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Design of an information system for planning and decision making in the marketing of recyclable materials

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**Design of an information system for planning and decision making in the
marketing of recyclable materials**

by

Sharad Kumar Gupta

A Thesis Submitted to the
Graduate Faculty in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE

Department: Industrial and Manufacturing Systems Engineering
Major: Industrial Engineering

Signatures have been redacted for privacy

Iowa State University
Ames, Iowa
1993

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TABLE OF CONTENTS

1.	INTRODUCTION	1
2.	LITERATURE REVIEW	4
2.1	Introduction	4
2.2	Environmental database systems	4
2.3	Information systems	8
2.3.1	Data and information	8
2.3.2	Information systems characteristics	9
2.4	Development of information system	10
2.4.1	System design	10
2.4.2	Implementation	11
2.5	Database	12
2.5.1	Data models	12
2.5.2	Structured query language	15
2.6	Zip code classification	17
2.7	Graph theory terminology	18
2.8	Shortest path algorithms	19
3.	STATEMENT OF THE PROBLEM	22

4. MARTIN DATABASE MANAGEMENT SYSTEM	24
4.1 Introduction	24
4.2 Surveys	25
4.3 Recycling businesses survey response analysis	26
4.4 Database development	27
4.5 System operation	28
4.6 Implementation	32
5. INFORMATION SYSTEM DESIGN	33
5.1 Introduction	33
5.2 System objectives	33
5.3 Database structure	34
5.3.1 MARTIN database	34
5.3.2 Other data files	35
5.4 System Design	37
5.4.1 User-interface design	37
5.4.2 Structured query language	39
5.4.3 Queries	39
5.4.4 Zip code search	44
6. TOOLS FOR DECISION MAKING	46
6.1 Introduction	46
6.2 Available data	46
6.3 Inter-city road distance calculation	47
6.4 Model development	49
6.4.1 Assumptions	49

6.4.2	k-shortest path algorithm	49
6.4.3	Double sweep algorithm	50
6.5	Model application	53
6.5.1	Introduction	53
6.5.2	Problem formulation	54
6.5.3	Solution procedure	55
6.6	Example of the decision model	60
7.	CONCLUSIONS	71
7.1	Conclusions	71
7.2	Recommendations for future research	73
	BIBLIOGRAPHY	74
	ACKNOWLEDGEMENTS	78
	APPENDIX A. DATABASE AND BULLETIN BOARD SYSTEMS	79
	APPENDIX B. RECYCLING BUSINESSES SURVEY FORM . . .	82
	APPENDIX C. MARTIN DATABASE STRUCTURE	86
	APPENDIX D. FLOWCHART FOR INFORMATION SYSTEM .	89

LIST OF TABLES

Table 4.1:	Overall response to recycling businesses survey.	27
Table 6.1:	Distance between selected cities in Iowa	48
Table 6.2:	Arc distances and corrected distances from Ames, IA for cities for markets of materials	61
Table 6.3:	Distance matrix for the state of Iowa for network	63
Table 6.4:	Recommendations for shipping materials separately	65
Table 6.5:	Recommendations for shipping paper and plastics together	65
Table 6.6:	Recommendations for shipping paper and iron together	66
Table 6.7:	Recommendations for shipping plastics and iron together	66
Table 6.8:	Recommendations for shipping all three materials together	67
Table 6.9:	Overall three shortest path recommendations for shipping at- most two materials together	67

LIST OF FIGURES

Figure 1.1:	U.S. municipal solid waste generation, 1960-2010	2
Figure 2.1:	Examples of path, chain, circuit and cycle	18
Figure 2.2:	Shortest path from node s to node t	20
Figure 4.1:	MARTIN's login menu	29
Figure 4.2:	Materials menu	30
Figure 4.3:	State menu	30
Figure 4.4:	Full company record	31
Figure 5.1:	MARTIN database structure	36
Figure 5.2:	Screen for full company record	40
Figure 5.3:	Screen for transportation information	41
Figure 5.4:	Help screen for explanations of abbreviations used in full com- pany record	42
Figure 5.5:	Zip code search for zip code 50010	45
Figure 6.1:	Directed network for shortest path problem	54
Figure 6.2:	Sample Network for calculating $O \rightarrow 3$ shortest path	58
Figure 6.3:	Comparison of lengths of two feasible paths	59
Figure 6.4:	Cities identified in Iowa as markets	64

Figure 6.5:	Page 1 of report of the decision model	68
Figure 6.6:	Page 2 of report of the decision model	69
Figure 6.7:	Page 3 of report of the decision model	70

1. INTRODUCTION

As the United States enters the middle 1990s, it continues to confront a serious, ongoing solid waste crisis. Many of the existing landfill facilities are quickly reaching capacity, or will do so in the near future. To increase the shrinking landfill capacity, either existing capacity must be extended, or new landfills must be established. However, the main disposal strategies used previously - disposing of the waste in landfills or burning it in high- temperature incinerators - are under fire from public challenges, legislative restrictions, rising prices, increased tipping fees, and widespread health and environmental concerns [1]. These problems are compounded by the fact that the volume of municipal solid wastes, the range of non-liquid, presumably non-hazardous, and nonradioactive wastes that fill our dumpsters continues to grow at about a rate of one percent each year (See Figure 1.1) [2]. With both landfills and incineration facing strong community based opposition and serious financial and political constraints, alternative options are being explored. The waste disposal options specified and prioritized by the US Environmental Protection Agency (EPA), in the "The Solid Waste Dilemma: An Agenda For Action", are [3]:

1. Maximize source reduction or reduce the amount of waste generated;
2. Reuse or recycle as much as possible;

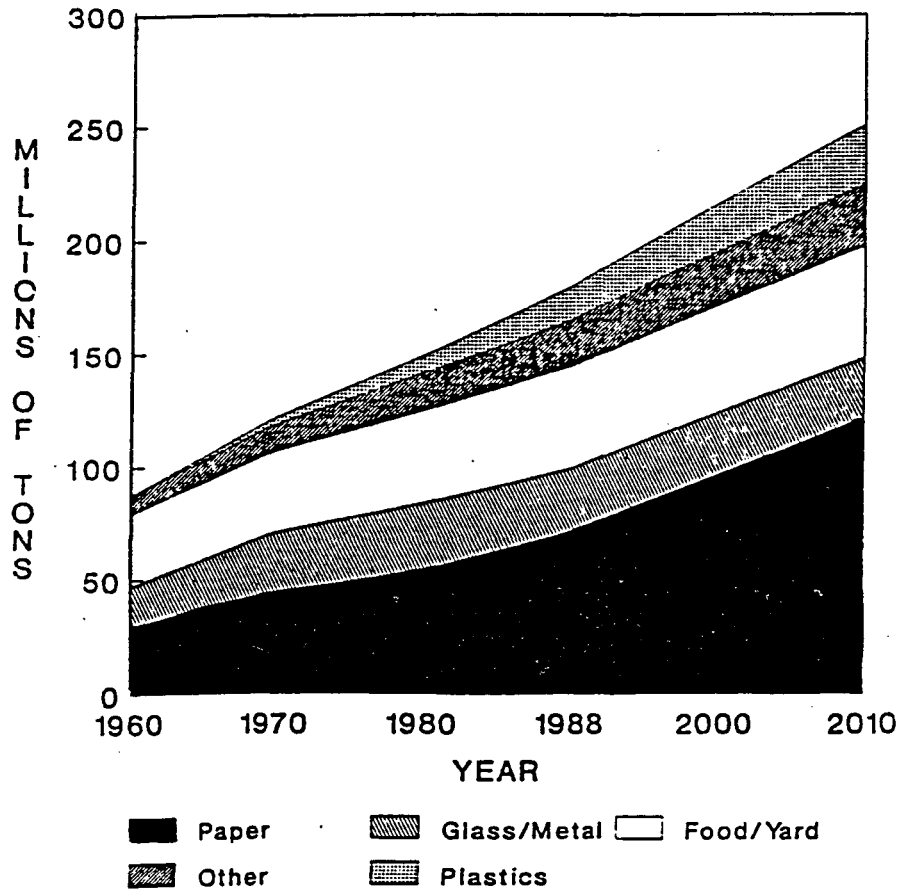


Figure 1.1: U.S. Municipal Solid Waste Generation, 1960-2010

3. Burn what remains in a waste-to-energy plant; and
4. Landfill, but only as a last resort.

→ A study was conducted by Adams et al [5] to develop a comprehensive solid waste analysis for the state of Iowa. The purpose of the study was to determine the optimum locations for mechanical solid waste-to-energy plants and to develop collection and transportation strategies and networks to serve these plants. During the course of study, they found that the market values of paper and cardboard far

exceeded their values as refuse derived fuel. Hence they concluded that solutions to solid waste problems lie in community recycling programs and not in incineration with or without energy recovery.

Faced by the new legislative laws in various states which bar landfilling of certain recyclable materials, cities are emphasizing various recycling programs to eliminate the restricted materials from the waste stream. The flurry of recycling activity that has emerged in the last several of years has centered primarily on the supply side of recycling. This has included expanded source (curb-side) separation programs, "bottle bills," and materials recovery facilities. While supply side activities have increased substantially the availability of materials for recycling, they have not led to the development of markets for recyclables.

There exists a need to establish markets for the secondary materials and the development of the suitable logistics. A research project termed MARTIN (Mid America Recycling and Transportation Information Network), undertaken at Iowa State University, Ames, Iowa [4] concentrated on development of a regionalized computer based database system that would provide market and transportation information for secondary materials to recyclers and users of secondary materials. During the course of the project it was realized that there is a need to provide users with tools that would aid the user in decision making for the marketing of materials. The purpose of this thesis is to develop MARTIN into a decision support information system that would provide decision making tools and would help users in identifying markets for the secondary materials. This thesis is a part of a project funded by the U.S. Environmental Protection Agency, Region VII through the Iowa Department of Natural Resources.

2. LITERATURE REVIEW

2.1 Introduction

A major setback to recycling by industry has been the very erratic supply of the recyclable materials. According to a study conducted in Illinois [6], developing or enhancing markets for secondary materials is likely to be the most important aspect of reselling residuals diverted from municipal waste streams. Merely increasing the efficiency of separating residuals from waste may extend landfill capacity, but the benefits will be offset by the costs of warehousing the recyclables until they can be sold. There is a definite need for better information sources regarding markets for the materials. In last few years there has been a flurry of activity in development of bulletin board systems from local to national level for the purpose of providing information on recycling.

2.2 Environmental database systems

As attention directed towards the environment increases, the number of sources for accessing environmental information also grows. A series of articles in the journal Database [7] [8] [9] reviews the sources available to access information on environmental issues. According to these articles, searching for environmental information often seems like standing at the base of a towering cliff unprepared to begin the

laborious climb. Although there are numerous sources to access environmental information, there are only a handful of databases available that provide information on issues concerning recycling and marketing of recyclable materials. With the advent of numerous laws and regulations during the past few years encouraging recycling as a cogent goal of waste management, information on the markets for secondary materials has increased tremendously. Many states and agencies are busy developing their own bulletin board systems for providing information on recycling and to develop markets for recycled materials. Some of the bulletin boards and database systems that provide the information related to recycling and are currently online are discussed below.

SWICH (Solid Waste Information Clearinghouse) is an electronic bulletin board system which was developed by The Solid Waste Association of North America under a grant from USEPA, Office of Solid Waste. It provides information on solid waste issues such as state and federal legislation and regulations, upcoming meetings and conferences, books and publications, and educational information. It also provides electronic mailing facilities. The bulletin board can be accessed through a computer/modem and is available free of cost. The user has to pay the call charges only.

PenCycle, created in 1990 by the Pennsylvania Resources Council is a regionalized electronic bulletin board system that provides information on recycling various materials. It contains a feature 'ask the experts' which allows a user to leave a query on the system that would be answered by an expert in the pertinent field. It provides electronic mail services and allows teleconferencing. It also provides an online shopping plaza where the user can buy various products from catalogs. The system can

be accessed through a computer/modem or through a fax machine. A subscription is charged for the system.

RecycleNet is a bulletin board service developed by the Colorado Office of Energy Conservation. It provides electronic mail and bulletin board services providing information on meetings and conferences and other general information on recycling. The system can be accessed through a computer/modem.

Recycling: America is a bulletin board system with the purpose of educating about the advantages of recycling. It also allows users to place advertisements for buying or selling recyclable materials. It provides electronic mail and teleconferencing. The system can be accessed through a computer/modem and is available free of charge.

Recyclable Materials Market Directory is a database maintained by the Wisconsin Bureau of Solid and Hazardous Waste Recycling and the Wisconsin Department of Natural Resources. It is a regionalized database containing the directory of firms dealing with recyclable materials. The program can be obtained on a floppy disk by sending ten dollars to the Wisconsin DNR.

PIES (Pollution Prevention Information Exchange System) is a bulletin board system maintained by Office of Environmental Engineering and Technology Demonstration (OEETD) and Office of Pollution Prevention in Washington, D.C. The system contains descriptions of Federal and State pollution prevention programs, abstracts of technical case studies and actively used publications and expert contacts in the field. A calendar of events containing a comprehensive list of national and international conferences, training seminars, and workshops is available. An on-line library is available from which documents can be selected and transmitted directly

to a PC or a fax machine. The bulletin board can be accessed free of charge through a computer/modem. Few sections of the bulletin board are restricted to subscribers of the system only.

RecycleLine is a database and bulletin board system that provides information on buyers and sellers of recyclable materials, a recycled product guide, and a listing of equipment and service companies. Other features include commodities pricing information, a calendar of events and classified advertisements to buy or sell materials. It also provides electronic mailing and teleconferencing services. The bulletin board can be accessed through a computer/modem. The system is operated by American Recycling Market Inc. and has been online since May 1992. A subscription fee is charged for accessing and using the system.

Environet is a public bulletin board system sponsored by Greenpeace Action. The system is located in Greenpeace regional office in San Francisco. Environet operates primarily as a person-to-person information exchange for people and grassroots groups interested in the areas of ecology. It is also a source of Greenpeace related material such as press releases, newsletters and bulletins.

FRMS (Florida Recycled Material System) is an electronic bulletin board system that provides general recycling information along with recycling directories. In addition, classified advertisements for buying or selling recyclable materials can be placed on the system. It also provides electronic mail and teleconferencing services. The system can be accessed through a computer/modem and is available free of charge to any user through a toll free telephone number.

MAKAAO is bulletin board system containing information on environmental resources for Hawaii. It provides electronic mail and bulletin board services providing

information on meetings, conferences and other general information on recycling. It maintains a directory of environmental organizations and directory of environmental and ecological businesses and services. The system can be accessed through a computer/modem.

The telephone numbers for accessing and getting more information on the database and bulletin board systems discussed in this subsection are given in Appendix A.

2.3 Information systems

An information system is a tool for accepting data as input and producing information in various forms as output for the system users. Improving system performance is the ultimate objective of information systems - not storage of data, the production of reports or even "getting the right information to the right person at the right time."

2.3.1 Data and information

Data serve as the input to an information system. Data are raw facts and figures that are not currently being used in a decision process. A further distinction between data and information is that data are language, mathematical, and other symbolic surrogates which are generally agreed upon to represent people, objects, events, and concepts [12].

Information is data placed into a meaningful context for its recipient. Information consists of data that have been retrieved, processed, or otherwise used for informative or inference purposes, argument, or as a basis for forecasting or decision making [10]. In an information system, the information is stored in a database.

2.3.1.1 Formal versus informal information Formal information systems are based on the supposition that the system can identify the information requirements of the user and can also determine the methods of producing information from data to satisfy these requirements. Formal information allows us to extract from the recipient the processing or conversion procedures for producing information from data. On the other hand, the value of informal information is arbitrarily assessed by its recipient. The form and content of informal information are both subjective and unstructured, and the process which converts data to information cannot be separated from the recipient [12].

2.3.2 Information systems characteristics

Following are the most important characteristics of an information system:

The **range** or **scope** of activities that the information system supports may vary depending on the specific needs of an organization.

The **capacity** of the system may be represented by several possible measures such as number of data transactions processed in a given period of time, volume of data stored, or the amount of processing that can be handled.

The **accuracy** of an information system refers to the lack of errors in its output. Errors can occur in the original collection and entry of data, in its processing, or in its output.

Accessibility refers to the availability of information to the system's users when it is needed by them and without an unreasonable amount of effort.

The **age** of data refers to the currency of the data. In some applications, data must be very current, e.g. an airline reservations system; in other applications data

may not require great currency.

The **usefulness** of information must be measured in terms of its users. This is a function of factors such as format, clarity of presentation, etc.

Consistency means that the information provided to different users or to the same user does not contradict itself and reconciles correctly. This is primarily a function of using homogeneous data and of updating stored data in an internally uniform and compatible manner. Consistency does not, however imply accuracy.

2.4 Development of information system

The evolution of an information system project from the original idea to full implementation and operation is a long and complex process. The motivation for initiation of a systems project may come from a number of sources such as: problems or deficiencies in an existing system; conversion of a manual system to a computer based system for greater efficiency; faster information retrieval; implementation of a new idea/technology; or better accuracy and improved consistency in processing data. A system undergoes a life cycle of its own. The system development life cycle is a set of activities which analysts and users carry out to develop and implement an information system [17].

2.4.1 System design

The system objectives outlined during the information analysis serve as the basis from which to structure an information system design. Equipment independent data system solutions are designed for the information system that has been described in the information analysis. System design proceeds through two phases: logical

design and physical design. During logical design, detailed specifications of the new system are written describing its features: outputs, inputs, files and data bases, and procedures - all in a manner that meets project requirements. Physical design, the activity following the logical design, produces program software, files, and a working system. Design specifications are for instructing the programmers about what the system should do.

The main goal is to develop a methodology which enables [15]:

- a faster development of information system,
- more flexible and reliable information system with an adequate level of functionality,
- more maintainable system, and
- an extended scope (e.g., to solve more complex problems and to realize more integrated system).

2.4.2 Implementation

Implementation includes all activities that take place to put the new system into place.

After the system is implemented, a review of the system is conducted by users and analysts alike. It determines how well the system is working, how it has been adapted, and whether adjustments are needed. The review is also important to gather information for the maintenance of the system.

2.5 Database

This section covers details about the database management systems. How database are organized and how to manipulate data in the database are the major concerns discussed here. A database is an integrated collection of logically organized data. The various pieces of data within the database must have some logical connections or relationships among themselves for the database to be integrated [10].

2.5.1 Data models

A data model is defined as a logical representation of a collection of data elements and the association among these elements [11]. Data models form the underlying structure for the database management systems (DBMSs). From a logical aspect, data are stored in varying schemes. These schemes are called data models. The data model is a representation of entities and their association. Database management systems have characteristics of data consistency and data integrity. These characteristics result from applying data models to DBMS. The constraints of the DBMS are superimposed on the data model to form the distinguishing features of each DBMS. Data models can be classified as hierarchical, network, and relational models. Each model presents a different path of data access.

2.5.1.1 Hierarchical model The hierarchical model is the oldest of the three data models. An hierarchical database uses the tree as its basic data structure. The tree consists of a number of nodes arranged in hierarchy. Relations are represented as branches or pointers between nodes. A hierarchical database consists of one or more trees. A single tree represents one data file; its records are organized

into tree structure.

Nodes of the trees in the hierarchical model represent data records. Each node contains one or several fields or attributes. The nodes and branches in the hierarchical model are used to describe the parent/child relationships. A single node at the highest level of hierarchy is the root. A node may have any number of children, but each child node may have only one parent node on which it is dependent.

The advantage of an hierarchical model is that its database design is very simple. When one understands the hierarchical path, one can easily address the data. Accordingly, the operation of an hierarchical database system is fast. In addition, because “no child (node) is allowed to exist without its parent (node),” data integrity exists [13].

There are a few limitations of the hierarchical model. Since a child can have only one parent, one-to-many or many-to-many relationships cannot be made which could result in data redundancy. For example, some nodes that may have common subtrees will have to create their own sub-trees to maintain data consistency resulting in data redundancy. Another limitation is that following the natural path of the hierarchy may be time-consuming. Also, it is difficult to modify the structure of an hierarchical database. For example, adding some parent nodes would lead to children nodes reorganization. There is minimal data independence in an hierarchical model. Application programs which are sensitive to the change of a hierarchical path require modification when database changes occur.

2.5.1.2 Network model A network model uses a network structure. A network is a directed graph consisting of nodes connected by links or directed arcs.

A network is like a tree structure which allows each child node to have multiple parent nodes. A network model is classified as being either simple or complex based on the multiple parentage. A simple network model allows multiple parent nodes only with different record types. A complex network permits the multiple parent nodes to be of either the same or different record types.

Simple network models still can not represent many-to-many relationships, thus the data redundancy can not be eliminated completely. Complex networks can represent many-to-many relationships and, as the result, reduce the data redundancy. However, this makes its implementation difficult. Like hierarchical model, the structure of network model is too rigid to modify.

2.5.1.3 Relational model The relational approach to database design takes advantage of the power of mathematical abstraction and of expressiveness of mathematical notation to develop a simple but powerful structure for databases [20]. The basic structure of the relational model is simple and allows for separation of logical and physical levels, so that logical design can be performed without considering storage structures. The model uses a few very powerful commands to accomplish data manipulations that range from the simple to the complex.

The relational database is based on the concept of a relation, which is physically represented as a **table**. A relation is represented as a two dimensional table in which the rows correspond to individual records called **tuples** and the columns correspond to **attributes** or fields.

In a table, each column has the same data type. The data type is called the domain of column. Each row must have a unique value in a certain column in order

to identify it. These columns in a table are called keys. The key(s) assignment must be distinct. The most distinct column of a table is called the primary key, which serves the table for identification purpose. Some columns are not the primary keys of the table they located, while they are other table's primary keys.

A relational model has several high-level languages for data manipulation. Some of the languages, such as SQL, QUEL, and QBE are based primarily on relational calculus. The relational database operations will be discussed in the next section by introducing structured query language or SQL.

2.5.2 Structured query language

Structured query language (SQL) is a nonprocedural relational database language. It includes defining the structure of the data set, modifying data in the database, and specifying security constraint. There are three elements of SQL: Data Definition language (DDL), Data Manipulation language (DML), and Data Control language (DCL). There are only twelve SQL commands which fall into these three sub-languages. The following section explains some of these commands.

2.5.2.1 Data definition language The DDL creates SQL objects and stores the definitions in tables. The objects mean tables and indexes. To create the FIRM table, the SQL syntax shall be:

```
CREATE TABLE FIRM
(ID INT NOT NULL, NAME CHAR(25) NOT NULL,
ADDRESS CHAR(40), PHONENUMBER INT,
MATERIALS CHAR(45))
```

CHAR is the domain of NAME, which defines the column NAME containing a string of characters. Numbers in the parentheses show the length of strings. The NOT NULL specification means all records of ID and NAME must contain values. If these two columns are used as keys of the table, these columns can not default their value. On the other hand, the rest columns, without NOT NULL specification, can default their data value. The INT represents the domain of the column in numeric data.

With this CREATE TABLE syntax, table and its columns are defined. There are some other DDL commands, which is not ANSI standard but implemented by vendors, such as CREATE INDEX and ALTER TABLE.

Opposed to CREATE TABLE command, there is DDL command for the purpose of destroying the table; that is, the DROP TABLE command. Its syntax is:

DROP TABLE FIRM

After enforcing this command, the FIRM table no longer exists in database.

2.5.2.2 Data manipulation language It is used to process the database. The command SELECT is used in SQL for such purposes. SELECT command retrieves data from a table and can execute simple or complex queries.

2.5.2.3 Data control language DCL guarantees data security. A database usually serves many users. Due to the background, knowledge, and custom of users are different, their data manipulation are also different. Sometimes one individual user may change data and endanger other users who share the same data.

The GRANT command is used to give the users different levels of permission for manipulation of database.

2.6 Zip code classification

Zip code identifies areas within the United States and its territories for purpose of simplifying the distribution of mail by the U.S. Postal Service. The first digit of zip code divides the country into 10 large groups of states numbered from 0 in the Northeast to 9 in the far West. Within these areas, each state is divided into an average of 10 smaller geographical areas, identified by the 2nd and 3rd digits of the zip code [33]. In the past few years, zip codes have become widely recognized as a useful and practical means for delineating marketing units. Most often this unit is the Zip Code Sectional Area. Defined by the first three digits, or prefix, of the five-digit zip code, the Zip Code Sectional Area offers the dual advantage of being readily identifiable and relatively homogeneous [32]. It therefore provides the marketer with a convenient and appropriate tool for inquiries, prospects, etc.

There are 559 Zip Code Sectional Areas. Because many Sectional Centers require more than one three-digit prefix, the number of prefixes exceeds the number of Sectional Areas. This is required either to handle individually zoned cities within a Sectional Area or because the area has a large number of separate post offices. However, within any given Sectional Area the prefixes are consecutive. For example, the Chicago three-digit Zip Code Sectional Area comprises prefixes 600 through 606 inclusive. The Zip Code Sectional Areas do not cross state lines. With minor exceptions, if a Sectional Center services a district in another state, that portion of its area is given its own three-digit prefix.

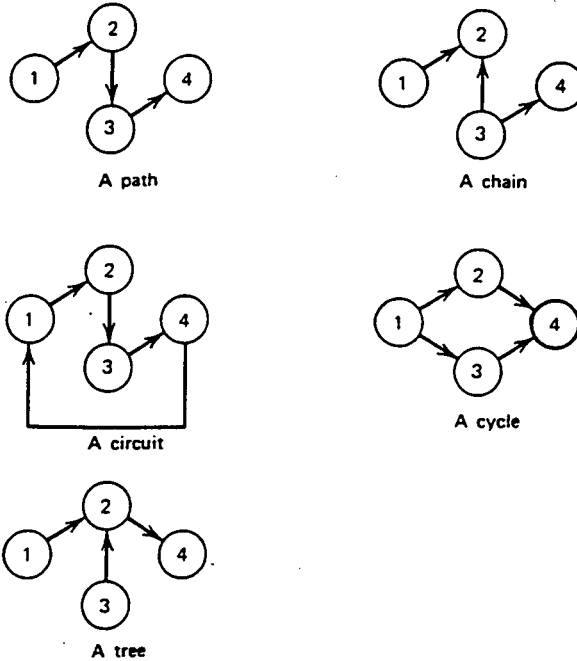


Figure 2.1: Examples of path, chain, circuit and cycle

2.7 Graph theory terminology

A network consists of a set of nodes and a set of arcs connecting the nodes. Let $G = (N, A)$ be a directed network with a finite set of nodes $N = 1, 2, \dots, n$ and a set of directed arcs $A = (i, j), (k, l), \dots, (s, t)$ joining pairs of nodes in N . The graph is said to be proper if the cardinalities of N and A satisfy $|N| \geq 2$ and $|A| \geq 1$. Two nodes are considered to be adjacent if they are directly connected by some arc [36].

A path from node i_0 to i_p is a sequence of arcs $P = (i_0, i_1), (i_1, i_2), \dots, (i_{p-1}, i_p)$ in which the initial node of each arc is the same as the terminal node of the preceding arc in the sequence and i_0, \dots, i_p are all distinct nodes. A chain is a path in which

not all arcs are necessarily directed toward node i_p . A cycle is a closed chain. A circuit is a path from some node i_0 to i_p plus the arc (i_p, i_0) . Thus a circuit is a closed path. Figure 2.1 demonstrates path, chain, circuit and cycle.

A graph G is connected if there exists a chain between every pair of nodes in G . A strongly connected graph is one where there is a path from each node to every other node. A complete graph is one where each node is connected by an arc to every other node.

2.8 Shortest path algorithms

Shortest path problems are by far the most fundamental and also the most commonly encountered problems in the study of transportation and communication networks [34]. Let G be a directed graph. Let the length of an arc $e(x, y)$ be denoted by $l(x, y)$. The length of a path p , denoted by $l(p)$, is the sum of the lengths of the individual arcs comprising the path. A shortest path from a node s to a node t is a path from s to t whose length is minimum. This is demonstrated in Figure 2.2 where darkened arcs denote the shortest path from s to t .

A simple and one of the most efficient algorithms for shortest path is due to Dijkstra [35]. This algorithm finds a shortest path between two specified vertices when all arc lengths are non-negative. It uses a labeling procedure to estimate the shortest path. Ford [39] modified the algorithm to incorporate negative arc lengths in the network. His algorithm did not allow any negative cycles or circuits in the network in which case the circuit might be repeated infinitely yielding a path whose length is infinitely negative.

All-shortest path algorithms involve finding shortest paths between every pair of

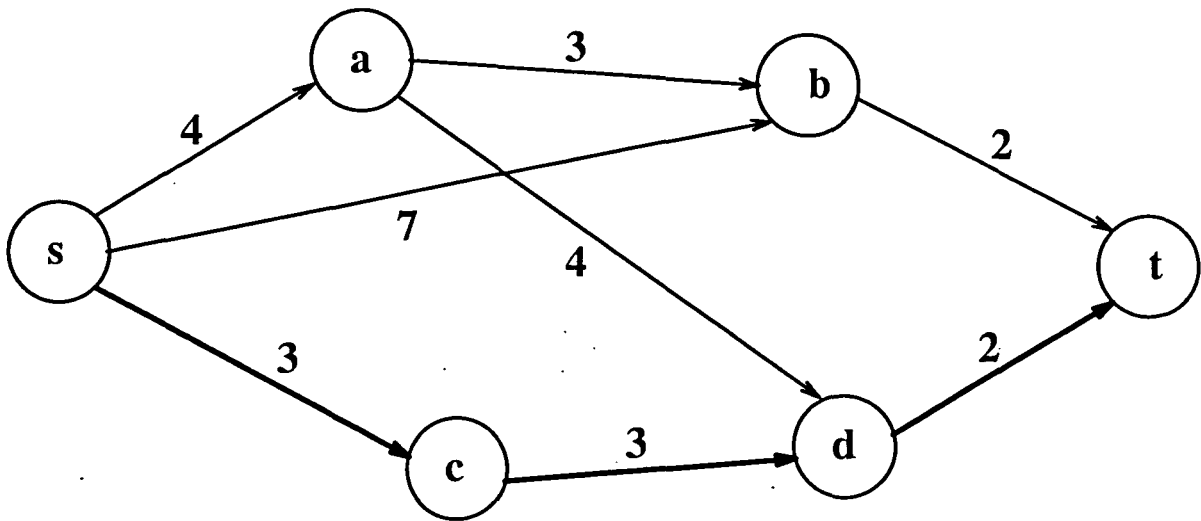


Figure 2.2: Shortest path from node s to node t

nodes in the network. Two similar algorithms were developed by Floyd [40] and Dantzig [41]. In both algorithms negative arc lengths were permitted as long as there are no negative circuits. To find the shortest chain between nodes i and k , the algorithms successively examine all possible intermediate nodes between i and k , and if the length of a chain through any intermediate node is shorter than the current distance, then the current distance is changed to the new value.

The k -shortest path problem finds k shortest paths, arranged in increasing order to their lengths, in contrast to simply finding single shortest path. This approach identifies alternative solutions for planning when the best solution is not available or is infeasible. The general version of k -shortest path problem admits cycles in the paths and ties between the path lengths. Numerous algorithms are available with several relaxations of the problem to provide solution to a network of interest.

The generalized Floyd algorithm and generalized Dantzig algorithm are available

to solve the k-shortest path problems. Fox [43] proposes a method with integer programming application. His algorithm maintains a list at each node with length equal to the number of nodes in the network minus one in which a node is changed at each iteration as a new minimum is found.

A labeling algorithm for computing k-shortest path lengths in Euclidian networks is proposed by Skiscim and Golden [44]. The algorithm proposed is an adaptive version of Dijkstra algorithm [35]. The double sweep algorithm by Shier [38] is an efficient algorithm for finding k shortest path lengths from a specified vertex to every other vertex in the graph. This algorithm works for a network with no negative cycles.

A paper by Shier [42] compares several k-shortest path algorithms His results indicate that the double sweep algorithm fares the best in high density networks.

3. STATEMENT OF THE PROBLEM

Faced with the dwindling landfill space and the rising costs of waste disposal, many states and communities have rediscovered the benefits of recycling. However, there exists a need to establish markets for the recyclable materials. A liaison needs to be developed between the sellers/collectors and buyers of the materials.

A computer based database management system termed MARTIN (Mid America Recycling and Transportation Information Network), has been developed by Adams et al[4] to provide market information to recyclers and users of recycled materials. MARTIN is a regionalized marketing and transportation online database system containing information on buyers, sellers and brokers of recyclable materials located in the Midwestern states of the United States.

However, during the course of development of MARTIN, it became apparent that for such a system to be more useful, it should provide users with decision making tools. In order to achieve this objective it will be best to convert MARTIN to a decision support information system.

The purpose of this thesis is development of MARTIN into an information system for planning and decision making. The scope of the thesis involves the design of an information system to provide current market information on the recyclable materials and provide decision making tools for identifying feasible markets for following four

materials: paper, plastics, glass and ferrous metal. The information system would be a source of information to the buyers and sellers of the secondary materials and provide them with the decision making tools to find the markets for the materials. The advantages of this approach will include a more flexible and efficient system that will give users more control over manipulating the database.

Decision support model incorporated into the information system will help sellers identify the markets for materials at hand. The model would provide a seller of recyclable materials with a list of feasible buyers based on the average transportation costs. It is assumed that the transportation cost is proportional to the distance and hence the markets for which transportation distance is least will be most feasible. Double sweep algorithm, a k-shortest path algorithm is used for finding three shortest paths. The algorithm finds the cities (market locations) located on a path that would minimize the total transportation distance.

Because of lack of data for the other states, this concept will be demonstrated only for the state of Iowa.

4. MARTIN DATABASE MANAGEMENT SYSTEM

4.1 Introduction

This chapter describes the MARTIN database system that has been developed by Adams et al [4] at Iowa State University, Ames, Iowa. This thesis is undertaken to develop MARTIN into an information system for planning and decision making. Following is a brief overview of the project MARTIN.

MARTIN¹ is a regionalized marketing and transportation database system developed at the Department of Industrial and Manufacturing Systems Engineering at Iowa State University, Ames, Iowa. The system has been online since April 1991 and was developed under a grant from U.S. Environmental Protection Agency and Iowa Department of Natural Resources. It provides current market information on recyclable materials on availability of resources, quantity and container specifications, and shipping costs.

The scope of the project included both marketing and transportation for the following secondary materials: paper, plastics, glass, ferrous metal, non-ferrous metals, tires, automobile lead-acid batteries, and used motor oil. Sources included post-consumer and industrial waste. The states covered in the database are: Iowa, Nebraska, Kansas, Missouri, Illinois, Minnesota, North Dakota, South Dakota and Wis-

¹Mid America Recycling and Transportation Information Network

consin. Following six states were added in the second year of the project: Arkansas, Colorado, Kentucky, Oklahoma, Tennessee, and Wyoming.

The development of the system was carried out in two parallel sequences of activities which merged during the final three months. One activity consisted of mailing survey forms to various organizations for gathering data. Other activity consisted of procuring hardware and software and developing overall database structure.

4.2 Surveys

Data was collected through survey forms mailed to the firms in order to gather the data for the system. This method of data collection was used because very large number of firms had to be contacted. The present market database is the result of four separate surveys of:

1. City and County Engineers and Landfill Supervisors
2. Iowa Manufacturers
3. Transportation Companies
4. Recycling Businesses

The first two surveys pre-dated the project by one year and were a part of the 1989 study of regionalized collection, processing, material recycling and energy derivation conducted for the Iowa Department of Natural Resources [5]. The first survey determined the generation and disposal of post-consumer and industrial solid waste on a county basis for the state of Iowa. The second survey was designed to determine the identity and location of manufacturing industries in the state that generated or

used secondary materials. It also identified transportation modes, routes and carriers available to each company.

The third survey was made for major transportation companies operating rail or truck routes throughout the nine states. This survey was designed to obtain typical freight rate information for each secondary material. This type of information can help recycling business minimize transportation costs for a given material.

The fourth survey was a comprehensive survey of recycling businesses in Iowa, Illinois, Minnesota, Missouri, Nebraska, North Dakota, South Dakota and Wisconsin. In this survey, the markets for materials were targeted more precisely since the entire survey was based on businesses that identified themselves as purchasers or sellers of secondary materials. A sample form used in the Midwest Recycling Businesses Survey is included in Appendix B.

4.3 Recycling businesses survey response analysis

Because of its large scope, the Recycling Businesses Survey was conducted over a period of six months, with two separate mailings. A follow-up survey was needed in addition to the original survey to ensure sufficient response for the development of a database of recyclers. A total of 1,055 surveys were mailed to recycling businesses throughout the nine-state region. To increase the response, a follow-up survey form was sent to nonrespondents from the first survey, accompanied by a letter urging their participation to increase their market visibility over a wider area. Overall responses to the survey totaled 302 out of 1055 surveys sent, resulting in a 31.1 percent response rate when wrong addresses were excluded. Details of the total response to the first and second surveys on a state-by-state basis are shown in Table 4.1.

Table 4.1: Overall response to recycling businesses survey.

STATE	#SURVEYS	#WRONG ADDRESS	#RESPONDING	%RESPONSE
Iowa	185	25	61	38
Illinois	80	6	26	35
Kansas	45	6	10	26
Minnesota	134	26	42	39
Missouri	144	13	38	29
North Dakota	22	2	8	40
Nebraska	108	3	34	32
South Dakota	22	5	9	53
Wisconsin	315	15	74	25
TOTAL	1055	101	302	31.7

4.4 Database development

The surveys discussed in the previous section were conducted to obtain the information that is stored in the database. All of the information associated with a company is stored in its record, under the appropriate field. The collection of database records is stored in a file on computer disk. Two types of database file are used in the system. The first is a "mailing list" of company names and addresses to which the Recycling Businesses Survey was sent. The second is an active database file that contains a record for each business that responded to the survey. The information that would be useful to the users was included into this database file which contains the following fields:

- Name of Business
- Address of Business

- Name of Contact Person
- Telephone Number
- Kinds of Operation (broker, material processor, product/component producer)
- Grades of Materials Accepted
- Transportation Modes (highway/interstate number, railroad, barge line)

4.5 System operation

In addition to the database files, the system modules include a device driver routine that interface the system with telephone line for communication through a computer modem. The main program is “menu-driven”: information on recycling firms is provided through access to a series of menus from which the user makes selections. MARTIN’s login display is shown in Figure 4.1. Once logged in, the user is asked to make a selection from the Main Menu for a material or to look up for the national/international markets as shown in Figure 4.2. Following the selection at this menu, the State Menu in Figure 4.3 is displayed and the user is asked to choose a state from which the information on the sellers/buyers of the material is desired.

Figure 4.4 shows a form of screen displaying information associated with the material (PAPER in this case) and Alter Trading Corporation in Dubuque. The user “steps through” the sequence of records stored in the database for the chosen material and state in alphabetical order using N to view the next company’s record, or M to view another screen full of company names.

```

MM      MM      AAAAAAA  RRRRRRRR  TTTTTTTTTTTTTT  III  NN      NN
MMM     MMM     AAAAAAAAA  RRRRRRRRR  TTTTTTTTTTTTTT  III  NNN     NN
MMMM    MMMM    AA      AA  RR      RR      TT      III  NNNN    NN
MM MM   MM MM   AA      AA  RR      RR      TT      III  NN  NNN  NN
MM MM   MM MM   AA  AAA  AA  RRRRRRRRR  TT      III  NN  NNN  NN
MM  MM   MM  AA  AAA  AA  RR  RRR      TT      III  NN  NN  NN
MM      MM  AA      AA  RR      RR      TT      III  NN  NNNN
MM      MM  AA      AA  RR      RR      TT      III  NN  NNN

```

MARTIN - MID AMERICA RECYCLING AND TRANSPORTATION INFORMATION NETWORK

Press ENTER to continue...

Welcome to the Mid America Recycling and Transportation Information Network. The bulletin board contains information on the following secondary materials Paper, Plastics, Glass, Ferrous metals, Non-ferrous metals, Tires, Batteries and Waste oil.

The information is available for the midwest and the neighboring states: Iowa, Kansas, Missouri, Nebraska, Illinois, Minnesota, North & South Dakota, Wisconsin, Arkansas, Colorado, Kentucky, Oklahoma, Tennessee and Wyoming.

MARTIN is being developed in the Department of Industrial and Manufacturing Systems Engineering at Iowa State University, Ames, Iowa 50011. If you have any questions or comments, please contact Dr. John C. Even or Dr. S. Keith Adams at (515) 294-1682 or the laboratory at (515) 294-8561.

Press ENTER to continue...

Figure 4.1: MARTIN's login menu

```

*****
MARTIN:  MAIN MENU
*****

1 ..... PAPER
2 ..... PLASTICS
3 ..... GLASS
4 ..... FERROUS METALS
5 ..... TIRES
6 ..... LEAD ACID BATTERIES
7 ..... USED MOTOR OIL
8 ..... NON-FERROUS METALS
9 ..... National/International Markets
10 ..... Exit

```

Enter your selection for RECYCLING INFORMATION.
TYPE THE COMMAND AND PRESS ENTER==>

Figure 4.2: Materials menu

SELECT ONE STATE FROM WHICH YOU WANT TO SEE THE INFORMATION

```

1 ..... IOWA
2 ..... ILLINOIS
3 ..... KANSAS
4 ..... MINNESOTA
5 ..... MISSOURI
6 ..... NEBRASKA
7 ..... NORTH DAKOTA
8 ..... SOUTH DAKOTA
9 ..... WISCONSIN
10 ..... ARKANSAS
11 ..... COLORADO
12 ..... KENTUCKY
13 ..... OKLAHOMA
14 ..... TENNESSEE
15 ..... WYOMING

```

Please enter your selection.
TYPE THE COMMAND AND PRESS ENTER==>

Figure 4.3: State menu

MATERIAL SELECTED - PAPER

STATE - IA

FIRM Alter Trading Corp.
 CONTACT Jeff Goldstein PHONE 319-344-5200
 ADDRESS 2333 Rockingham Rd.; Davenport, IA 52802

KIND OF OPERATION: Broker Material Processor
 GRADES ACCEPTED : Bond/Ledger Computer Paper
 COMMENTS:

QUANTITIES ACCEPTED: Pickup truck Semi truck Rail car Barge

HIGHWAY NO.	LOAD: 20 tons
TRUCKING CO.: Jack Gray	
TYPICAL MILES: 123	COST: \$14 per net ton
RAILROAD: CNW	LOAD: 80 tons
TYPICAL MILES: 406	COST: \$16 per net ton
BARGE/RIVER: Mississippi	BARGE CO.: PEAVEY
LOAD: 1500 tons	TYPICAL MILES: 982
	COST: \$10/net ton

Type I for Index; R to repeat list; M for more entries; E for EXIT.
 TYPE THE COMMAND AND PRESS ENTER==>

Figure 4.4: Full company record

4.6 Implementation

The computer database is maintained using the Ashton-Tate database package dBase IV. The user interface is designed for computer/modem. The modem is connected to the Com1 serial port of the computer. A control program written in Microsoft C detects a telephone ring from the port and then signals the modem to answer the phone call.

MARTIN is currently online 24 hours a day, seven days a week. Users can call the toll free number 1-800-437-8932 to access the network using computer and a modem. To access the network through a computer modem, the modem should have speed 2400/1200/300 baud and be set to full duplex, 8 data bits, 1 stop bit, no parity.

5. INFORMATION SYSTEM DESIGN

5.1 Introduction

This chapter covers the design of the proposed information system. There are several important components in the design of an information system: input design, database structure and a database management system for querying and data manipulation, and output design. Complex querying provided gives the user extreme flexibility in manipulating the database. Hence a user can access information of his/her interest efficiently without going through all the records in the database.

5.2 System objectives

It is quite difficult to state the real objectives of an information system. Stating the objectives in vague term such as “reduce costs,” “improve efficiency,” etc. is not enough. The objectives stated should be specific enough to provide a measure of performance of the system or to design an information system to help achieve the objective [10]. The objectives of the proposed information system are as follows:

- Provide a list of recyclers in the following Midwestern states of the U.S.: Iowa, Nebraska, Kansas, Missouri, Illinois, Minnesota, North and South Dakota and Wisconsin.

- Provide market information on the following secondary materials: Paper, Plastics, Glass, Ferrous metals, Non-ferrous metals, Tires, Batteries and Waste oil.
- Provide a list of county operated recycling programs.
- Provide flexible queries to give the user more control over manipulation of the database.
- Provide decision support tools to the sellers/collectors of secondary material.
 - Based on averaged cost of transportation, provide a list of feasible buyers to the user.
 - Based on the zip code of a user, provide a list of recyclers in adjacent zip code regions based on the first two or first three digits of the user's zip code.
- Provide easy user interface so that a person with very little computer knowledge is able to use the system.

5.3 Database structure

5.3.1 MARTIN database

The data used was collected from a survey of Midwest recycling businesses done as a part of project MARTIN [4] in nine states: Iowa, Nebraska, Kansas, Missouri, Illinois, Minnesota, North and South Dakota and Wisconsin.

The database has been designed as a relational model. This approach is taken because this would enable the system to process more complex queries from the users

and would provide them with greater control over manipulation of data stored in the database. This structure of the database would also aid in the incorporation and implementation of the decision model.

The MARTIN database is stored in a collection of small tables or files. Data for each firm obtained through the surveys is stored as a tuple or record in the relation. The master table has a primary key for identifying each firm. A unique identification number assigned to each firm, is used as the **primary key** for the entire database. This value is distinct for each firm and may be used to distinguish this tuple from all others in the relation. The data stored in various tables can be linked together through this primary key. A portion of the database structure is shown in Figure 5.1. Complete database structure is listed in Appendix C.

5.3.2 Other data files

The latitude and longitude of all the cities in Iowa are stored in a database file. This information is used to determine approximate road distances between two cities. The file was obtained from Ames office of the Iowa Department of Transportation. The coordinates of the firms in the states adjacent to Iowa which are product producers were stored in a separate file. Since the model for decision support would be demonstrated only for the state of Iowa, coordinates of all the towns in adjacent states were not required.

A file containing the information about the roads passing through each town in Iowa was obtained from Iowa Department of Transportation, Ames, Iowa. The file contains a list of towns on a particular highway for all Interstate highways, U.S. highways and State highways passing through Iowa.

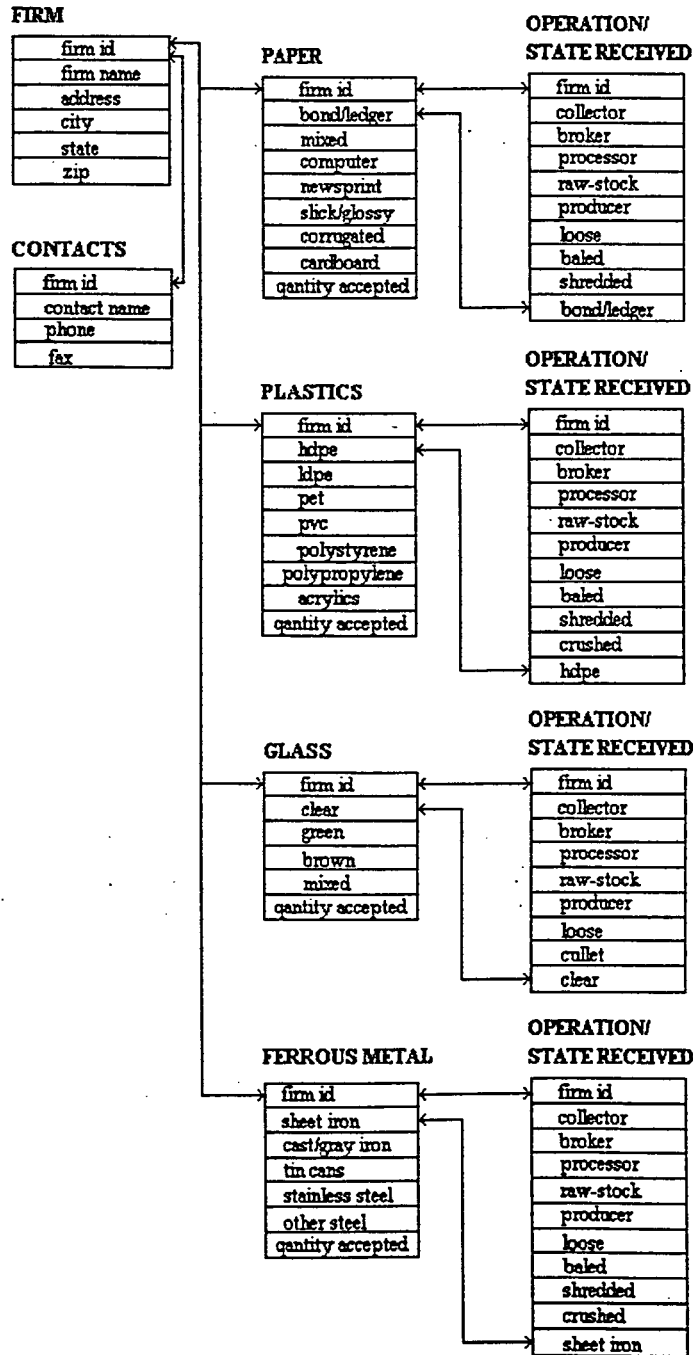


Figure 5.1: MARTIN database structure

Two separate files containing the first two and first three digits of the zip codes of the nine state region are stored. The first digit of a zip code divides the country into ten large groups of states numbered from 0 in the Northeast to 9 in the far West. Within these areas, each state is divided into an average of ten smaller geographical areas, identified by the second and third digits of the zip code. The fourth and fifth digits identify a local delivery area.

For each zip code, the first three digits stored are in a table and the first three digits of all adjoining zip codes are stored. This makes it possible to look up all the regions adjacent to a town including the adjacent states, where applicable, using the zip code. A similar approach is taken in storing the first two digits of the zip codes in a separate file.

5.4 System Design

After defining the database structure, software modules need to be written that would work as an interface between the user and the database. A program written in Ashton-Tate dBase IV SQL is used for manipulation of data from the database. A goal of the software design is to make the system flexible and extendible. This is accomplished by programming a high degree of functionality into the design.

5.4.1 User-interface design

Since most users of MARTIN information system have very little knowledge of computer operations, easy and user-friendly interface is extremely important for wide-spread acceptance of the system. During the initial development of MARTIN by Adams et al [4], user-interface was changed several times based on the recommenda-

tions of several users to make the system more user-friendly. Several of those features have been kept intact during the new user-interface design. However, many significant changes have been made in this work to provide the information concisely and comprehensively. Care was taken to present the information in a consistent manner.

Following factors were considered in input and output forms design:

- The form should be attractive and easy to read.
- Most forms should have a title which should be specific enough so that the function of the form may be determined.
- Items in a form should be arranged in a logical flow.

5.4.1.1 Input design Simplicity was the main objective kept in mind while designing the screens that require input from the user. Sequential menu driven design was used for user input.

5.4.1.2 Output design The output represents the product of an information system. Since output enables users to make intelligent decisions, the design of output must be customized to the users' needs. Care should be taken in putting too much on a single screen. However, the data should not be divided into numerous screens as it would be cumbersome to go page after page to look at the data of a single firm. Since the user will have to pay the phone charges for accessing the system, it is necessary that information is presented concisely but clearly so that the user can go through a screen as quickly as possible. It was decided to divide the information provided for each company into two screens: one screen providing recycling information about the firm and the other providing transportation information for the firm.

A few output screens are shown in the Figures 5.2 and 5.3. Since a lot of information was presented in just two screens, abbreviated codes were used for some of the terms. An explanation of these codes is available to the user through help screen which is shown in Figure 5.4.

5.4.2 Structured query language

Structured query language (SQL), a relational database language provided by Ashton-Tate dBase IV is used for data entry and retrieval. SQL retrieves the data base on the queries constructed by the users. Queries that can be constructed by the users are described in the following section.

5.4.3 Queries

The system is capable of supplying the recyclers with tools that would aid them in decision making. Complex querying is provided that enables the users to ask very specific questions. The user is allowed to get information on recyclers for multiple materials, grades and states at the same time. Two different materials, up to four grades or all the grades of selected materials and up to three states can be selected by the user for querying. This provides the user with a powerful decision making tool thus saving him/her time and the expense of going through the entire database record by record. None of the database systems or bulletin board systems reviewed in Section 2.2 of literature review provide such complex querying for manipulation of database.

Following queries are provided for database manipulation:

1. Show single/multiple grade(s) of a single material:

MATERIALS - materials selected

STATES - states selected

FIRM:

CITY :

ADDRESS:

STATE: ZIP:

CONTACT:

PHONE:

MATERIALS	GRADES	MATERIAL STATE	OPERATION
Paper	bond mix news cptr slic corrug plain	l b s	cl br mp rs pp
Plastics	hdpe ldpe pet pvc p-styr ppropy acry	l b s c g	cl br mp rs pp
Glass	clear green brown mixed	l cl	cl br mp rs pp
Ferrous	sheet cast tin-can st-less othe-steel	l b s c	cl br mp rs pp
Aluminum	cans scrap	l b s c	cl br mp rs pp
Copper		l b s c	cl br mp rs pp
Brass		l b s c	cl br mp rs pp
Tires	car truck/tractor	l b s sl	cl br mp rs pp
Batteries	auto(lead-acid) dry-cells	wh pt	br mp rs pp
Motor oil		gal dr tnk	br mp rs pp

COMMENTS:

QUANTITIES ACCEPTED: household pickup_trk straight_trk semi_trk railcar barge

H for HELP; T for TRANSPORTATION INFORMATION; N for NEXT; E to EXIT

TYPE THE COMMAND AND PRESS ENTER==>

Figure 5.2: Screen for full company record

MATERIALS -

STATES -

TRANSPORTATION INFORMATION

FIRM:		CITY:	
ADDRESS:		STATE:	ZIP:
CONTACT:		PHONE:	
HIGHWAY :			
TRUCKING CO.:			
TYPICAL COST:	TYPICAL MILES:	TYPICAL LOAD(tons):	
RAILROAD :			
TYPICAL COST:	TYPICAL MILES:	TYPICAL LOAD(tons):	
BARGE/RIVER:			
BARGE CO. :			
TYPICAL COST:	TYPICAL MILES:	TYPICAL LOAD(tons):	

H for HELP; F for FIRM INFORMATION; N for NEXT; E to EXIT.
TYPE THE COMMAND AND PRESS ENTER==>

Figure 5.3: Screen for transportation information

HELP SCREEN

=====

GRADES OF MATERIALS:

Paper: bond - bond/ledger/copy paper
 mix - mixed paper
 news - newsprint
 cptr - computer paper
 slic - slick (magazine) paper
 corrug - corrugated cardboard
 plain - plain cardboard

Plastics: pvc - poly-vinyl chloride
 p-stry - polystyrene
 ppropy - polypropylene
 acry - acrylics

Ferrous: sheet - sheet iron
 cast - cast iron
 st-less - stainless steel
 othe-steel - other steel

MATERIAL STATE : Denotes the state in which material is accepted/shipped.

l - loose	b - baled	s - shredded
c - crushed	g - granulated	cl - cullet
sl - sliced	wh - whole	pt - parts
gal - gallon	dr - drum	tnk - tank car

QUANTITIES ACCEPTED: Denotes quantity of material accepted/shipped.

household	- household quantites	pickup_trk	- per pickup truck
straight_trk	- per straight truck	semi_trk	- per semi truck
railcar	- railcar load	barge	- barge load

OPERATION: Denotes kind of operation carried by the firm.

cl - collector	br - broker	mp - material processor
rs - raw stock producer	pp - finished product producer	

Figure 5.4: Help screen for explanations of abbreviations used in full company record

View according to one of the following options:

- single state
- multiple states
- first two or first three digits of a zip code

2. Show single grade each of multiple materials:

View according to one of the following options:

- single state
- multiple states
- first two or first three digits of a zip code

3. Show multiple grades of multiple materials

View according to one of the following options:

- single state
- multiple states
- first two or first three digits of a zip code

4. View all the recyclers lying on an Interstate highway, U.S. highway or State highway accepting a material or particular grade of a material. This concept will be demonstrated for the state of Iowa only since data is not available for the other states.

5.4.4 Zip code search

A database file is maintained containing all the adjoining zip code regions for the first two and first three digits of each zip code for the nine Midwestern states. The user is asked to input a zip code. The database is then searched according to first two or first three digits of the specified zip code as desired by the user. For example, for the first three digit zip code search for the zip code “50010”, all the zip code regions included in and adjacent to the zip code region of “500” are extracted from the above mentioned database file. The MARTIN database is then searched for the recyclers located in the selected zip code regions. This list is shown to the user. The regions searched according to first three digits of the zip code “50010” are shown in Figure 5.5.

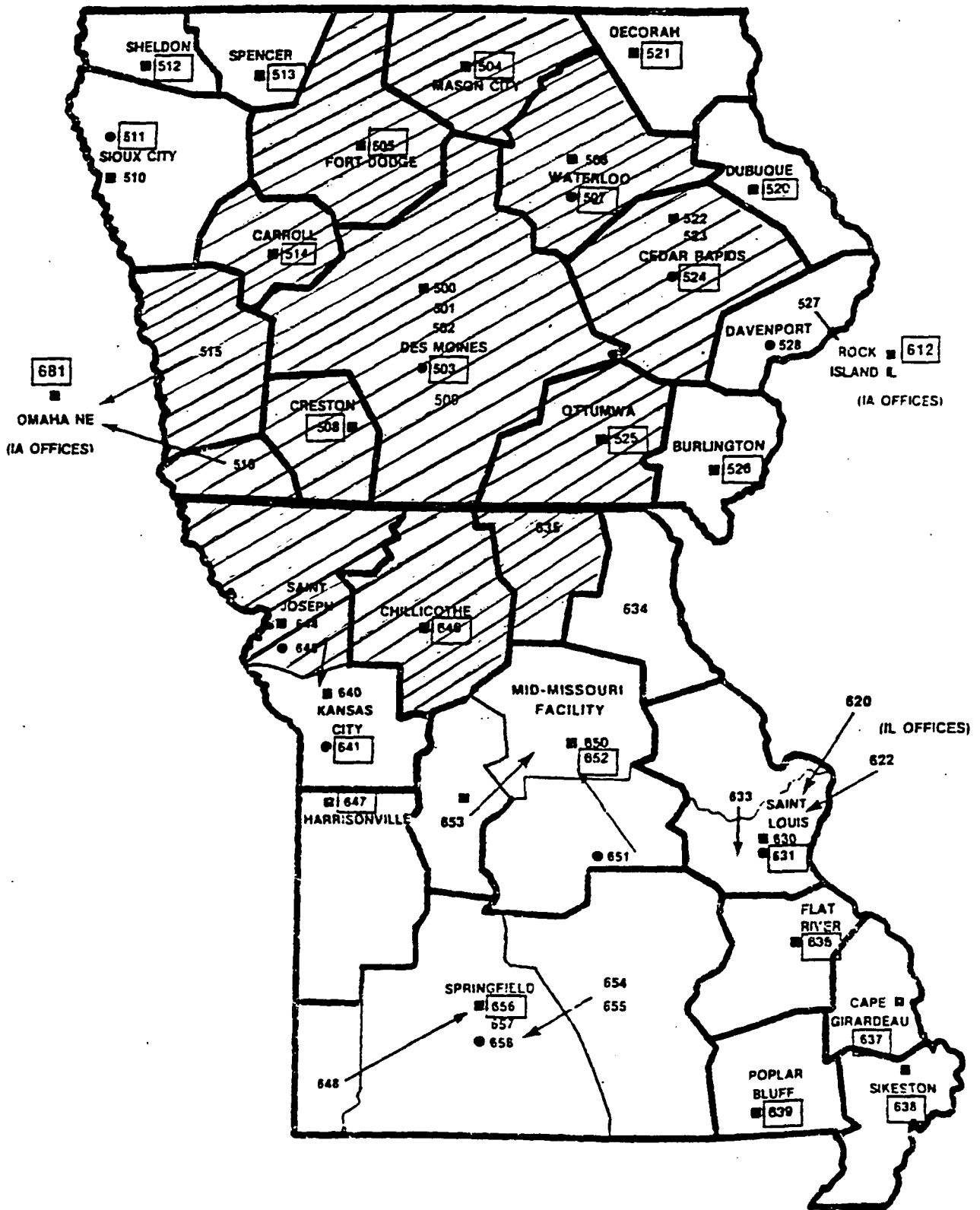


Figure 5.5: Zip code search for zip code 50010

6. TOOLS FOR DECISION MAKING

6.1 Introduction

The concept of providing sellers with a feasible list of buyers based on the average transportation costs is demonstrated for the state of Iowa in this chapter. The model provides the user with least cost options for transporting the materials to potential markets. This approach provides the user with market options which may not be very obvious. Currently, there are no information systems available that provide decision making tools for recommending markets for secondary materials.

The double sweep algorithm to compute three-shortest paths is used to make recommendations to recyclers based on the quantity of material at hand. A collector or seller of recyclable material may ask for recommendations for shipping the materials at least possible cost to the available markets.

6.2 Available data

Transportation cost data was estimated from transportation survey of Midwest recycling businesses conducted in the second year of project MARTIN [4].

A database file containing latitude and longitude of all cities in Iowa was obtained from Iowa Department of Transportation in Ames, Iowa. Another database file contains latitude and longitude of the cities in Midwestern states where buyers

are located as provided in the MARTIN database. Road distances between pairs of cities are calculated from the latitudes and longitudes with the help of a model. This procedure is described in the Section 6.3.

6.3 Inter-city road distance calculation

A file containing latitude and longitude of all Iowa cities was obtained from the Iowa Department of Transportation. The latitude and longitude corresponds to the geographic center point for a given city. The spherical straight line distance is calculated from the latitude and longitude of the two cities using the following equation [21]:

$$\cos D = (\sin a \sin b) + (\cos a \cos b \cos P) \quad (6.1)$$

where,

D = arc distance between A and B

a = latitude of A

b = latitude of B

P = degrees of longitude between A and B

Since all degrees of latitude are nearly equal and approximately 69 miles, the length of the arc is determined by multiplying D by 69.

The distance calculated above is the air distance or spherical distance along the arc of the earth. However, this distance does not reflect the actual road distance between the two cities represented by points A and B in the equation given above. The coordinate distances have to be transformed into road distances between the two given cities. A distance function has to be used for the estimation of approximate

Table 6.1: Distance between selected cities in Iowa

FROM	TO	ARC DISTANCE	CORRECTED DISTANCE	ACTUAL DISTANCE
Ames	Davenport	160.47	174.83	177
Council Bluffs	Mason City	223.46	242.47	250
Sioux City	Waterloo	206.39	224.17	229
Des Moines	Keokuk	142.58	155.57	169
Spencer	Burlington	262.00	283.73	326
Ottumwa	Shenandoah	157.26	171.38	177

road distances between the cities or locations. Several models [22] [23] are available for such purposes. However, since the model has to be used online over the phone, time constraint does not permit a complex model to be used. A simplified version of the function proposed by Love and Morris [22] has been used for getting an estimate of the road distances.

$$d(a, b) = k \left[(b - a)^p \right]^{1/s} \quad (6.2)$$

where k , p and s are parameters of the function and $(b - a)$ is the spherical distance measured along the arc of the earth.

The following values of k , p and s are taken for calculation of road distance $d(a, b)$ between the two cities [22]:

$$k = 1.16, \quad p = 1.60, \quad s = 1.62$$

Table 6.1 shows the application of the model using equations 6.1 and 6.2 for selected cities in Iowa and displays the distances calculated and actual road distances from a Rand McNally Road Atlas [31].

6.4 Model development

6.4.1 Assumptions

The following assumptions have been used in formulating the problem:

1. If the amount of a material is less than the capacity of the vehicle, then if required, more than one material can be loaded on the same vehicle to its capacity.
2. A vehicle is allowed to visit multiple destinations on its route.
3. There is no restriction on the quantity of material that can be accepted by the destination nodes (buyers). This restriction is valid since no more than a truck-load (22 tons) of one material would be supplied to a buyer at a time.
4. There is no constraint on vehicle or crew availability, time to complete a tour or time of delivery.
5. The objective is to minimize total route length. Transportation cost is assumed to be proportional to distance.
6. No negative cycles are allowed in the network.

6.4.2 k-shortest path algorithm

Let $G = (N,A)$ be the directed network with a finite set of nodes $N = \{1,2,\dots,n\}$ and a set of directed arcs $A = \{(i,j), (k,l),\dots,(s,t)\}$ joining pairs of nodes in N .

The k-shortest path algorithm will be used to get k shortest paths from a node i to all other nodes in G . Several methods are available for the solution of the general k-

shortest path problem. Double-sweep method developed by Shier [38], simultaneously calculates the k -shortest path lengths from a particular source node to all other nodes in the network, will be used for the solution.

6.4.3 Double sweep algorithm

The representation of Shier's double sweep algorithm given below is by Minieka [39]. Consider a directed network with nodes numbered from 1 through n . For each node there is a vector with estimates of the k shortest path lengths from a given origin node. The double sweep algorithm successively reduces the estimates until the optimal vector of estimates is achieved in a finite number of iterations.

Each iteration consists of two passes. In forward pass, the nodes are considered in increasing numerical order (i.e., $j = 1, 2, \dots, n$). After identifying the list of nodes i incident to node j , such that $i < j$, the k shortest path lengths from the source to node j are successively examined to verify if shorter path lengths are possible through the incident nodes. If such path length exists, they will be used as new estimates in future iterations. A similar procedure is performed during the backward pass of the algorithm in which the nodes are considered in decreasing numerical order (i.e., $j = n, n - 1, \dots, 1$) and only incident nodes $i > j$ are investigated.

The solution procedure involves a sequence of two algebraic operations, generalized minimization and generalized addition. The vectors to be considered should all have the same dimension with elements arranged in strictly increasing order. The elements can contain infinity elements. The convention that $\infty < \infty$ is adopted because of the above mentioned restriction, when there are several infinite entries in the vectors.

Following is an example of such vector:

$$A = [0, 3, 7, \infty, \infty]$$

Let R be the set of real numbers, and k be the desired number of shortest path lengths. Let R^k be the set of vectors of dimension k arranged in strictly increasing order. Let $A = (a_1, a_2, \dots, a_k)$ and $B = (b_1, b_2, \dots, b_k)$ be two members of R^k .

Generalized minimization, denoted by \oplus is defined as

$$A \oplus B = \min_k \{a_i, b_i : i = 1, 2, \dots, k\} \quad (6.3)$$

where $\min_k(X)$ denotes the k smallest distinct members of set X .

Generalized addition denoted by \otimes , is defined by

$$A \otimes B = \min_k \{a_i + b_j : i, j = 1, 2, \dots, k\} \quad (6.4)$$

The components of A and B are arranged such that $A \oplus B \in R^k$ and $A \otimes B \in R^k$. Since the components of the vectors are arranged in ascending order, generalized minimization does not require more than k comparisons and generalized addition does not require more than $k(k-1)$ additions and $k(k-1)$ comparisons.

Let d_{ij} denote the length of $\text{arc}(i, j)$ and $d_{ij}^0 = (d_{ij1}^0, d_{ij2}^0, \dots, d_{ijk}^0) \in R$ denote the lengths of the k shortest arcs from vertex i to vertex j . If there are less than k arcs from i to j , then the remaining components are filled with ∞ . If $i = j$, it denotes that there is an arc from vertex i to itself with zero length. Let D^0 denote the matrix whose i, j -th element is d_{ij} .

Let $d_{ij}^m = (d_{ij1}^m, d_{ij2}^m, \dots, d_{ijk}^m) \in R^k$ denote the k shortest distinct path lengths from vertex i to vertex j that use only vertices $1, 2, \dots, m$ as intermediate vertices.

Let D^m denote the matrix whose i, j -th element is d_{ij}^m .

Let $d_{ij}^* = (d_{ij1}^*, d_{ij2}^*, \dots, d_{ijk}^*) \in R^k$ denote the k shortest distinct path lengths from vertex i to vertex j . These path lengths are called the optimal path lengths. Let D^* denote the matrix whose i, j -th element is d_{ij}^* .

Let L be the matrix formed from matrix D^0 by replacing every component of every d_{ij}^0 by ∞ whenever $i \leq j$. Let U be the matrix formed from matrix D^0 by replacing every component of every d_{ij}^0 by ∞ whenever $i \geq j$. Matrices L and U are the upper and lower triangular portions of D^0 .

If the k shortest path lengths are to be found from a specific vertex, say i to every other vertex in the graph, then only the row $(d_{i1}^*, d_{i2}^*, \dots, d_{in}^*)$ of D^* need to be determined. Hence, altogether Nk values and the corresponding path need to be determined.

The algorithm consists of the following two steps:

Step 1: Initialization is done with any estimate $(d_{11}^{(0)}, d_{12}^{(0)}, \dots, d_{1n}^{(0)})$ of $(d_{11}^*, d_{12}^*, \dots, d_{1n}^*)$ in which each value should not be less than the corresponding value. The value of $d_{11}^{(0)}$ is zero since there is a path of zero length from vertex 1 to itself.

Step 2: The generation of vector estimates is done by the following pair of recursive relationships:

Backward Sweep:

$$d_1^{2r+1} = d_1^{2r+1} L + d_1^{2r} \quad (6.5)$$

Forward Sweep:

$$d_1^{2r+2} = d_1^{2r+2} U + d_1^{2r+1} \quad (6.6)$$

where $r = 0, 1, 2, \dots$

The step two is executed recursively till the two successive estimates d_1^{t-1} and d_1^t are identical for $t > 1$. The terminal d_1^t equals d_i^* .

Once the path lengths are obtained, a tracing procedure is used to identify the corresponding paths. If it is desired to find a path from the origin to node i , corresponding to the m shortest path length. Let H_{mi} be this path length, and let j be a node incident to node i . Then,

$$H_{mi} = H_{tj} + d_{ji} \quad (6.7)$$

where, d_{ij} is the length of the $arc(j, i)$ and H_{tj} is the t -shortest path length, $t \leq m$, corresponding to node j . Thus the tracing procedure performs a node search at each node i in order to identify the node j for which Equation 6.7 is satisfied. Once j is found, the same procedure is repeated until the origin node is reached.

6.5 Model application

6.5.1 Introduction

Given one or more materials at a given source, the problem is to find demand points located such that the cost of transporting the materials is minimized. It is assumed that the cost of transportation is directly proportional to the distance and hence a path with shortest distance would be the most economical path for transporting given materials. The double sweep algorithm used in this study is designed to handle up to three different grades of the same or different materials. The algorithm will calculate and store three shortest paths. In some cases the shortest path option recommended may not be feasible for transportation of materials. In

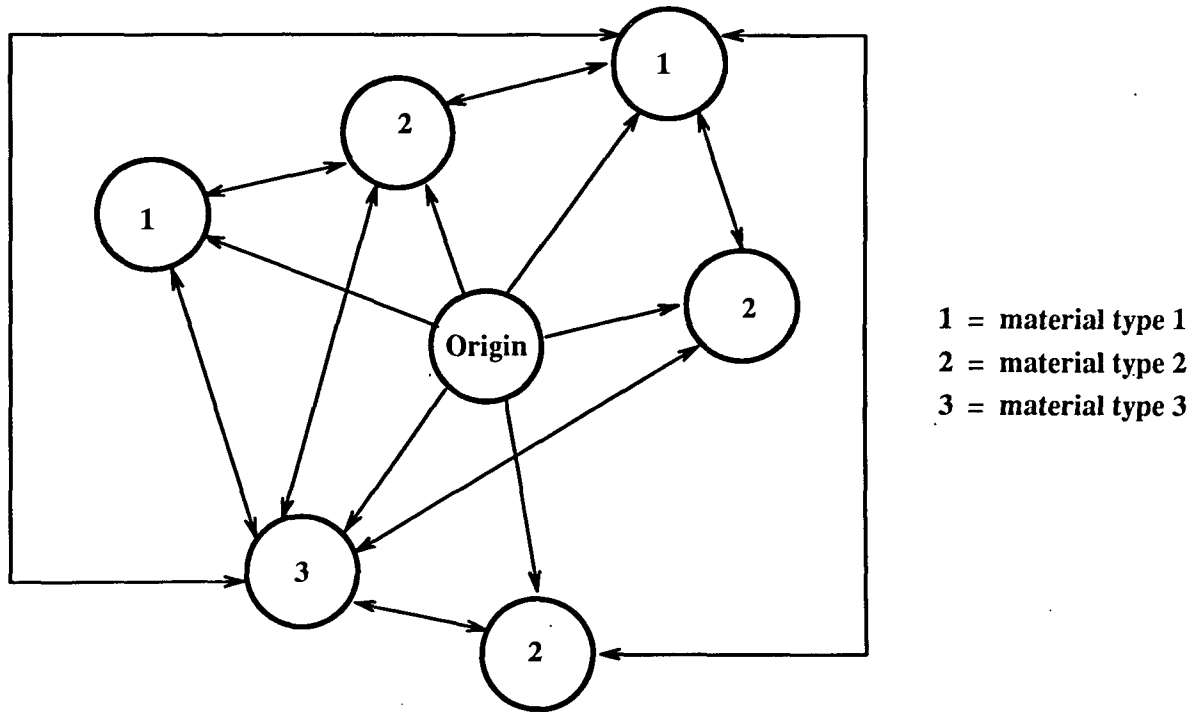


Figure 6.1: Directed network for shortest path problem

such case second or third shortest path can be used as alternatives.

6.5.2 Problem formulation

Once the user specifies the materials, MARTIN database is searched to extract the names of cities where buyers of the specified materials are located. A directed network is constructed with these cities as nodes. The arcs of the network depict flow of material from one city to another and specify the road distance between the two nodes. The city specified by the user is the origin node. The arc lengths are then computed by calculating the distance between two cities connected by an arc, as described in Section 6.3. An example of a network is shown in Figure 6.1.

All nodes except the origin node can be coded with three different codes, with each code indicating a different material or grade. A node can accept more than one material or grade and hence can have multiple codes. A pair of nodes with different codes is connected by two directed arcs pointing in opposite directions. These bi-directional arcs are equal in length and indicate that material flow can take place in either direction. A node with multiple codes depicting that it accepts more than one material, is divided into sub-nodes. Each sub-node depicts the node accepting a single material. The arcs connecting these sub-nodes to each other are of zero length and hence represent an arc from a node to itself. However for programming purposes, the arc from a node to itself (an arc connecting a pair of sub-nodes of the same node) is assigned a length of 0.1 mile. For example, a node i accepting two materials A and B is divided into two sub-nodes i_A and i_B with sub-node i_A accepting material A and sub-node i_B accepting material B . An arc from i_A to i_B represents a path from node i to itself and will have a length of 0.1 mile. This case may arise if a buyer accepts more than one material or multiple buyers accepting different materials are located in the same city.

6.5.3 Solution procedure

Currently the algorithm considers all the potential buyers in the nine Midwestern states since there are very few buyers of the secondary materials available. But as the demand for the material grows, number of buyers in the database will grow. In such case the network would become very large unless a destination point or a search region is specified. In the algorithm developed, the user has the option of specifying a search region of up to four states including the state where the user is located. A

destination and material accepted by the destination can also be specified.

The user is asked to input the city name to be used as a reference, materials or grades of materials and quantity of materials at hand. The model checks for all possible scenarios for transportation of materials. A standard truck capacity of 22 tons is assumed for the trucks. A loading/unloading fee of \$40 is added for each truck used. This fee is added to penalize the use of additional trucks. This data was obtained from transportation survey of recycling businesses for project MARTIN [4]. The model gives recommendations on all the different alternatives available for grouping the materials together for transportation. As an example, if 7 tons of paper, 3 tons of glass and 4 tons of cast iron is to be transported, then the model checks for the following options:

- Cost of transportation of the materials in separate trucks
- Cost of transportation of 3 tons of glass and 4 tons of cast iron in one truck and 7 tons of paper in another truck
- Cost of transportation of 3 tons of glass and 7 tons of paper in one truck and 4 tons of cast iron in another truck
- Cost of transportation of 7 tons of paper and 4 tons of cast iron in one truck and 3 tons of glass in another truck
- Cost of transportation of all the materials in one truck.

However, the total quantity of material that can be transported on a truck is subject to capacity of the truck. In cases where it is not possible to load all the

materials on a single truck because of the capacity constraint, the load would be divided into two separate trucks.

A network is then constructed with all the nodes extracted from the database. Distances between pairs of cities, which represent arc lengths, are calculated as described in Section 6.3. All nodes, arcs and arc lengths are stored in separate matrices. The procedure constructs different networks to explore the different alternatives mentioned. Finding three shortest paths is trivial for the case of shipping the materials separately. For each material code, the three shortest distances are calculated by comparing the distances of the specified code nodes from the origin.

In case of shipping two or three materials together, separate networks are formed for each case. The networks are constructed such that the double sweep algorithm can be directly applied to them. The nodes, arcs and arc lengths for a given network are extracted from their respective matrices to form the network. The shortest paths, passing through intermediate nodes from origin to nodes of type 1, nodes of type 2 and nodes of type 3, are calculated separately. In case of shipping three materials together, following enumerations are explored for finding the shortest paths:

1. $O \rightarrow 2 \rightarrow 3 \rightarrow 1$
2. $O \rightarrow 3 \rightarrow 2 \rightarrow 1$
3. $O \rightarrow 1 \rightarrow 3 \rightarrow 2$
4. $O \rightarrow 3 \rightarrow 1 \rightarrow 2$
5. $O \rightarrow 1 \rightarrow 2 \rightarrow 3$
6. $O \rightarrow 2 \rightarrow 1 \rightarrow 3$

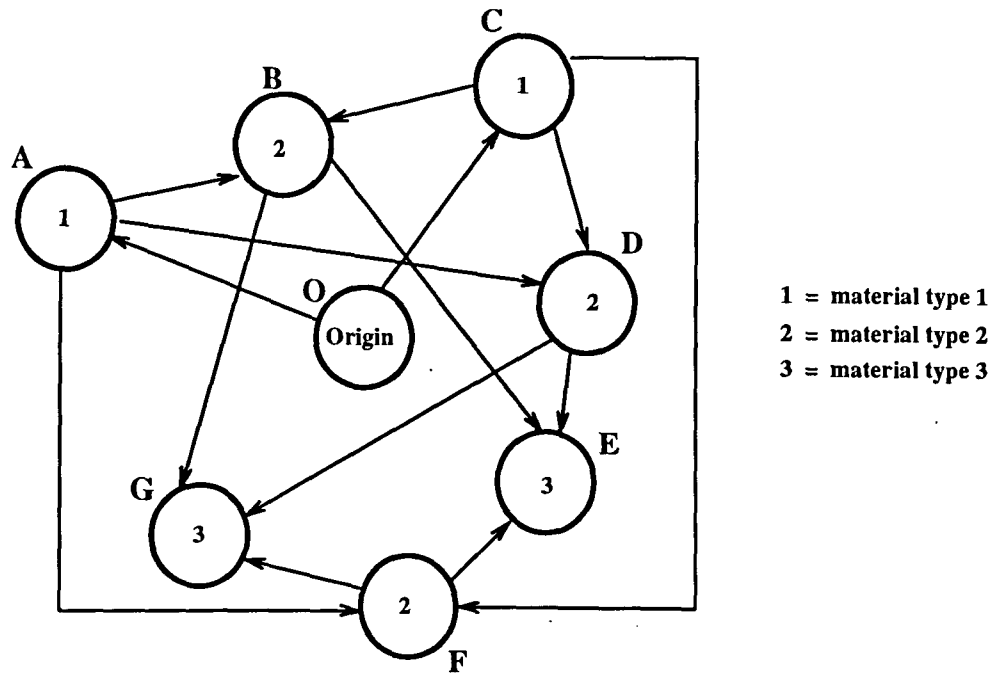


Figure 6.2: Sample Network for calculating $O \rightarrow 3$ shortest path

where,

O = origin node

1 = all nodes accepting material 1

2 = all nodes accepting material 2

3 = all nodes accepting material 3

For each of the above enumerations, a directed network is constructed. For example, the fifth enumeration denotes the problem of finding shortest paths from origin to all nodes accepting material 3, passing through nodes accepting material 1 and nodes accepting material 2. The network is constructed in which the origin is connected to all nodes of material type 1 by directed arcs pointing away from the

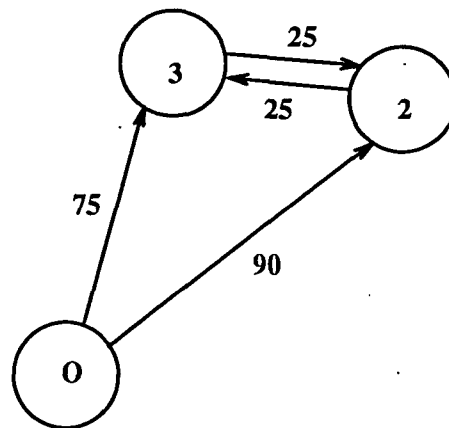


Figure 6.3: Comparison of lengths of two feasible paths

origin, each node of material type 1 is connected by directed arcs to all nodes of material type 2 which are then connected to all nodes of material type 3. This is shown in Figure 6.2. The double sweep algorithm is applied to each of the cases to find three shortest paths in the network. After computing three shortest paths for all the variations, the overall three shortest paths are obtained by comparing the numeric values of all the paths computed. All the enumerations listed are necessary since, for example, the length of a path from origin to node 2 and from node 2 to node 3 may be less than the length of the path from origin to node 3 and from node 3 to node 2. Both paths are feasible and hence both the possibilities need to be explored. An example for the paths $O \rightarrow 2 \rightarrow 3$ and $O \rightarrow 3 \rightarrow 2$ is shown in Figure 6.3. From the figure it can be seen that path $O \rightarrow 3 \rightarrow 2$ of total length 100 is shorter than the path $O \rightarrow 2 \rightarrow 3$ which has a total length of 115.

For the case where a destination and grade of a material accepted by the destination are specified, only two of the given enumerations need to be examined. For

example, if a destination is given which accepts material 2, then only the enumerations $O \rightarrow 1 \rightarrow 3 \rightarrow 2$ and $O \rightarrow 3 \rightarrow 1 \rightarrow 2$ have to be examined where destination is the specified node accepting material type 2.

A report is given to the user for all combinations of materials (separate materials, two or three materials together) that can be transported. Hence, the user has up to five options to choose from. It also gives a solution for transportation that is most cost effective after comparing solutions of all the alternatives at hand.

The model uses estimates of road distances between pairs of cities. Since road distances can be estimated with only a fair amount of accuracy, the three least cost options provided by the model may not represent the same order if actual road distances were taken into account. However, this problem can arise only if the difference in the total distance between the options is very small. This limitation is offset by providing three least cost marketing options to the user.

6.6 Example of the decision model

The algorithm application is demonstrated for a user located in Ames inquiring about market options for the following materials:

- 5 tons of bond/ledger paper
- 3 tons of HDPE plastic
- 9 tons of cast/gray iron.

Once the data has been input, the database is then searched for all the cities where buyers of the above materials are located. The list of cities identified in the above case and their arc distance and corrected distance as calculated by model in

Table 6.2: Arc distances and corrected distances from Ames, IA for cities for markets of materials

STATE	CITY	ARC DISTANCE	CORRECTED DISTANCE
IA	CEDAR FALLS	68.83	75.78
IA	CEDAR RAPIDS	101.32	111.02
IA	DES MOINES	30.04	33.42
IA	DUBUQUE	154.22	168.11
IA	FAIRFIELD	111.14	121.64
IA	HULL	150.42	164.01
IA	IOWA CITY	110.46	120.90
IA	IOWA FALLS	38.48	42.67
IA	MOUNT PLEASANT	129.65	141.63
IA	SPENCER	108.71	119.01
IA	WEST LIBERTY	125.37	137.01
IL	ALSIP	303.26	327.82
IL	CHICAGO	306.58	331.36
IL	PEORIA	228.34	247.71
KS	HUTCHINSON	356.26	384.34
KS	KANSAS CITY	208.33	226.25
MN	SAINT CLOUD	245.42	265.99
MN	SAINT PAUL	202.63	220.13
MO	BOONVILLE	216.39	234.89
MO	BRIDGETON	283.02	306.20
MO	JEFFERSON CITY	250.72	271.66
MO	KANSAS CITY	208.65	226.59
MO	MONETT	353.05	380.93
WI	APPLETON	303.66	328.27
WI	ASHLAND	342.07	369.22
WI	CEDARBURG	298.65	322.90
WI	GREEN BAY	329.31	355.62
WI	KAUKAUNA	310.24	335.27
WI	MADISON	226.04	245.23
WI	MILWAUKEE	298.57	322.81
WI	PORTAGE	234.67	254.48
WI	POYNETTE	233.43	253.15
WI	SHEBOYGAN	319.69	345.35

Section 6.3 are given in Table 6.2. A network is then constructed with arcs connecting the cities where separate materials can be transported. For example, Iowa Falls and Des Moines in Iowa are markets only for HDPE plastics and hence are not connected in the network. The arc lengths, i.e., distances between pairs of cities connected in the network, is then calculated. The distance matrix for state of Iowa for the above problem are given in Table 6.3.

Based on the above data, following choices are available for transportation:

- Transporting materials separately.
- Transporting bond/ledger paper and hdpe plastic in one truck and cast/gray iron separate.
- Transporting bond/ledger paper and cast/gray iron in one truck and hdpe plastic separate.
- Transporting hdpe plastic and cast/gray iron in one truck and bond/ledger paper separate.
- Transporting all three materials together in one truck.

Figure 6.4 shows the nodes identified as markets by the model. The model then calculates three shortest paths for each of the above alternatives as shown in Tables 6.4 through 6.8. A loading charge of \$40 is added to the total cost of transportation for each of the trucks employed for transporting the materials. The three overall shortest paths in this case are the ones in which all the materials are transported together, are shown in Table 6.8. From this example, it can be concluded that

Table 6.3: Distance matrix for the state of Iowa for network

	Cedar Falls	Cedar Rapids	Des Moines	Dubuque	Fairfield	Hull	Iowa City	Iowa Falls	Mount Pleasant	Spencer	West Liberty
Cedar Falls	X	59.95	95.91	99.19	117.91	208.68	83.43	45.1	128.08	155.89	98.28
Cedar Rapids	59.95	X	114.95	66.55	78.16	262.43	27.62	98.1	79.46	211.13	X
Des Moines	95.91	114.95	X	177.65	103.82	X	117.5	X	125.88	144.15	132.38
Dubuque	99.19	66.55	177.65	X	134.11	303.64	80.1	143.59	126.34	250.44	78.22
Fairfield	117.91	78.16	103.82	134.11	X	282.82	55.68	135.25	23.85	X	58.7
Hull	208.69	262.43	X	303.64	282.82	X	278.39	X	303.04	55.01	294.55
Iowa City	83.43	27.62	117.5	80.1	55.68	278.39	X	116.36	53.18	228.6	17.08
Iowa Falls	45.1	98.1	X	143.59	135.25	X	116.36	X	151.06	114.77	132.49
Mount Pleasant	128.08	79.46	125.88	126.34	23.85	303.04	53.18	151.06	X	257.28	49.25
Spencer	155.89	211.13	144.15	250.44	X	55.01	228.6	114.77	257.28	X	244.37
West Liberty	98.28	X	132.38	78.22	58.7	294.55	17.08	132.49	49.25	244.37	X

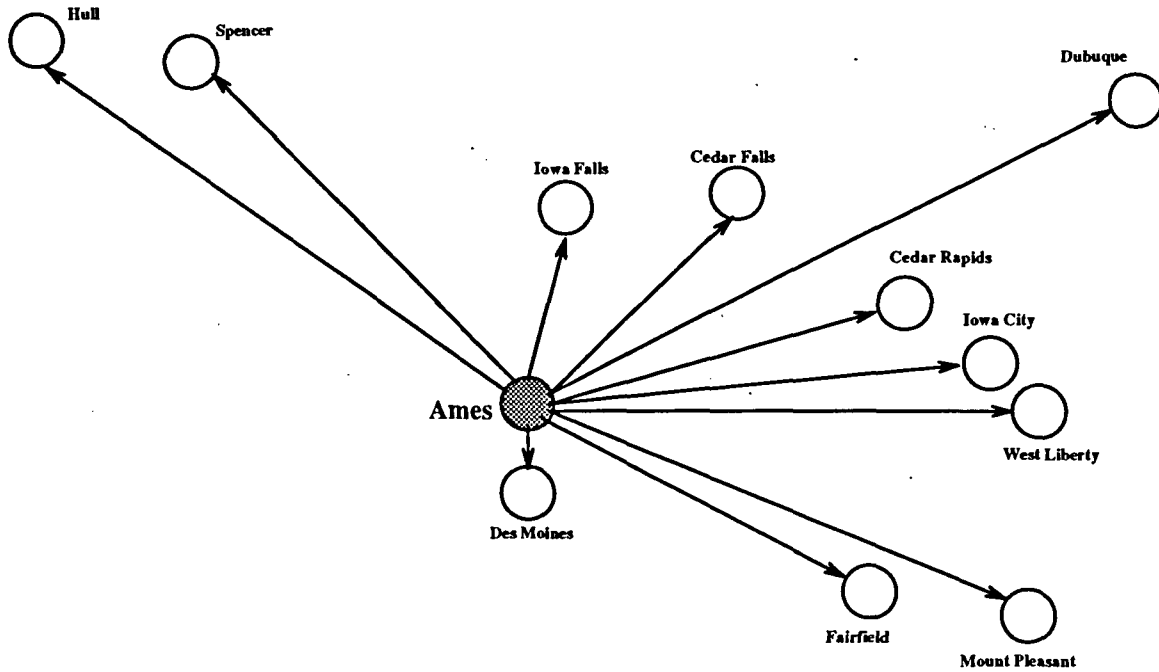


Figure 6.4: Cities identified in Iowa as markets

it is most economical to transport the materials collectively. The report presented to the user is shown in Figures 6.5, 6.6 and 6.7.

In some cases, it may not be possible to transport all the materials in a single 22 ton truck. In the example given above, if we have 10 tons of bond/ledger paper instead, then the total quantity of materials exceeds the truck capacity. In this case only two materials can be transported in one truck and third material has to be transported separately. In this case, the optimal path found by the algorithm recommends transporting paper and iron in one truck and plastics in a separate truck. The three shortest paths calculated by the algorithm for this case are shown in Table 6.9.

Table 6.4: Recommendations for shipping materials separately

MATERIAL	THREE SHORTEST PATHS	TOTAL DISTANCE
Bond/ledger paper	Ames → Cedar Falls	75.78
	Ames → Cedar Rapids	111.02
	Ames → Iowa City	120.90
HDPE plastics	Ames → Des Moines	33.42
	Ames → Iowa Falls	42.67
	Ames → Cedar Falls	75.78
Cast/gray iron	Ames → Cedar Rapids	111.02
	Ames → Spencer	119.01
	Ames → Fairfield	121.64

Table 6.5: Recommendations for shipping paper and plastics together

MATERIAL	THREE SHORTEST PATHS	TOTAL DISTANCE
Bond/ledger paper and HDPE plastics	Ames → Cedar Falls	75.88
	Ames → Iowa City	121.00
	Ames → Des Moines → Cedar Falls	129.33
Cast/gray iron	Ames → Cedar Rapids	111.02
	Ames → Spencer	119.01
	Ames → Fairfield	121.64

Table 6.6: Recommendations for shipping paper and iron together

MATERIAL	THREE SHORTEST PATHS	TOTAL DISTANCE
Bond/ledger paper and cast/gray iron	Ames → Cedar Rapids	75.88
	Ames → Cedar Falls → Cedar Rapids	110.02
	Ames → Iowa City → Cedar Rapids	148.52
HDPE plastics	Ames → Des Moines	33.42
	Ames → Iowa Falls	42.67
	Ames → Cedar Falls	75.78

Table 6.7: Recommendations for shipping plastics and iron together

MATERIAL	THREE SHORTEST PATHS	TOTAL DISTANCE
HDPE plastics and Cast/gray iron	Ames → Des Moines → Fairfield	137.24
	Ames → Cedar Rapids → Iowa City	138.64
	Ames → Iowa Falls → Cedar Rapids	140.77
Bond/ledger paper	Ames → Cedar Falls	75.78
	Ames → Cedar Rapids	111.02
	Ames → Iowa City	120.90

Table 6.8: Recommendations for shipping all three materials together

MATERIAL	THREE SHORTEST PATHS	TOTAL DISTANCE
Bond/ledger paper	Ames → Cedar Falls → Cedar Rapids	135.83
HDPE plastics	Ames → Cedar Rapids → Iowa City	138.74
Cast/gray iron	Ames → Fairfield → Mount Pleasant	145.59

Table 6.9: Overall three shortest path recommendations for shipping atmost two materials together

MATERIAL	THREE SHORTEST PATHS	DISTANCE	TOTAL DISTANCE
paper & iron hdpe plastics	Ames → Cedar Rapids	111.12	144.54
	Ames → Des Moines	33.42	
paper & iron hdpe plastics	Ames → Cedar Falls → Cedar Rapids	135.73	169.15
	Ames → Des Moines	33.42	
paper & iron hdpe plastics	Ames → Iowa City → Cedar Rapids	148.52	181.94
	Ames → Des Moines	33.42	

Report of options for shortest paths available for transportation of
bond/ledger, hdpe and cast/gray iron from AMES, IOWA.

=====

The following options are given on the basis of cost of trucking to be proportional to the distance. Here, trucking cost is assumed to be \$1 per mile. A loading charge of \$40 per truck is added. Since these costs are taken constant, changing trucking cost or loading cost to another number will not affect the options.

OPTION 1: Transporting the materials in separate trucks

	#	AMES to	Cost of shipping
bond/ledger	1.	CEDAR FALLS	115.78
	2.	CEDAR RAPIDS	151.02
	3.	IOWA CITY	160.9
hdpe	1.	DES MOINES	73.42
	2.	IOWA FALLS	82.67
	3.	CEDAR FALLS	115.78
cast/gray iron	1.	CEDAR RAPIDS	151.02
	2.	SPENCER	159.01
	3.	FAIRFIELD	161.64

Figure 6.5: Page 1 of report of the decision model

OPTION 2: Transporting bond/ledger and hdpe in one truck and
cast/gray iron separate

	AMES to	Cost	Total cost
1. bond/ledger, hdpe	CEDAR FALLS	115.88	266.90
cast/gray iron	CEDAR RAPIDS	151.02	
2. bond/ledger, hdpe	IOWA CITY	161	312.02
cast/gray iron	CEDAR RAPIDS	151.02	
3. bond/ledger, hdpe	DES MOINES ->	169.33	320.35
	CEDAR FALLS		
cast/gray iron	CEDAR RAPIDS	151.02	

OPTION 3: Transporting bond/ledger and cast/gray iron in one
truck and hdpe separate

	AMES to	Cost	Total cost
1. bond/ledger, cast/gray	CEDAR RAPIDS	151.02	224.44
hdpe	DES MOINES	73.42	
2. bond/ledger, cast/gray	CEDAR FALLS ->	175.73	249.15
	CEDAR RAPIDS		
hdpe	DES MOINES	73.42	
3. bond/ledger, cast/gray	IOWA CITY ->	188.52	261.94
	CEDAR RAPIDS		
hdpe	DES MOINES	73.42	

Figure 6.6: Page 2 of report of the decision model

OPTION 4: Transporting hdpe and cast/gray iron in one truck and bond/ledger separate

	AMES to	Cost	Total cost
1. hdpe, cast/gray	DES MOINES ->	177.24	293.02
	FAIRFIELD		
bond/ledger	CEDAR FALLS	115.78	
2. hdpe, cast/gray	CEDAR RAPIDS ->	178.64	294.42
	IOWA CITY		
bond/ledger	CEDAR FALLS	115.78	
3. hdpe, cast/gray	IOWA FALLS ->	180.77	296.55
	CEDAR RAPIDS		
bond/ledger	CEDAR FALLS	115.78	

OPTION 5: Transporting all materials together in one truck

#	AMES to	Shipping cost
1.	CEDAR FALLS -> CEDAR RAPIDS	175.83
2.	CEDAR RAPIDS -> IOWA CITY	178.34
3.	FAIRFIELD -> MOUNT PLEASANT	185.59

OVERALL LEAST COST OPTIONS:

	#	AMES to	Shipping cost
all materials	1.	CEDAR FALLS -> CEDAR RAPIDS	175.83
all materials	2.	CEDAR RAPIDS -> IOWA CITY	178.34
all materials	3.	FAIRFIELD -> MOUNT PLEASANT	185.59

Figure 6.7: Page 3 of report of the decision model

7. CONCLUSIONS

7.1 Conclusions

With increasing awareness for the need for recycling, programs for collection of secondary materials have grown considerably. While supply side activities have substantially increased the availability of materials for recycling, they have not led to the development of markets for recyclables. A major setback to recycling by industry has been the very erratic supply of the recyclable materials. This problem can be partially solved by providing better information sources regarding markets for the materials.

This work was undertaken with the goal of providing market information to the recyclers and providing decision support tools to the sellers to aid them in making marketing decisions. An information system has been developed which provides information on eight secondary materials (paper, plastics, glass, ferrous metal, non-ferrous metals, battery, tires and used motor oil) in the nine Midwestern states: Iowa, Kansas, Missouri, Minnesota, Nebraska, Illinois, North and South Dakota, and Wisconsin. Complex queries were built in the information system so that a user can extract very specific information from the database without having to go through scores of records in the database. A query has been provided to search the recyclers according to first two or first three digits of a zip code. The advantage of using zip

codes is that they are readily identifiable and relatively homogeneous, thus providing an effective tool to the marketer for inquiries, prospects, etc. Another query allows the user to view the recyclers located on a particular Interstate highway, U.S. highway or State highway.

A decision support model has been built in the system to provide the sellers of secondary materials with a list of feasible markets based on the quantities and grades of materials at hand. Transportation is a major portion of the total cost incurred in dealing with secondary materials. A market closer to a seller will be most feasible because of lower transportation cost. It is assumed that the transportation cost is proportional to the distance and hence the markets for which transportation distance is least will be most cost effective. The model uses the double sweep algorithm developed by Shier [38] to estimate three shortest paths that can be used for transporting up to three materials together in single truck. The algorithm finds the cities (markets) located on a path that would minimize the total transportation distance. The user is given a report on three shortest paths each for shipping one, two or three materials together in a truck. This model is particularly useful for small recyclers who cannot collect materials in bulk to fill a truck-load. They may be able to ship two or more materials together in a single truck, thus reducing the transportation cost significantly.

This research shows that decision making tools incorporated in the information system can aid recyclers in making their marketing decisions. By providing market options with the least transportation cost, the system gives solutions which may not be very obvious by just looking at a list of buyers. It offers initial solutions to recyclers which can be explored in greater detail by them. Due to the low cost of materials to

be transported, it is very crucial for the seller to make best possible market deal to stay in business. Such model may also give the seller an insight into how the material can feasibly be transported to a location while making a certain percentage of profit.

Lack of data in the field of recycling and transportation is a major bottleneck in providing the user with better decision making tools. The information system could be extended to providing a feasible set of sellers for the buyers of secondary materials. However, today in the field of recycling, selling of material is the biggest problem and hence the decision model took only sellers into account.

7.2 Recommendations for future research

1. The model presented for providing sellers with market information was oversimplified for its operation online over the phone. A more realistic model could be implemented to give more accurate feedback to the user. A possible extension in the model could minimize the transportation cost while maximizing profit from the sale of materials. It can be formulated as a multiple-criteria decision making model.
2. The model can be extended to incorporate different modes of transportation and making recommendations based on all the modes of transportation available.
3. Keeping the information current is a very important aspect in an information system that contains market information. Providing the online updating facility for the firms ensures the currency of information in the system. Such a feature could be provided in the future if the security concerns can be addressed adequately.

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APPENDIX A. DATABASE AND BULLETIN BOARD SYSTEMS

- **Solid Waste Information Clearinghouse (SWICH)**

Contact: Lori Swain
 The Solid Waste Information Clearinghouse
 P.O. Box 7219
 Silver Spring, MD 20910
 Phone: (301) 585-2898 or (800) 67-SWICH
 Fax : (301) 585-0297

Telephone number to connect to SWICH: (301) 585-0204.

Connection through 2400/1200/300 baud modem: 8 bits, 1 stop bit, no parity.

- **Pencycle**

Contact: Kurt A. Grotz
 Pennsylvania Resources Council, Inc.
 25 West Third Street
 Media, PA 19603
 Phone: (215) 565-9191
 Fax : (215) 892-0504

Telephone number to connect to PenCycle: (215) 892-9940.

Connection through 2400/1200/300 baud modem: 8 bits, 1 stop bit, no parity.

Subscription fee charged.

- **Recycling: America**

Telephone number to connect to Recycling: America : (818) 902-1477.

Connection through 2400/1200/300 baud modem: 8 bits, 1 stop bit, no parity.

- **RecycleLine**
Contact: George Leshchuk or Ed Lowe
American Recycling Market Inc.
P.O. Box 577
Ogdensburg, NY 13669
Phone: (800) 267-0707

Connection through 2400/1200/300 baud modem: 8 bits, 1 stop bit, no parity.
Subscription fees charged.

- **Florida Recycling Marketing System (FRMS)**
Contact: Paul Still or Peter Lee
Florida Center for Solid and
Hazardous Waste Management
3900 SW 63rd Blvd.
Gainesville, FL 32608
Phone: (904) 392-6264 x 118 or 133

Telephone number to connect to FRMS: (800) 348-1239.
Connection through 2400/1200/300 baud modem: 8 bits, 1 stop bit, no parity.

- **RecycleNet**
Contact: Michael Wenstrom
Colorado Office of Energy Conservation
1675 Broadway, Suite 1300
Denver, CO 80202-4613
Phone: (303) 620-4292 or (303) 865-811)

Telephone number to connect to RecycleNet: (800) 877-6670.
Connection through 2400/1200/300 baud modem: 8 bits, 1 stop bit, no parity.

- **Recyclable Materials Market Directory**
Wisconsin Department of Natural Resources
Bureau of Solid & Hazardous Waste Recycling
101 S. Webster St.
Madison, WI
Phone: (608) 264-6072

The system can be obtained on floppy disk through Wisconsin-DNR.

- **Pollution Prevention Information Exchange System (PIES)**
Contact: Priscilla Flattery
Pollution Prevention Office
U.S. Environmental Protection Agency
410 M Street, S.W.
Washington, D.C. 20460
Phone: (202) 245-3557

Telephone number to connect to PIES: (703) 506-1025.
Connection through 2400/1200/300 baud modem: 8 bits, 1 stop bit, no parity.

- **Environet**
Greenpeace Action
Building E
Fort Mason, CA 94123
Phone: (415) 474-6767

Telephone number to connect to Environet:
(415) 512-9108 for 2400/1200/300 baud access
(415) 512-9120 for 9600/14400 baud access
Connection through modem: 8 bits, 1 stop bit, no parity.

- **MAKAAO**
Contact: Dennis P. Leong
P.O. Box 88671
Honolulu, HI 96830-7878

Telephone number to connect to MAKAAO: (808) 672-8276.
Connection through 2400/1200/300 baud modem: 8 bits, 1 stop bit, no parity.

APPENDIX B. RECYCLING BUSINESSES SURVEY FORM

SURVEY OF MIDWEST RECYCLING BUSINESSES

MATERIALS

Please indicate the types of solid waste materials recycled by your firm. Use the following classifications: broker/trader, processor (sort, clean, refine, size), raw stock producer (semi-finished product such as particle board), and (finished) product producer.

	KIND OF OPERATION			PRICE RANGE			ANNUAL TONNAGE	AS RECEIVED	
	Broker Processor	Raw Stock Producer	Product Producer	Low	Average	High		Loose Baled Shredded	Crushed Granulated
PAPER									
Bond/Copy/Ledger	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	_____	_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
Mixed Papers	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	_____	_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
Newsprint	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	_____	_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
Computer Paper	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	_____	_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
Slick/Glossy	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	_____	_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
Corrugated Cardboard	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	_____	_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
Plain Cardboard	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	_____	_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
									<input type="checkbox"/>
PLASTICS									
HDPE	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	_____	_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
LDPE	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	_____	_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
PET	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	_____	_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
Poly-vinyl chloride	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	_____	_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
Polystyrene	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	_____	_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
Polypropylene	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	_____	_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
Acrylics	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	_____	_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
									<input type="checkbox"/>
GLASS									
Clear	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	_____	_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
Green	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	_____	_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
Brown	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	_____	_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
Mixed Colors	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	_____	_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
									<input type="checkbox"/>

Loose Cullet

TRANSPORTATION

1) What transportation facilities serve your plant?

HIGHWAY Interstate# _____ RAILROAD Line _____ BARGE River _____
U.S.# _____ Mile# _____ Mile# _____
State# _____ Do you have access to siding? _____ Port# _____
County# _____

2) Do you own your own transportation vehicles or equipment? Trucks Rail cars Barges

3) Please indicate the quantities of the secondary materials accepted at your facility.

Typical household Pickup truck Straight truckload Semi truckload Rail car Barge

4) Please indicate the mode and unit quantity (by weight) by which you ship materials sold by you to your customers.

	Name of truck, rail, or barge line	Approximate weight of load in tons
a) Semi truckload	_____	_____
b) Rail car	_____	_____
c) Barge	_____	_____

5) Please estimate the costs of transporting the materials sold by you to your customers. (Use the unit load of #4.)

	Typical cost per ton (or specify other)	Approximate distance in miles
a) Semi truckload	_____	_____
b) Rail car	_____	_____
c) Barge	_____	_____

6) Are there any additional transportation costs for handling the secondary materials you ship (loading/unloading, vehicle cleaning, special fees, etc.)? Please specify the amount and cost basis (per load, per ton, etc.).

7) Please enter the name and telephone number of a person whom we may contact for additional information.

8) How many full-time equivalent employees work at your facility?

9) Please enter any additional information needed for you to buy or sell materials that we did not cover.

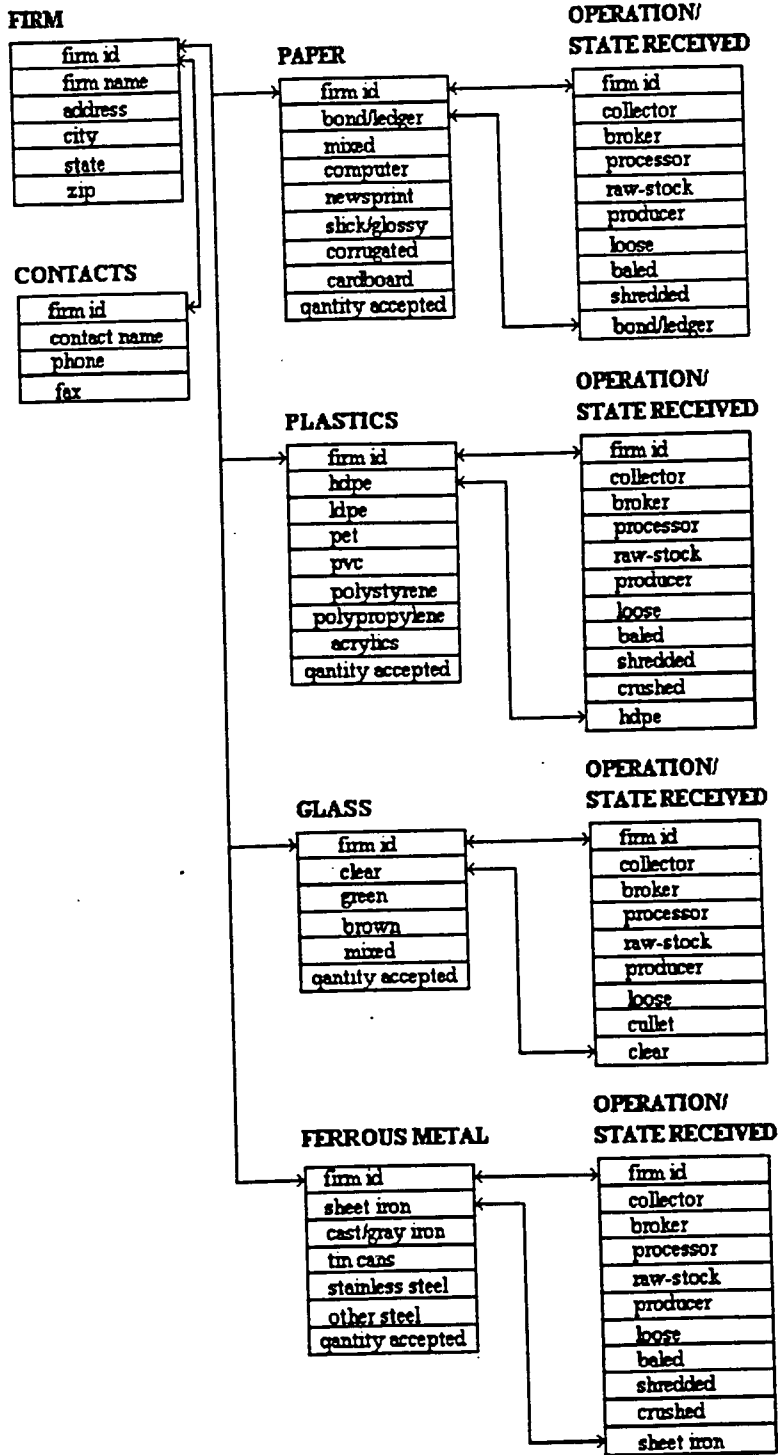
If you have questions or comments regarding this survey form, please contact:

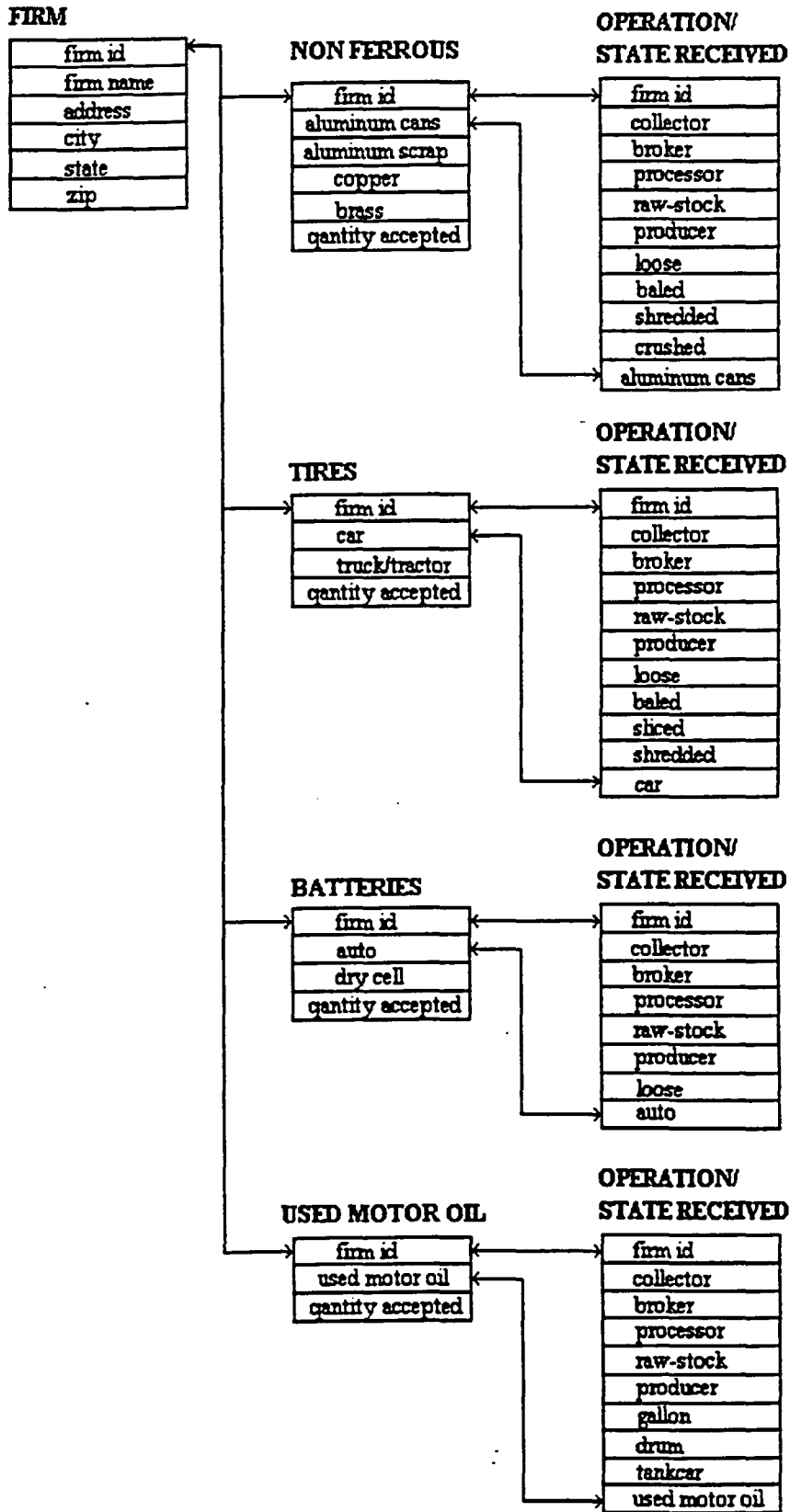
Dr. Keith Adams
(515) 294-5065

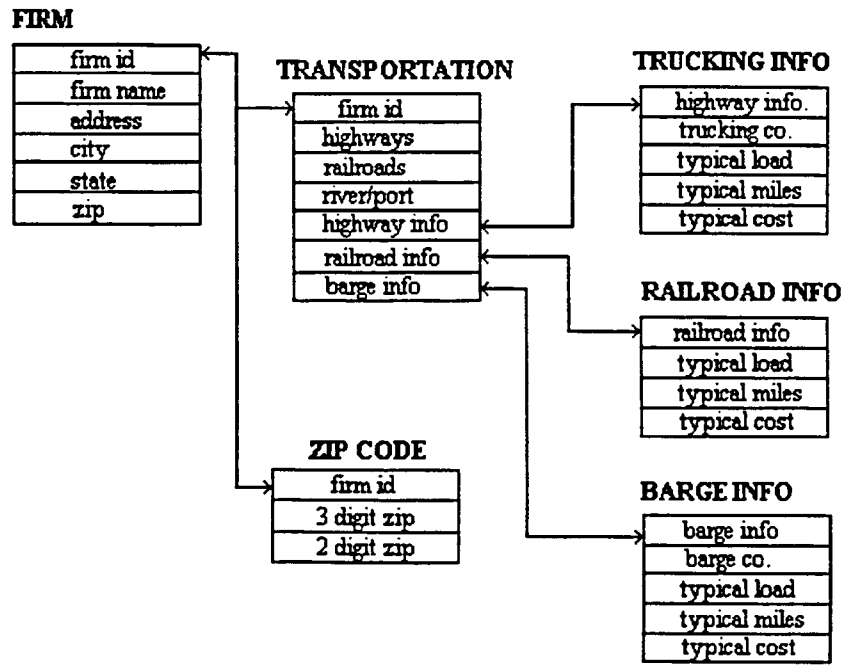
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APPENDIX C. MARTIN DATABASE STRUCTURE







APPENDIX D. FLOWCHART FOR INFORMATION SYSTEM

