franklin Associates, Ltd. Such a system could take the form as in Figure 26:

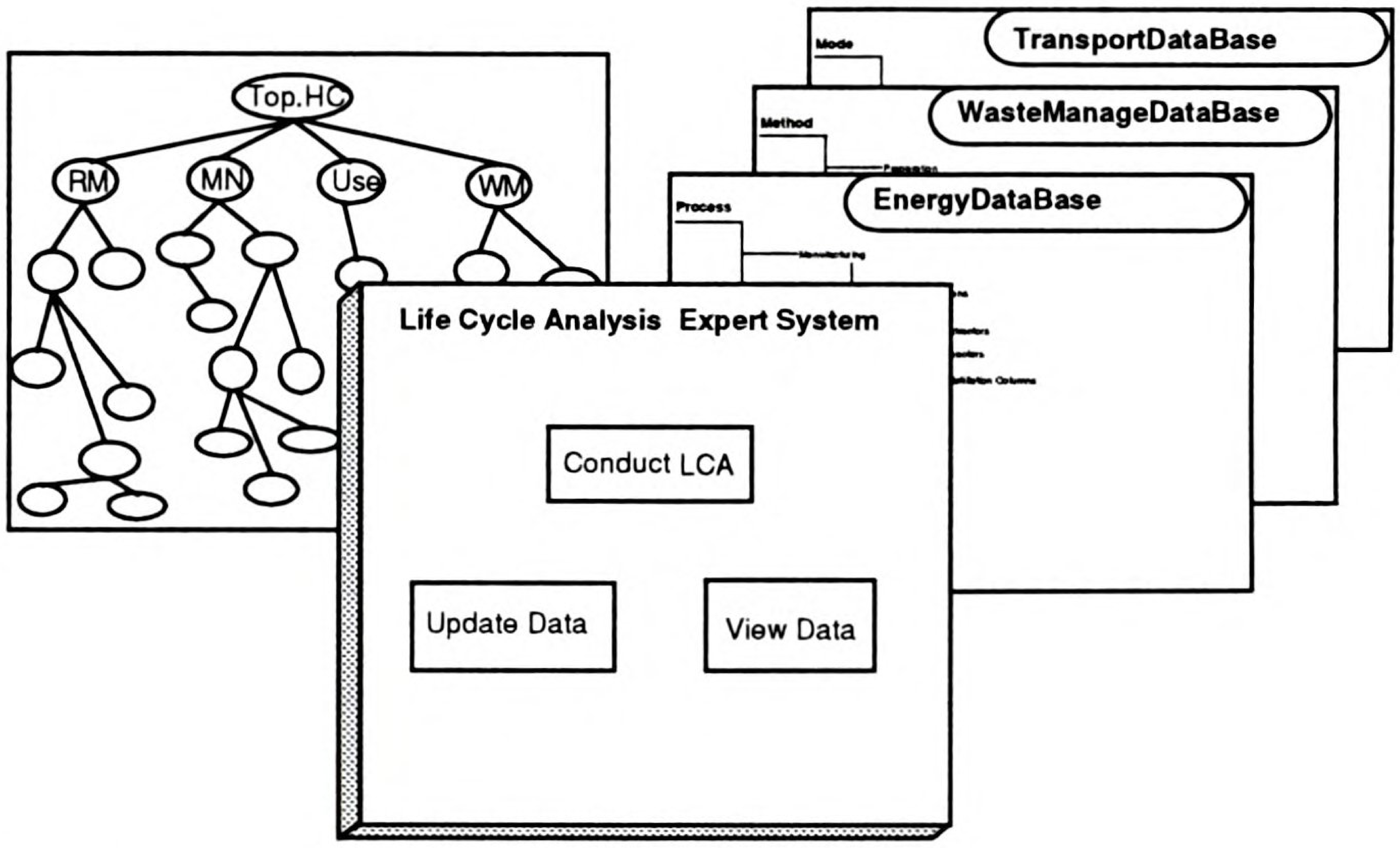

Figure 27: Potential LCA Expert System Application

Where the HC is a sub-part of the entire system. The Hierarchical Classification system could be run by the "Conduct LCA" button. The classifier will determine the processes involved for the desired product input by the user. Then via access to the appropriate databases, the system could return a quantified Life Cycle Analysis in a User-acceptable (i.e. understandable) manner. Or, once the process information has been established by the HC, a mathematical model such as the Manufacturing Systems of Koenig and Tummala could be adapted.

The Data manipulation buttons ("Update Data", and "View Data") will be of great use need to update or viewe the Rules or Data for accuracy. These buttons would lead to questions about the

information to update or view and would alter show accordingly. The nice feature about this is that this higher level will take care of the manipulation of the hierarchy such that no prior knowledge about the inner workings of the system is necessary, only the knowledge about the information architecture. This system will lead the user with appropriate questions to assure correct input of data. Since this system's integrity is an issue, data input should only be allowed through various security checks (password levels for example). This could help prevent hackers or desperate manufacturers from adulterating the system.

5.3.2 System Scope

The system needs to include not only paper products but also other major product components such as: ferrous and non-ferrous metals, composites, plastics, and cloth. The Higher Level System mentioned above should consist of a database also to determine the end impact values. This system should provide as concise and subjective a result as possible. It might be suitable to develop eco-balance modules for important subsystems such as energy production, waste treatment and transport. Standard modules for the production of important materials encompassing all the life cycle stages up to the final production stage could also be calculated and provided as input into product eco-balances.

5.3.3 Knowledge Acquisition and Domain Expertise

Once the basic system has been built, the task is long from over. The knowledge acquisition phase is a long and arduous task. This system should be able to classify a wide spectrum of products. For a new product, for example, a design engineer is faced with the same basic questions, i.e. how will this design affect the environment, or is full compostability the best design for a particular product? In order to accomplish such a decision making process, the information in the system must be extensive. Not only must the information be attainable to the system, it should be correct (the acquisition module should have a feasibility checker, though it cannot check for correctness).

Hence, the knowledge acquisition phase will involve interviews with many experts (essentially corresponding to the nodes represented in Figure 24, Chapter 4). This system must attempt to imitate such expert knowledge. Some engineers may know about the manufacturing of Polymethylmethacrylate but know nothing about paper bag manufacturing. So, in order to make the manufacturing nodes as 'smart' as possible, as much expertise from as many sources as possible needs to be included.

5.3.4 Continual Validation of System Performance

The system will have to be tested for performance throughout its continued development. This will provide information as to system capabilities, limitations and areas in need of improvement.

These tests can be made using LCAs that have been previously studied. These results can then be compared with those obtained from the system.

The Expert System construction should include continual checking of the decision making rules involved in the system. These rules should be discussed and verified by the appropriate experts (as mentioned in Section 5.3.3, a data acquistion module cannot check for correctness).

5.4 IMPACT OF THIS RESEARCH

This research introduces a new, more scientific approach to Life Cycle Analysis. In the past, Analyzers oversimplified life cycles to make data more manageable. With computer-aided design, this unruly amount of data can be easily managed and studied in an efficient manner.

There are nearly 135 public LCAs are available. Without a set standard for carrying out such a study, conclusions can vary greatly, confusing an already difficult question. This application could help define *the* standard to minimize the grayness around environmental decisions. A tool such as a Computer-Aided Life

Cycle Analyzer would minimize the amount of time needed to evaluate the impacts associated with a product. Such studies will then aid designers in developing as environmentally sound a product as possible, and will also help legislators determine and develop environmental regulations.

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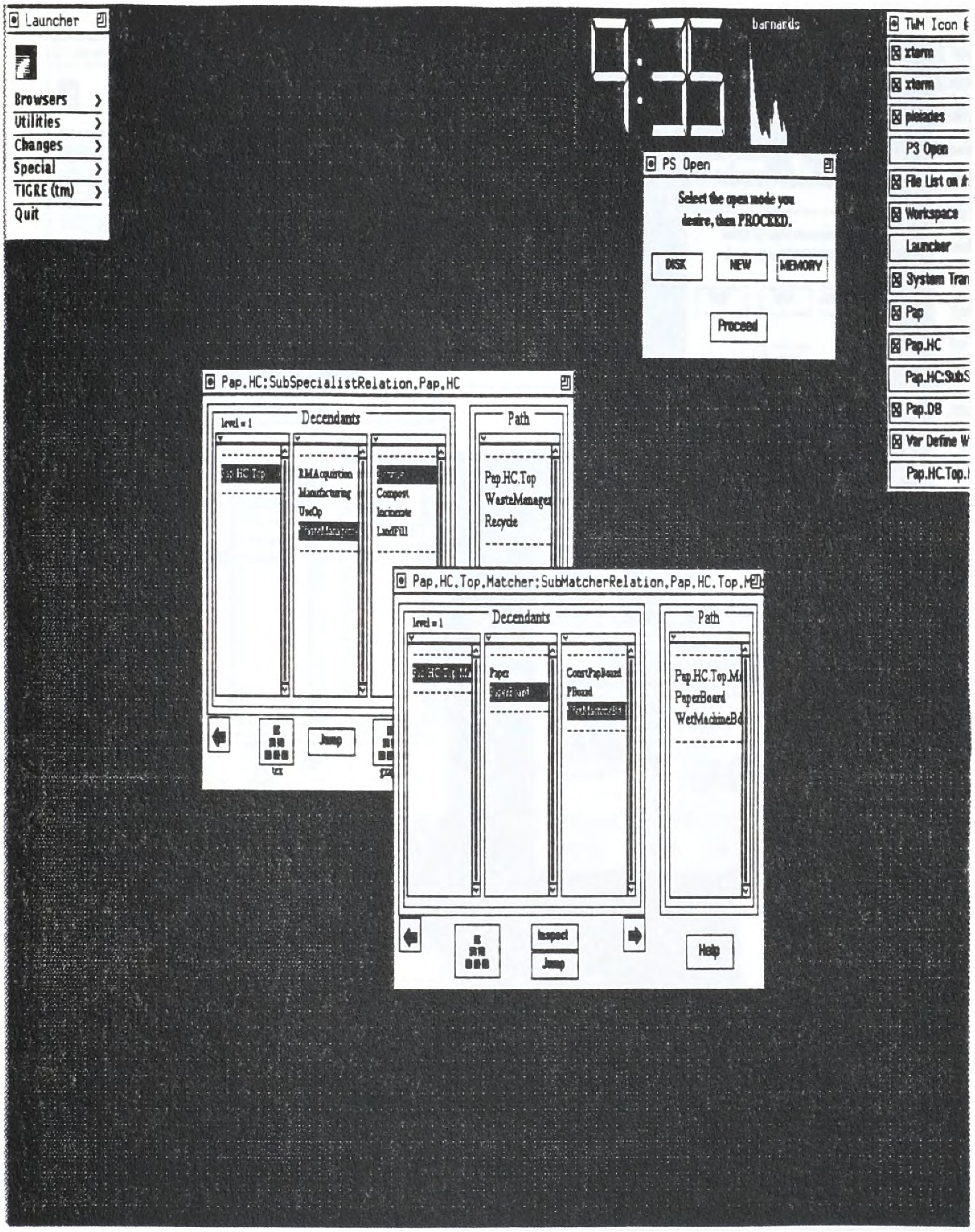
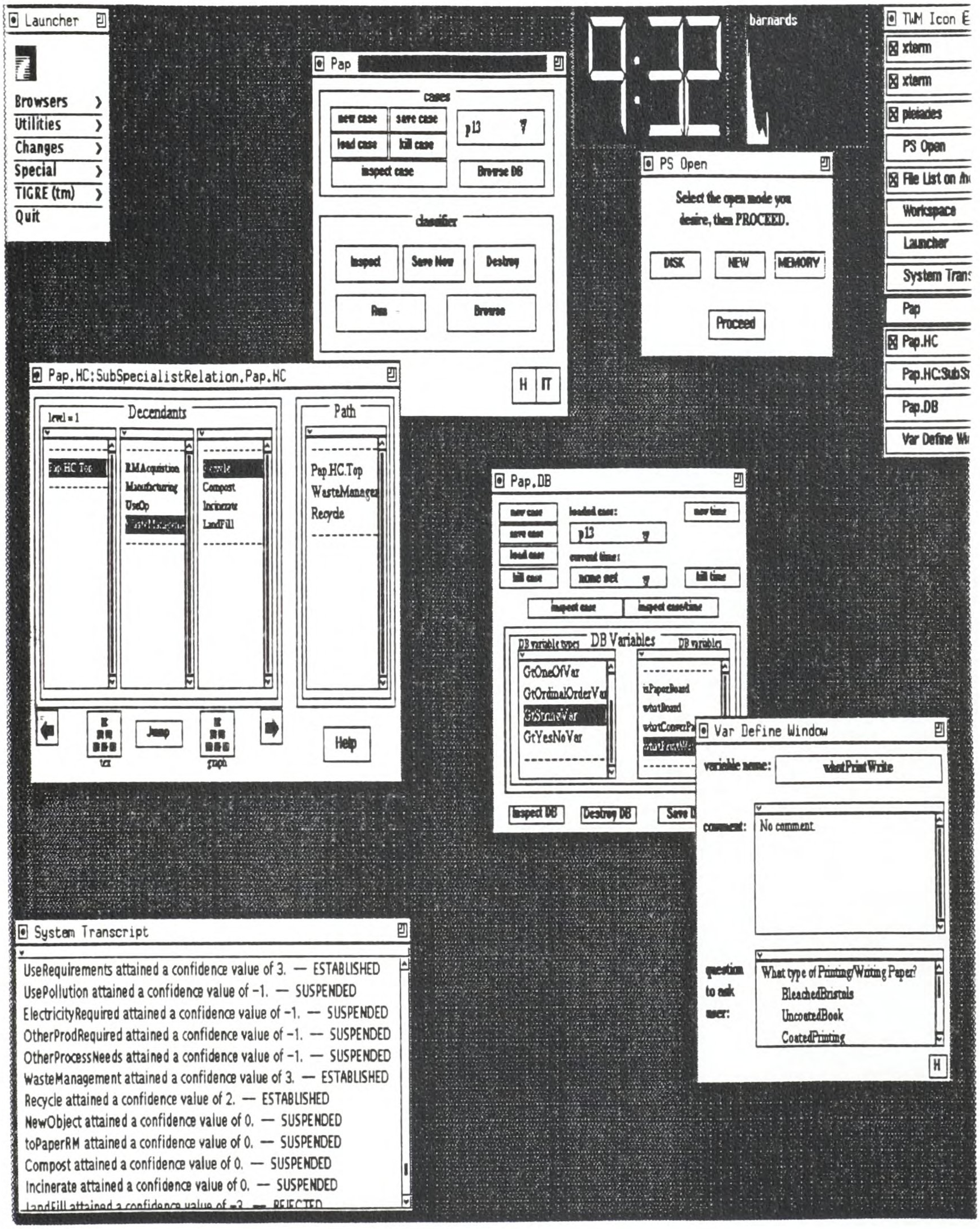
APPENDIX A

UNIX HIERARCHICAL CLASSIFICATION WINDOWS

This appendix contains the working windows for operation of the Hierarchical Classifier



Launcher
Browsers
Utilities
Changes
Special
TIGRE (tm)
Quit
barnards
9:35
PS Open
Select the open mode you desire, then PROCEED.
DISK
NEW
MEMORY
Proceed
xterm
xterm
pleiades
PS Open
Workspace
Launcher
Pap
Pap.HC
Pap.DB
Pap.HC:SubSpecialistRelation.Pap.HC
Decendants
Path
level = 1
RMAcquistion
Manufacturing
UseOp
Compost
Incinerate
LandFill
Pap.HC.Top
Recycle
Jump
Pap.HC.Top.Matcher:SubMatcherRelation.Pap.HC.Top.M
Decendants
Path
level = 1
Paper
ConstPapBoard
PBoard
PaperBoard
Inspect
Jump
Help


Launcher
Browsers
Utilities
Changes
Special
TIGRE (tm)
Quit
Pap
cases
new case
save case
load case
kill case
inspect case
p13
Browse DB
classifier
Inspect
Save New
Destroy
Run
Browse
H
IT
barnards
TWM Icon
xterm
xterm
pleiades
PS Open
File List on
Workspace
Launcher
System Trans
Pap
Pap.HC
Pap.HC:SubS
Pap.DB
Var Define W
PS Open
Select the open mode you desire, then PROCEED.
DISK
NEW
MEMORY
Proceed
Pap.HC:SubSpecialistRelation.Pap.HC
level = 1
Decendants
Path
Pap.HC.Top
RMAcquisition
Manufacturing
UseOp
Recycle
Compost
Incinerate
LandFill
Pap.HC.Top
WasteManage
Recycle
Jump
txt
graph
Help
Pap.DB
new case
save case
load case
kill case
loaded case:
p13
current time:
none set
new time
kill time
inspect case
inspect case/time
DB Variables
DB variable types
DB variables
GtOneOfVar
GtOrdinalOrderVar
GtStringVar
GtYesNoVar
isPaperBoard
whatBoard
Inspect DB
Destroy DB
Var Define Window
variable name:
whatPrintWrite
comment:
No comment.
question to ask user:
What type of Printing/Writing Paper?
BleachedBristols
UncoatedBook
CoatedPrinting
H
System Transcript
UseRequirements attained a confidence value of 3. — ESTABLISHED
UsePollution attained a confidence value of -1. — SUSPENDED
ElectricityRequired attained a confidence value of -1. — SUSPENDED
OtherProdRequired attained a confidence value of -1. — SUSPENDED
OtherProcessNeeds attained a confidence value of -1. — SUSPENDED
WasteManagement attained a confidence value of 3. — ESTABLISHED
Recycle attained a confidence value of 2. — ESTABLISHED
NewObject attained a confidence value of 0. — SUSPENDED
toPaperRM attained a confidence value of 0. — SUSPENDED
Compost attained a confidence value of 0. — SUSPENDED
Incinerate attained a confidence value of 0. — SUSPENDED