



Design of a computer-based information retrieval system for highway planning
by Francis Chung Fai Yu

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE in Civil Engineering
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Abstract:

This thesis is a treatise on the systems engineering approach to the design of a rapid-access, computer-based, information retrieval system for highway planning.

The highway administration of the federal, state, and local governments are discussed and the need for establishing a data bank system for planning purposes is stressed.

The current state of the art in data bank design among all the state highway departments in the U.S. is surveyed and results compiled.

A systems design embracing exploratory planning, development planning, and implementation phases of the systems engineering framework is the main body of this thesis. Discussions in each phase are reinforced with the case study, wherever applicable, of a data bank design currently being carried out in Montana.

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FOR HIGHWAY PLANNING

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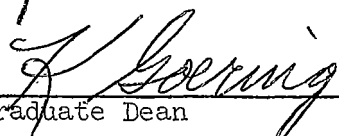
in

Civil Engineering

Approved


Head, Major Department


Chairman, Examining Committee


Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

December, 1970

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TABLE OF CONTENTS

CHAPTER	Page
I INTRODUCTION	1
Federal Highway Administration	1
The State Highway Department	5
County and Local Road Administration	7
Federal-Aid Procedure	8
The Need for an Information Retrieval System	9
II THE CURRENT STATE OF THE ART	11
Survey Analysis	13
Conclusion of the Survey	20
III THE SYSTEMS ENGINEERING APPROACH	23
The Pattern of Systems Engineering	23
Systems Studies	24
Exploratory Planning	24
Development Planning	25
Implementation	25
Systems Maintenance	26
IV SYSTEMS DESIGN	27
Exploratory Planning	28
Problem Definition	28
Setting Objectives	28
Systems Synthesis	29
Systems Analysis	30
Exploratory Planning Documentation	34
Development Planning	34
Activity-Module Transform	35
System Element Analysis	36
Compatibility Determination	41
Generic System Description	42
Systems Selection	42
Equipment Selection	44
Systems Optimization	44
Implementation	47
Programming Assignment	47
Detailed Design	49
Programming Languages	49
Documentation	50

CHAPTER	Page
Conversion	51
Systems Design Summary	53
V A LOOK TO THE FUTURE	55
APPENDIX	57
REFERENCES	61

LIST OF FIGURES

Figure	Page
1. Organizational Structure of the Federal Highway Administration.	3
2. Organization Chart of the Montana State Highway Commission.	6
3. Various Computers Used by 37 State Highway Departments.	14
4. Stated Reasons for not Developing a Data Bank.	19
5. HIS Generic View.	43

LIST OF TABLES

Table	Page
I Activity-Report Chart.	21
II Roadlog Record Structure.	31
III Resources Table.	32
IV Medium-Sized Computers Available in the U.S.A.	45

ABSTRACT

This thesis is a treatise on the systems engineering approach to the design of a rapid-access, computer-based, information retrieval system for highway planning.

The highway administration of the federal, state, and local governments are discussed and the need for establishing a data bank system for planning purposes is stressed.

The current state of the art in data bank design among all the state highway departments in the U.S. is surveyed and results compiled.

A systems design embracing exploratory planning, development planning, and implementation phases of the systems engineering framework is the main body of this thesis. Discussions in each phase are reinforced with the case study, wherever applicable, of a data bank design currently being carried out in Montana.

CHAPTER I

INTRODUCTION

Because this thesis addresses itself to information retrieval systems for highway planning purposes, it is desirable that the reader become acquainted with the highway system and be aware of the types of data necessary to manage the highway system. The total highway system includes toll roads, interstate highways, primary and secondary highways, county roads, city streets, and special use roads. The overall coordination of a major portion of the system is the responsibility of the Federal Highway Administration, U.S. Department of Transportation, with the major routes under direct administration of the individual state highway departments.

Federal Highway Administration

The Federal Highway Administration, FHWA, represents the federal government in matters relating to highways. Created in 1893 as the Office of Road Inquiry of the U.S. Department of Agriculture, the Office operated under several names on a very limited scale until 1916 when its functions were greatly broadened by the Federal Aid Highway Act. In 1918 the organization became the Bureau of Public Roads of the U.S. Department of Agriculture. Under a federal reorganization effective July 1, 1939, the name was changed to the Public Roads Administration and was transferred to the Federal Works Agency. In

1949, under a reorganization of the Executive Branch of the federal government, the organization became the Bureau of Public Roads of the U.S. Department of Commerce. Administrative control of the Bureau of Public Roads was changed to the U.S. Department of Transportation on April 1, 1967. Effective August 10, 1970, the name was changed to the Federal Highway Administration and administrative control remains with the U.S. Department of Transportation.

The principal function of FHWA is the administration of monetary federal aid to the individual states. The present organizational structure of FHWA is shown in Figure 1.

The planning activities of FHWA are shared by many of its branches, but the overall coordination of the planning effort appears to be carried out by the Office of Highway Planning. The specific functions of the Office of Highway Planning (Ref 1) are essentially as follows:

1. Develops and promotes application of policies and procedure, standards and instructions for selection of routes for inclusion in the federal-aid highway systems and their extension into the urban areas.

2. Develops techniques for long-range plans and programs to serve national, state, local, urban and rural highway needs.

3. Assembles and interprets planning information on highways and other forms of transportation, as a basis for major decisions in the development of the federal-aid highway policy.

4. Develops and applies new and improved techniques focusing on the economic, sociological and environmental considerations

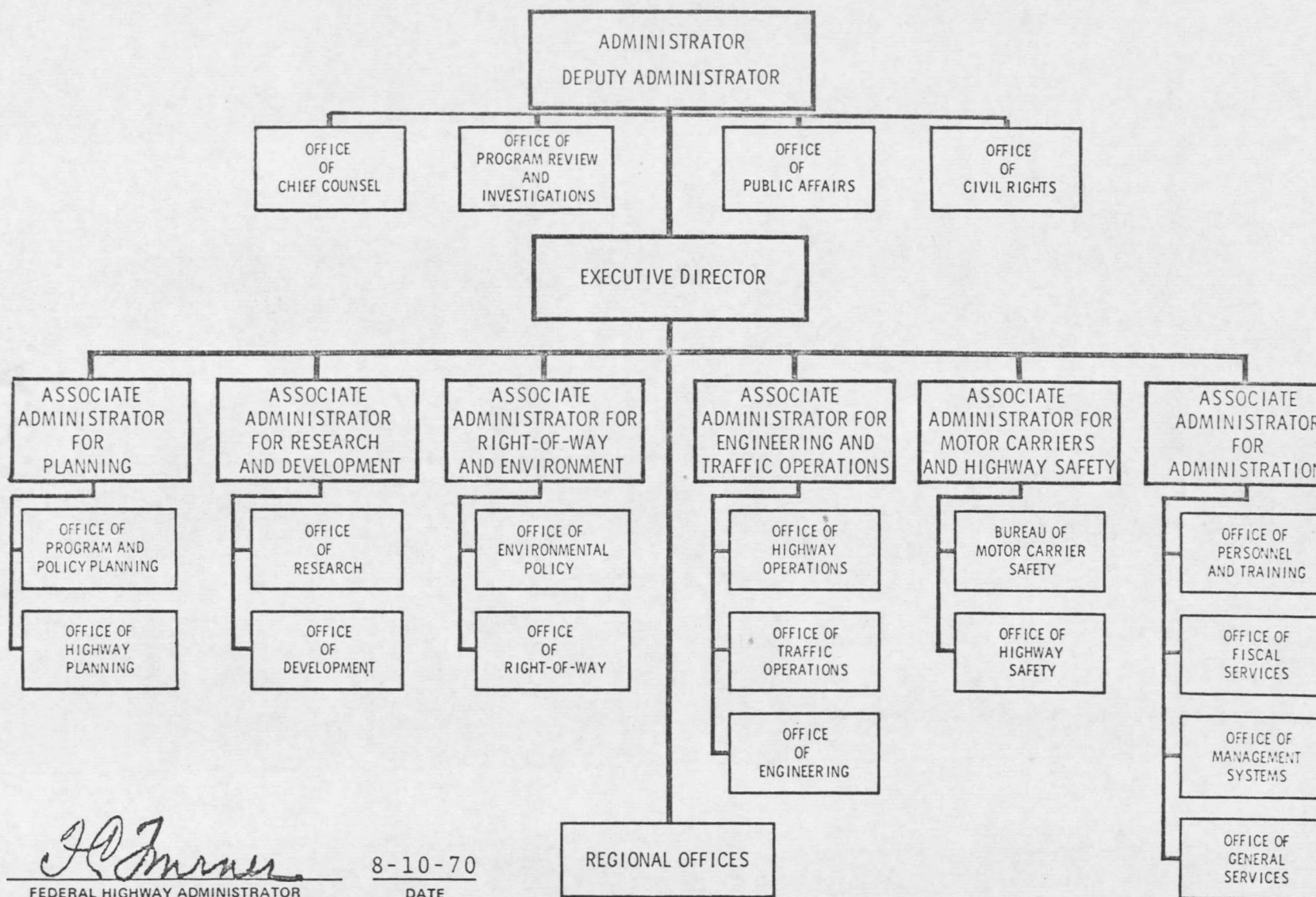


Figure 1. Organizational structure of the Federal Highway Administration.

for application by states and local communities in highway planning and programming.

5. Develops procedures for use by states and local communities in determining capital improvement program needs and costs, including administration and maintenance, forecasting of highway use and of revenue sources available for highway system financing, and evaluation of financial consequences of system plans.

6. Coordinates the statewide highway planning programs.

7. Implements and coordinates with state highway departments the highway planning and programming aspects of highway systems developed under the Appalachia Regional Development Act of 1965 and within the economic development regions established under the Public Works and Economic Development Act of 1965.

8. Administers the continuing comprehensive planning process relating to urban transportation planning.

9. Compiles, evaluates, and publishes pertinent statistical data on all phases of highway development and finance.

10. Provides technical advice and guidance on all aspects of highway planning and programming, and organizes and conducts training programs for FHWA, state highway personnel, and others in the areas of statewide and urban transportation planning..

The above functions are enumerated primarily to indicate the dependence of FHWA on current and accurate data. It is incumbent on the individual state highway departments to furnish FHWA with the current and accurate data necessary to evaluate existing methods and

procedures and plan future systems. It is therefore important that the state highway departments be organized and managed in such a way that appropriate data can be collected, processed, and reported in a rapid, accurate, and economical manner.

The State Highway Department

The administrative organization of the individual state highway departments has developed at different paces, with divergent philosophy guiding the development in the different states. Some highway departments are headed by single executives with no boards or controlling group of any kind. The single executive is then, of course, responsible directly to the Governor of the State. In other administrative organizations the highway department may be headed by a single executive with a commission or board acting in an advisory capacity, or with a commission or board dividing authority with the executive and each acting in a coordinating capacity to the other.

The State of Montana, whose highway department's organization is similar to many others, has a single executive, the State Highway Engineer, and an appointed five-man commission. The organization of the Montana State Highway Commission is shown in Figure 2.

The Statistics and Research Division, commonly call the Planning Survey Division, of the Montana State Highway Commission is responsible for collecting information from other divisions for statistical analysis and report compilation. Specifically, the Planning Survey Division, in cooperation with FHWA, compile annual reports such as

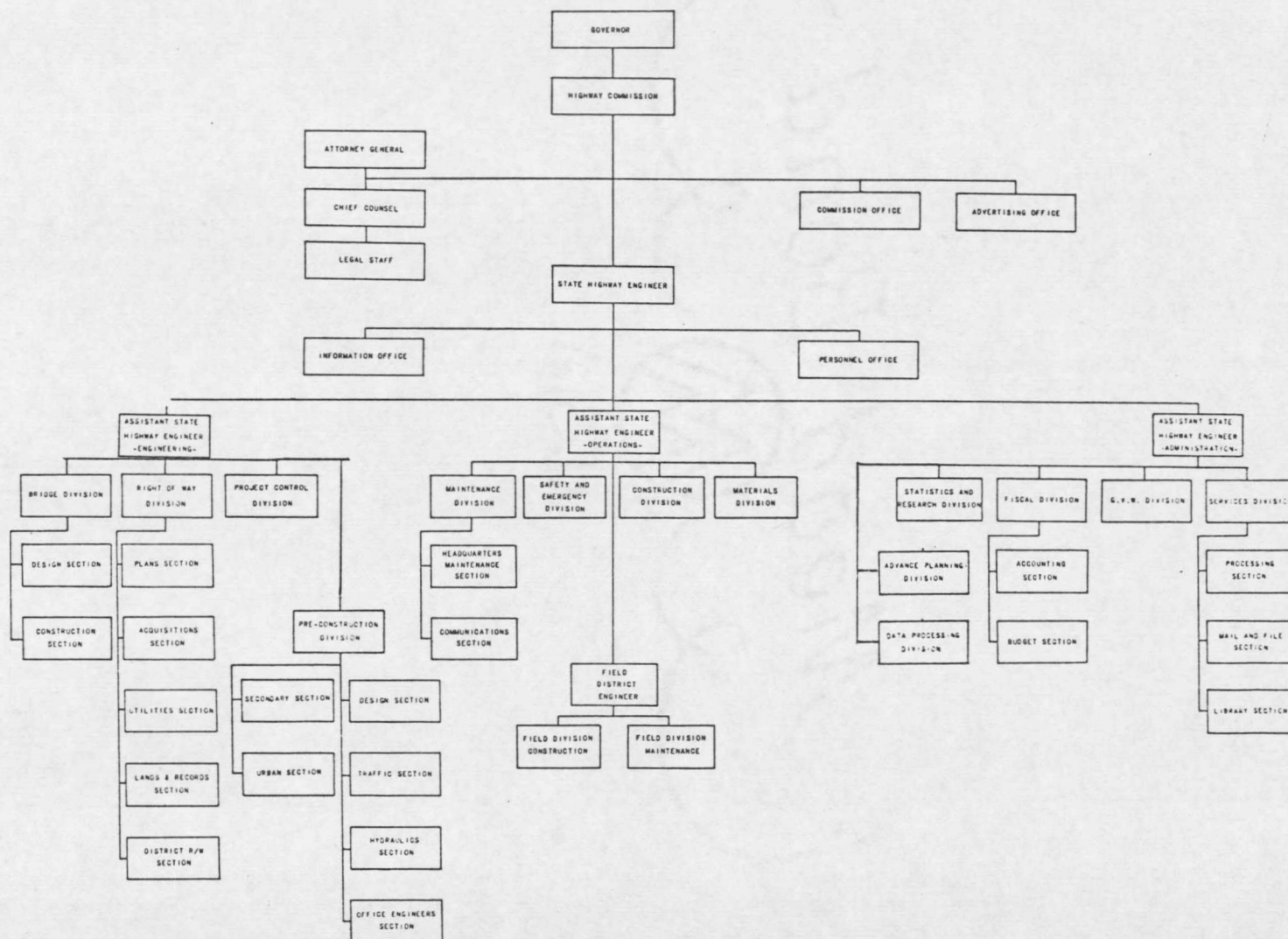


Figure 2. Organization Chart of the Montana State Highway Commission

Roadlog, Accident by Sections, Traffic by Sections, Sufficiency Rating, and Bridge Listing. As pointed out earlier, FHWA relies on these data to evaluate projects submitted by the state for project approval by FHWA. Procedures for federal aid in highway projects will be discussed in the latter part of this chapter.

County and Local Road Administration

The administration of highways at the local level varies from place to place. In the New England states and in Pennsylvania very small subdivisions of the states administer those roads not in the state system. In the Northeast part of the country, a dual plan of local highway administration generally exists, in which counties are responsible for systems of main county roads, and townships are responsible for the remaining mileage. In Iowa, Indiana, and Michigan, township roads are under the jurisdiction of the county. Rural roads that are not a part of the state highway systems are under county jurisdiction in the South and West of the U.S. Sometimes the county road system is supervised as a unit, and sometimes it is supervised by precincts.

In Montana the State Constitution (Ref 2) requires that each county be divided into three Commission Districts and that one County Commissioner be elected from each district by the entire electorate of the county.

In the major counties where the county surveyor is the roadway manager, the Board of County Commissioners acts as the policy-making

board and allows the county surveyor to take full control of the county road work, planning, maintenance, construction, and care of equipment.

In the remaining 52 counties, the Board of County Commissioners has general supervision over the county roads in their respective counties. Where a road supervisor is employed, his duties are comparable to those of the county surveyor. In counties where the Board of County Commissioners supervises highway operations, they sometimes work as a unit covering the entire county.

Federal-Aid Procedure

Authorizations of federal-aid funds are made to the states for a two or three year period, well in advance of the fiscal years for which they are intended. Funds for each year are apportioned to the states by federal authorities according to legally prescribed mathematical formulas. This apportionment takes place about six months in advance of the beginning of each fiscal year, which starts July 1.

The states are then required to submit programs of projects to be undertaken with the funds to FHWA. The FHWA then determines the general character of the immediate undertakings needed for an orderly improvement of the highway system. Following approval of a program, the state submits a more detailed description of each section of road to be improved, and the character of improvement proposed. Upon approval of a particular project proposal, a contractual agreement for improvement is entered into by the state and the federal government.

Subsequently the state highway department prepares plans and

specifications, receives bids for work to be done, awards a construction contract, reviews construction, and pays the contractor for work done. Each step is reviewed by, and is subject to the approval of FHWA. The federal share of the cost is reimbursed to the state only as portions of the work are satisfactorily completed.

Programs of works are reviewed in the regional office of FHWA which keeps in constant touch with field progress, but the district engineer in each state is authorized to approve each step following approval of a program.

The Federal-aid Secondary Program under the Federal-aid Highway Act of 1944 promotes works with counties on cooperative projects. This act also provides funds for construction of freeways in urban areas.

In Montana the state is divided into twelve financial districts by a selective grouping of counties. All money raised from gasoline taxes and other highway user fees are allocated to these twelve financial districts.

Need by Highway Departments for Information Retrieval Systems

Planning data are varied and extensive. They may be grouped into the following categories:

1. Existing highway network data: such as the location of bridges, interchanges, culverts, railroad crossings; the number of lanes; pavement types; thickness; median width; etc.
2. Areal data: the geographical limits of an area, such as a county or a city.

3. Cost data: the costs associated with the network data.

4. Event data: such as average daily traffic, service volumes, and classification of accidents.

To collect, classify and make available these voluminous data desirable for planning and design purposes is no easy task.

Each year, every state highway department, in cooperation with FHWA, compile reports on many aspects of the federal-aid highway system. As well, each state highway department is obligated to furnish information about their highway system upon request by other agencies. A computer-based, integrated, information system or a "data bank" is seen to be most fitting for these purposes.

A data bank logically consists of many inter-referral files linking all data to a common base of reference for rapid access and retrieval purposes. The need for an integrated data bank for planning is self-evident, just from the standpoints of time and cost alone.

CHAPTER II

THE CURRENT STATE OF THE ART

An ideal data bank, by the author's definition, is a collection of files which are to be computer based and organized in such a way that:

1. Data are stored on a direct access storage device(DASD) with an indexing system for rapid-access and multipl-t-referral purposes.
2. Data can be kept current through updating activities such as rewriting, deleting, or adding records whenever necessary.
3. Reports can be generated from the system, as specified.
4. Random retrieval facilities are provided.
5. All requests are command or pseudo-language oriented.

If one traces the development of data processing, the following methods, in chronological order, may be identified: manual, unit record, computer card, tape, and DASD.

A few affluent state highway departments were fortunate to have computers for processing data as early as the late fifties. Some started using second generation computers in the early sixties. The transition from the first to the second generation computers, as far as data handling is concerned, may be characterized bt the change from card to tape. Considerable efforts were invested on software. But the use of that same software is not suitable for the third generation computers which emerged in the late sixties.

The use of DASD was somewhat limited as compared to the use of tapes for storage. Programs written in the early sixties needed to be converted or modified drastically in order to take advantage of the DASD for data bank applications. Reports of any description, however, can still be generated, provided the data are sorted or collated in a specific order for each run. Most highway departments are limited in budget and restricted by other commitments such that conversion of existing programs for ideal data bank applications may seem beyond their resources.

It appears that most highway departments have the means to install a modern data bank, but are somewhat limited by the lack of manpower for implementation. Another deterrent may be the lack of a coordinated effort within the highway department. All these contribute to what the author terms the "transition era" in data bank development.

A questionnaire was sent to each of the state highway departments in the U.S. to survey the current state of the art in data bank development and usage, with a two-fold purpose in mind:

1. To confirm that the author's concept of the ideal data bank requirements are, in fact, adequate.
2. To determine if some of the state highway departments are, indeed, entrenched in the so-called transition era.

Survey Analysis

The questionnaire sent to all of the state highway departments, together with the cover letter, is shown in Appendix A. The analysis is based on 37 returns out of a possible 51. Because 14 state highway departments did not reply, the returns from this survey cannot represent true national statistics on the subject in question. It is pleasing to note that most of the returnees are eager to receive compiled results of the survey which shows a common interest among the state highway departments in the "current state of the art." For ease of discussion, the results are presented in a question-answer format below, with the questions numbered indentically to those of the questionnaire in Appendix A:

1. Configurations of your computer.

Most state highway departments have modern equipment with standard accessories. As shown in Figure 3, IBM, with 85% of the computers, completely dominates the market for highway department uses. The most popular model is the S360/40 which appears to be an ideal medium-sized computer for highway department applications. The number of computers larger than the S360/40 is not insignificant, and this may reflect the long-range planning of some highway departments in computer usage. Other manufacturers sharing the highway department market are UNIVAC, BURROUGHS, and RCA.

2. Do you have a data bank system similar to that described in our letter?

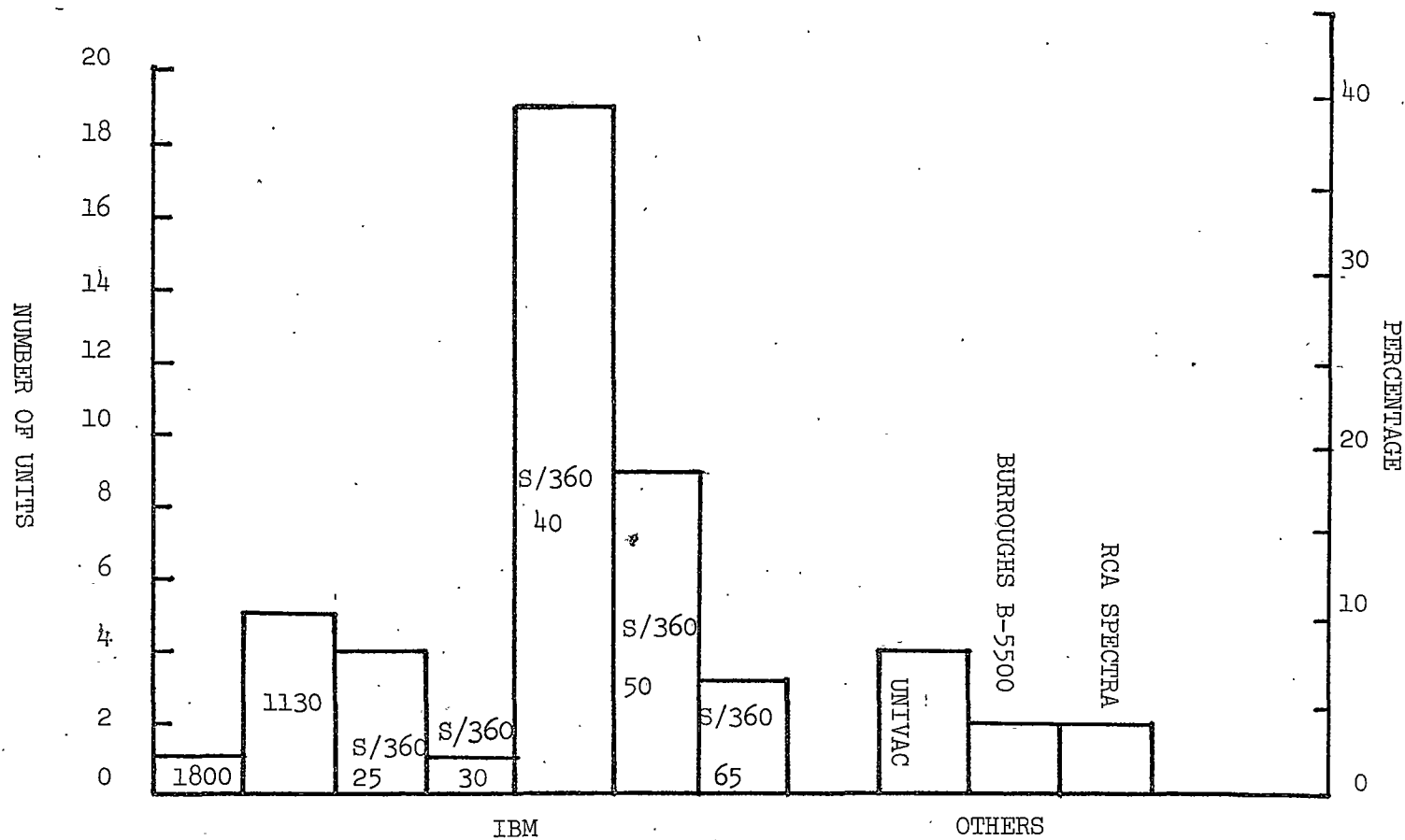


Figure 3. Various computers used by 37 state highway departments.

The word "similar" in this question introduced some confusion. Notably, a reply from one highway department reads as follows: "I had thought of our reference system as a data bank but our computer people tell me it is not." One department indicated that they had a data bank system capable of direct access using tape files. Another indicated "yes" to this question but have no files operational. The author deems it appropriate to divide the answers into four groups as shown below:

<u>Group</u>	<u>Number of Respondees</u>
Operational	1
Semi-operational	3
Questionable	1
none	32

3. State your common base of reference for cross-referencing your files.

The following combination of variables are identified by the respondees:

- a. County, route sequence.
- b. County, route, milepost.
- c. Project number.
- d. Federal-aid system, route number, milepost.
- e. County, route, section, log mile.
- f. Distance and direction from a given reference point.
- g. System, district, highway number, agreement number, mileage.

h. Road number, section, coordinates.

4. State the total number of files in your system that are operational.

<u>Files Operational</u>	<u>Respondees</u>
7	1
5	1
4	3
3	2
2	1

5. What programming language did you use?

<u>Programming Language</u>	<u>Respondees</u>
CØBØL	5
PL/I	2
ALP	1
FØRTRAN	1

6. What is the design "life" of your system?

<u>Design "life"</u>	<u>Respondees</u>
Annually	1
Constantly update	1
5 years	1
6 years	1
Indefinite	3

7. Did you make use of the existing format or design a new format for your data?

Five (5) indicated new and two (2) indicated both old and new.

8. Indicate the approximate time, if applicable, you spent on the following:

- a. Systems studies.....months.
- b. Systems design.....months.
- c. Programming and testing.....computer-hours.
- d. Documentation.....months.
- e. Implementation.....months.
- f. Data preparation for files.....months.
- g. Total project--Professional.....man-days.
Subprofessional.....man-days.

The answers to these questions are completely dependent on the scope of the data bank system. Answer to (a) varied from 2 to 6 months; (b) 6 to 60 months; (c) 3 to 1200 computer-hours; (d) 2 to 60 months; (e) 2 to 60 months; (f) 4 months to indefinite; and (g) 833 man-days to unknown for professional and 1800 man-days to unknown for subprofessionals.

9. Was the system documented?

Two (2) reported "yes."

10. Did you include a "straight line diagram" file (this file can be digitized into a geometric file) in your data bank?

This question was vague; so were the replies. Three (3) indicated "yes," four (4) indicated digital as the main form for retrieval, and one (1) indicated incremental plot.

11. What other applications did you use for your data bank than routine report generation and random retrieval purposes?

Replies to this question were:

a. Simulation, assessing the impact of variable financial conditions and project mixes on highway planning.

b. Needs study, post-performance analysis, lane miles, vertical clearance, overload and height routing analysis, state mileage table and road life table.

12. Is your department considering setting up a data bank in the future?

Six (6) indicated "no," two (2) indicated "maybe," and the rest indicated "yes."

13. State the major reasons for not having a data bank operational.

This is perhaps the most significant question. Some highway officials gave general remarks, other expressed bitterness about the management. Generally the answers were informative. They are represented in Figure 4. Items listed under "other" include:

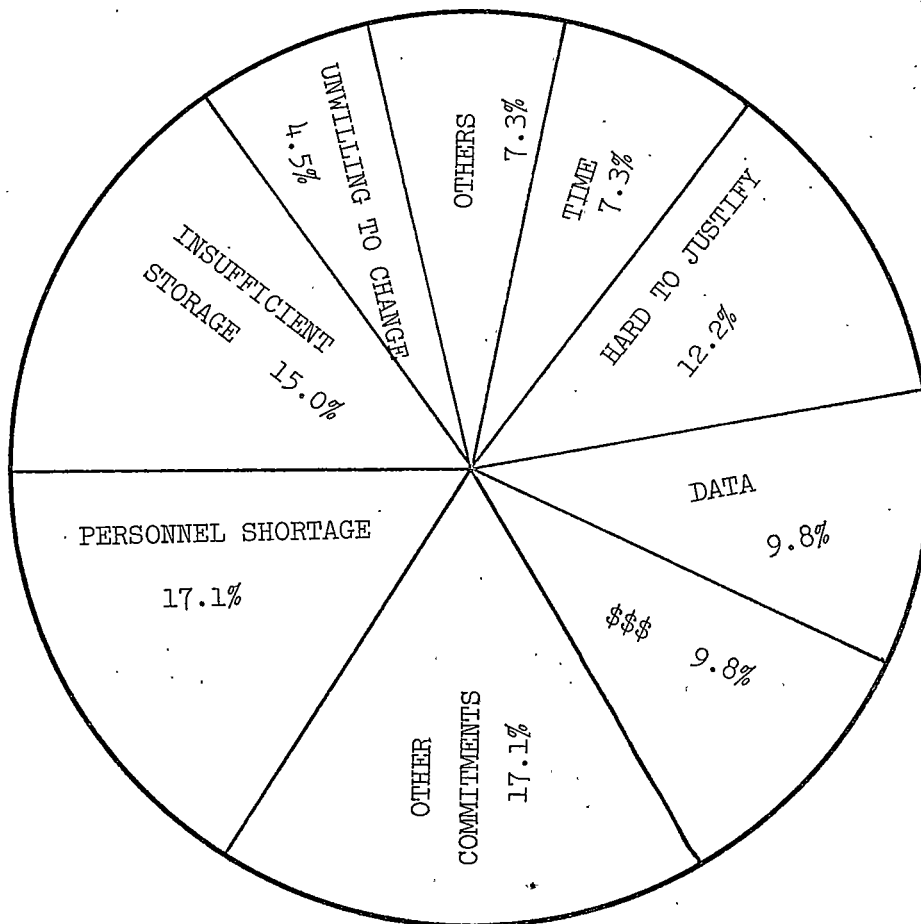


Figure 4. Stated reasons for not developing a data bank.

(Based on 37 returns)

- a. Work done in the regional office.
- b. Conversion trouble from old computers.
- c. Hard to get management to understand the system.
- d. Not ready.
- e. Lack of coordinated effort.

Specific information for "Activity-Report" chart shown in Table I, was disappointing. Many state highway departments ignored this page of the questionnaire altogether or detached the page from their returns for no obvious reasons. Figures tabulated were compiled from 21 returns.

Conclusion of the Survey

Results of the survey indicate the author's conceptual requirements for an ideal data bank were adequate. This is deduced from Table I, the "Activity-Report" chart returned by those state highway departments which are in the process of developing a data bank.

The high percentage of state highway departments not having a data bank system, coupled with the reasons given, confirms the author's conviction of the so-called "transition era" in data bank development and usage.

The survey was considered to be successful in that it:

1. Verified general interest in data bank development among highway officials. Their overall eagerness for the compiled results is self-explanatory.
2. Provides background knowledge in a systems approach to

TABLE I. ACTIVITY-REPORT CHART

(Compiled from 21 returns)

REPORTS ACTIVITIES						
	Road Log	Traffic by Sections	Accidents by Sections	Sufficiency Rating	Bridge Listing	Other Reports
DATA						
Card	6	4	4	5	10	2
Tape	13	13	9	12	8	3
Disk	4	5	8	5	5	8
Drum						
Datacell	1	1	1	1	2	3
Other ¹						
UPDATE						
Manually	4	4	2	4	4	
Programming	10	8	7	6	8	5
Weekly		1	1			
Monthly	2	5	7	1	1	3
Yearly	7	9	8	9	7	5
Other ²						
PROCESSING						
Manually	1	2	2	1	1	1
Semi-manually	4	3	2	4	3	1
Direct Listing	7	6	4	7	12	8
Sort/collate cards	4	3	1	2	4	
From Tape Files	9	11	7	9	7	6
From DASD Files	3	5	6	4	4	7
Remote Terminals					1	1
Visual Display						
Indexing Microfilms						
Other ³						

Remarks:

UPDATE other² includes $\frac{1}{4}$, 3, or 5 year-periods.

Other Reports: Needs Study, Contract Analysis, Project Scheduling, Truck Weight, and Mark IV.

the design of an information retrieval system for highway planning,
which is the topic of this thesis.

CHAPTER III

THE SYSTEMS ENGINEERING APPROACH

This chapter focuses on the system engineering approach to the design of an information retrieval system for highway planning. The systems engineering approach as discussed in this chapter is patterned after Hall (Ref 3).

The systems engineering approach is an attempt to shorten the time-lag between theoretical advances and their applications, and the practical production of the new system for human needs. Systems Engineering considers the content of the reservoir of new knowledge, then plans and participates in the action of projects leading to applications. According to Hall, systems engineering "considers the users' needs and determines how these can be met in the light of knowledge, both old and new. Thus, systems engineering operates in the space between research and application, and assumes the attitude of both. For those projects which it finds most worthwhile for development, it formulates the operational, performance and economic objectives, and the broad technical plan to be followed."

The Pattern of Systems Engineering

When a large number of completed projects are viewed collectively, five phases can be identified in the following order:

1. Systems studies.

2. Exploratory planning.
3. Development planning.
4. Implementation.
5. Systems maintenance.

Systems Studies -- Two objectives are considered in the systems studies phase:

a. To assist the management in reaching agreements on the total program of work. This phase may also entail negotiation between the systems designer and the highway department in matters concerning contracts, responsibility, etc.

b. To create an extensive background of information upon which subsequent projects may be initiated. Generally, the systems studies phase includes compilations of statistical data which experience has shown are needed on recurring types of problems (such as cost, usage, and performance data) on previously designed systems.

Exploratory Planning -- Exploratory planning is an outgrowth of systems studies. Associated with exploratory planning are six inter-related functions:

- a. Problem definition: isolating, possibly quantifying, and relating that set of factors which will define the system and its environment.
- b. Setting objectives: the logical end of problem definition.
- c. Systems synthesis: entails compiling or establishing

alternatives to satisfy the objectives.

d. Systems analysis: deducing the consequences of the entire list of hypothetical systems. The consequences are then measured against performance criteria such as cost, quality, etc.

e. Selecting the best system: evaluating the analysis and comparing these evaluations with the objectives to select the smallest possible subset of alternative systems that merit further study.

f. Documentation: communicate the findings of the exploratory planning phase to management for purpose of substantiating contract agreement between the systems designer and the highway department.

Development Planning -- The development planning phase is a recycling of the exploratory planning phase except that all steps are performed in much greater detail and on a drastically reduced set of choices. Development phase ends with the formulation of a plan of actions which lists objects and proposes ways of meeting them.

Periodic progress meetings on matters of management decision with the highway officials are encouraged. Sometimes these sessions will help prevent any misunderstanding which may prove to be too costly to rectify at a later stage. Also, these meetings will help expedite the project if mutual agreements between parties can be resolved without undue delay.

Implementation -- Implementation is the system design phase of the whole project. It involves organization of system design

personnel participating in the project, systems and programming development, testing, installation, evaluation of the new system in its working environment, conducting a training program to ensure adequate transmission of information. The latter process entails training highway department personnel to use and maintain the new system. Finally, the new system needs to be documented for presentation to the highway department.

Systems Maintenance -- In normal practice, once the system has been officially presented to the highway department and proved to be satisfactory, the system maintenance should logically be out of the hands of the system design team. The maintenance of the system should properly be the responsibility of the data processing staff, with the advice of the users within the department.

Systems maintenance may alternatively be known as the "follow up" or "feedback" phase of the system. The systems maintenance phase necessitates frequent contacts with the users regarding the performance of the system. Streamlined operation, cost reduction, simplification, increased reliability and accuracy should always be endeavored.

CHAPTER IV

SYSTEMS DESIGN

Systems design spans the period from the exploratory planning phase to the implementation phase. There seems to be a general practice among most highway departments that the planning survey division has already conducted the systems studies phase and is fairly aware of the need for establishing a data bank system pending favorable conditions, such as finance and manpower. This situation is confirmed from the national survey as described in Chapter II.

As soon as favorable conditions are met, some state highway departments will call for a consultant or a research institution to conduct the systems design. It is under this circumstance that the Department of Civil Engineering and Engineering Mechanics, Montana State University, is involved in the development of HIS, Highway Information System, for the State of Montana. The author is associated with the development of HIS. A systems engineering approach was used in the design of HIS. It is this systems engineering approach that triggers the author to write the thesis. For purposes of demonstration, the development of HIS, copious in material, has been used as a case study.

Exploratory Planning

Problem Definition -- Problem definition is isolating, possibly quantifying, and relating that set of factors which will define the system and its environment.

The problem statement of HIS is: To devise a computer-based information system for the Planning Survey Division which will keep current and available information necessary to produce reports as required by the Federal Highway Administration, U.S. Department of Transportation.

This problem statement is general in nature, wide in scope, and does not specify how and what type of system is to be used. It does, however, isolate a set of qualitative factors ("computer-based," "current," and "available") to define its environment. These factors will be related later, and further refined, to produce a system that will satisfy the problem definition.

Setting Objectives -- Objectives evolve from observing the existing practice or activities of the organization in question. In our case study the following activities were identified:

1. Manual coding of data.
2. Visual checking for errors.
3. Sorting of cards by sequence number before storing.
4. Collate and sort cards to run specific programs.
5. Manually compute certain summaries.
6. Manual search of vertical files for random inquiries.

To comply with the objectives stated above the following activities for system development were formulated:

1. Devise new methods for coding data.
2. Store data on a DASD.
3. Provide update facilities.
4. Provide random retrieval capabilities.
5. Monitor processing of programs through a control for easy handling of the system.
6. Train staff to use the new system.

The method of aligning objectives with activities yields broad activity definition. These generalized statements must now be refined, through system synthesis and system analysis, to provide a scope and boundary for each activity before the system can be defined.

Systems Synthesis -- Systems synthesis serves two purposes: to reapportion the parts of an old system to design a new one, or to use new components in a new way to build up a new system.

A creative approach in planning and design is the technique called functional synthesis. This technique starts with a statement of boundary conditions, desired I/O, and proceeds to a detailed list of functions or operations which must be performed in a block diagram form. These functions are then related, or synthesized, into a system model showing essential logical relationships.

As an example, the Roadlog report as generated by HIS is a report giving a section-by-section description of each federal-aid

route of the Interstate, Primary, and Secondary systems in Montana, together with many summaries conforming to FHWA requirements. It has been the responsibility of the Planning Survey Division to compile this report annually. Data for input are contributed principally from the Preconstruction, Field, Maintenance, and Construction Divisions. Each of these divisions has its own functions (Ref 4). Operationally they differ from each other, but their functions are related to each other in the data base of the Roadlog record structure as shown in Table II. Thus we have stated the boundary conditions, defined the I/O, and synthesized the functional relationship of one of the components of HIS. Likewise, one can deduce the functional relationship of other reports from the "Resources Table" as shown in Table III.

Systems synthesis is a prerequisite for system requirements. It determines each requirement, activity-by-activity, from the consideration of I/O, resources, and operations of each division of the highway department.

Systems Analysis -- The function of systems analysis is to deduce all of the relevant consequences of the proposed systems for selecting the optimum system. These consequences are then compared with the initial objectives using certain performance criteria, such as:

1. cost,
2. time,
3. reliability,

TABLE II

ROADLOG RECORD STRUCTURE

Variable	Data Bytes
System (I, P, or S)	1
Route Number.	3
Milepost.	5
Section Description	35
Maintenance Section	4
Project Class	11
Remarks	2
County Number	2
Forest Highway Code	2
Administration.	2
Other Code (State Forest, Military Reservation, Game Refuge, National Forest, National Monument, or State Park).	2
Number of Lanes	1
Divided or Undivided Highway.	1
Population Code	1
City Code	3
Year Built.	2
Surface Type.	4
Surface Thickness	2
Base Thickness.	3
Surface Width	2
Roadway Width	2
Section Length.	5
Constructed Length.	5
Unimproved Length	5
Wye Length.	3
Municipal Mileage	4
County Mileage.	5
National Forest Mileage	5
Indian Reservation Mileage.	5
"Other" Mileage	4
Year Improved	2
Maintenance Code.	2
Dummy	1
Total Bytes:	136

TABLE III. RESOURCES TABLE

REPORTS DIVISIONS	Road Log	Traffic by Sections	Accident by Sections	Sufficiency Rating	Bridge	Primary Needs	Contract Analysis	Materials
Preconstruction	x	x	x	x				
Bridge				x	x			
Right-of-way							x	
Project Control						x	x	
Maintenance	x							
Field	x			x				x
Construction	x			x				
Materials								x
Statistics & Research		x	x				x	
Planning Survey	x	x	x		x	x	x	

4. accuracy,
5. security,
6. quality,
7. flexibility,
8. capacity, and
9. acceptance.

In our case study the analyst established the following criteria:

1. Cost: must be comparable to the present system. If possible this criterion can be determined on a cost per report basis.
2. Time: once the system is fully operational annual reports are to be ready for submission to FHWA no later than one month follow the last report period.
3. Reliability: the system shall be able to cope with new system installation without service interruption. Backup procedures shall be provided.
4. Accuracy: to be at least as accurate as the manual methods.
5. Security: loading and updating of records in the file are limited to authorized personnel only. The data storage device shall be protected from mishandling or other unforeseen actions.
6. Quality: reports as generated from the proposed system shall be judged for legibility, neatness, and easy arrangement for publication.
7. Flexibility: the system is to be modular and capable of future expansion without difficulties.
8. Capacity: allowance must be made for multiprogramming environment.

9. Acceptance: the degree to which the system provides statistical data for management information and action.

Exploratory Planning Documentation -- The introduction of exploratory planning documentation should set the climate for the study, and state the ground-rules for performing the study which were agreed to by the highway department and the study team.

The purpose of the study is to be stated, and the scope of the study defined. Was the study to create an entirely new system, or was it conducted to improve the existing system? Was the objective to obtain dollar savings by improving the operating efficiency, or was it to raise the technical competence of the services? Whatever the purpose of the study, it should be explicitly stated.

The body of the report:

1. Must demonstrate that the study team has a complete understanding of the existing system.
2. May develop a new view of the system in terms of activities.
3. Should establish benchmarks in schedule, cost, and benefits.
4. Should serve as an adequate base for conducting later phases of the design.

Development Planning

Development planning phase is the recycling of the exploratory planning phase, except that all steps are performed in a much greater detail and on a drastically reduced set of choices.

To aid the study team to converge on the system requirements the following steps should be considered in designing a data bank:

1. Activity-module transform.
2. System element analysis.
3. Compatibility determination.
4. Generic system description.
5. Systems selection.
6. Equipment selection.
7. Systems optimization.

Activity-Module Transform -- A direct transform of the activities, established in the previous phase, into natural segmentation of system operation may be manifested by the following modules:

- a. Load Module.
- b. Maintenance Module.
- c. Report Generation Module.
- d. Random Retrieval Module.
- e. Command Module.

In HIS, the Load Module was designed to create data files. Data to be loaded on disk from card or tape files were thoroughly checked for validity, field, range, and sequence by means of a data check program. The Maintenance Module was designed to update and reorganize records to maintain high accuracy and efficiency of the system. The Report Generation Module was designed to classify data in their respective groups before summarizing them in report format. The Random Retrieval

Module provided the capability for rapid-access, through remote or display terminals. The Command Module acts as the command processor and facilitates execution of programs.

System Element Analysis -- Associated with the system in data processing are:

- a. Input/output.
- b. File processing method.
- c. Data and file organization.

Input/output: Inputs to the system may be of various forms such as punched cards, magnetic tapes, machine-sensible forms for optical scanning, or magnetic-ink character recognition, etc. A reasonable selection of input methods takes into account such factors as cost, ease of handling, time restriction, or equipment capabilities. Punched card input was selected for initial data entry to HIS files. For efficient access to data, the data must reside in a place where retrieval is rapid. A storage device that will satisfy the requirements of the HIS modules is a direct access storage device. It is one on which each physical record has a discrete location and a unique address. Records are stored in such a way that the location of any record can be accessed directly instead of serially as in a tape file. This concept of storing and retrieving data lends itself very well in data bank applications.

File Processing Method: A file is a collection of records, with each record identified by a key. Each record contains all of the data

associated with a particular key. In HIS, the Roadlog file contains records identified by the key which is a concatenation of the route system, federal-aid route number, and milepost.

Three regularly used methods for accessing files are:

- a. SAM, Sequential Access Method.
- b. DAM, Direct Access Method.
- c. ISAM, Index Sequential Access Method.

In SAM, the records are organized solely on the basis of their successive physical location in the file. The records are generally in sequence according to their keys as well as in physical sequence. The records are usually read or updated in the same order in which they appear. Individually records are not located rapidly. Records usually cannot be deleted or added unless the entire file is rewritten.

DAM operates under the assumption that the file is organized in a random manner characterized by some predictable relationship between the key of the record and the address of that record in a DASD. This relationship is established by the user. Although DAM has considerable flexibility, the accompanying disadvantage is that the user is largely responsible for the logic and programming required to locate records.

In ISAM, the records in a file are organized on the basis of a collating sequence determined by the keys that precede each record. An indexed-sequential file exists in space allocated on a DASD as the prime area, the index area, and the overflow area. The prime area is that area in which records are written when the file is first created or subsequently reorganized. The keys are imbedded in the records.

The index gives the location of each record, and the index area is created and written by the operating system when the file is created or reorganized. The overflow area provides for additional storage when the prime area becomes full.

ISAM, because of its ability to refer to indexes associated with the file, makes it possible to quickly locate individual records for random processing. In updating, the system locates the proper position in the file for new record and makes all necessary adjustments to the indexes. ISAM was used exclusively for processing HIS files.

Data and File Organization: Planning data are generally grouped into two categories--that which can be related to the roadway and that which cannot.

The first group of data includes roadlog, traffic characteristics, sufficiency rating, road life, historical, maintenance and accident information. The roadlog data ideally should be broken into four files: one file for cultural data, one for roadway characteristics, one for geometric data, and one containing administrative system information and location of jurisdictional boundaries. Presently the Roadlog File in HIS consists of all of the above except geometric data. Definite steps have been made to incorporate this file into HIS in the future. Finally an ideal data bank system should also include a file of map coordinates, which are related to the roadway, to provide for graphic display of planning data. It is to be noted that coordinates may help pinpoint event data, such as accidents, more accurately than using a reference point along the highway.

The second group of data includes information on finances, cost, and highway statistics such as fatality rate and cost index, etc. Although these data should be in separate files, the retrieval of data from them will be quite different from that for the first group. This is because each file bears no direct relationship to the other, as do those in the first group. The basis for retrieving data from files in the first group is invariably the roadway, regardless of the items desired. For the second group, the basis for retrieving data is on whatever variable is needed and that items of interest vary from user to user. The items of interest may be retrieved on the basis of year built, by contract number or even by dollar values.

There are two ways of organizing data files: one is the coordinated file concept and the other is the master file concept. A coordinated file system implies that all files are equal in rank or order. The several classes of data, such as roadway and traffic characteristics are considered to be of equal importance. Each class of data should therefore, be stored in a file that is equal to, but separate from, files containing other classes of data. Each file should not contain more than one class of data and all data elements in the file should pertain to that one class.

Generally, there are several sections within the planning survey division, each being responsible for collecting and processing some class of data and for supplying data to various users. In many cases, more than one user is coding, storing, and processing the same data elements, thus duplicating each other's effort. Typical examples are

found in the Roadlog and Traffic by Sections reports of the Montana State Highway Commission where such data as section description, and county number are duplicated.

In recording roadway data along the highway, there are physical changes that dictate a new set of values. This warrants a "break" in the file. These breaks are not necessarily the same for one class of data as they are for another. It is difficult for data recorders and users to agree on breaks collectively compatible to all of their needs. Thus, each user ordinarily selects the breaks to fit his own requirements. Too often breaks seem to be based on user considerations rather than on what actually exists, causing data observation to be broken into more lengths than necessary, which results in duplications, extra coding, and a loss of flexibility. To counteract this tendency of unnecessary breaks the Roadlog File in HIS incorporates pseudo-breaks designated by codes for specific purposes. These pseudo-breaks are an integral part of a "consolidated" coordinated file which will be explained later.

The advantage of a master file arrangement is that duplication of data is virtually eliminated. One of the requirements for the indexed sequential access method is that records in each file must be fixed length. The record for a master file for any data bank would necessarily have to be large and fixed length. Very often in a given section of highway the codable data may be very limited with the result that the remaining portion of the records are filled with blanks.

The Roadlog File in HIS is semi-coordinated and semi-master in

concept. The records have been consolidated by placing common data such as section break description, county number, etc. in only one file. Besides overall saving of storage and eliminating duplication of data, this consolidation and coordination technique shortens records in other files and makes all files more manageable.

It is not uncommon to have Traffic by Sections breaks differ from Roadlog breaks in HIS. To retrieve section break description from the latter file is not possible unless a pseudo-break is designated in that file. This method, though cumbersome, has proven to be satisfactory.

Compatibility Determination -- Sometimes characteristics of the dominant machine activity may be so overriding that other activities are subordinated. Developing an efficient solution to serve all machine activities can significantly increase equipment utilization. A large computer may be more efficient, but smaller machines may be more economical in processing specialized files.

Sometimes a "balancing" activity is added to take advantage of the higher price-performance ratio of larger equipment. An activity requiring extensive computation and limited I/O can be combined with another activity having high I/O volumes and little computation. A good example of this arrangement is balancing HIS (high search) with UNMES, Utah, New Mexico Earthwork System, (large volume of I/O).

Generic System Description -- The purpose of the generic system description is to show the logic flow of information and the logical operations necessary to carry out the proposed objectives. Figure 5 is a generic view of HIS, showing the interfacing components.

Systems Selection -- Systems selection is essentially a serial, iterative process to satisfy design requirements and boundary conditions, and at the same time select the most economical system. The first step in system selection is to segment the problem into a series of computer runs. These runs are usually associated with:

- a. Conversion of input.
- b. Serial processing.
- c. Random processing.
- d. Updating activities.
- e. Preparation of reports and other forms of outputs.

Next the volume of each activity is translated into a time estimate. Card input files are translated into card read-time by dividing the volume of cards by card reader-speed. Reasonable assumptions are made for blocking of tape files, and the total tape-passing time is calculated for each file. Disk files are judged for total file capacity, access time, and character-transfer time on the basis of the estimated percentage of activity. With this information available, the iterative process of system selection begins by comparing capacity with volume needed.

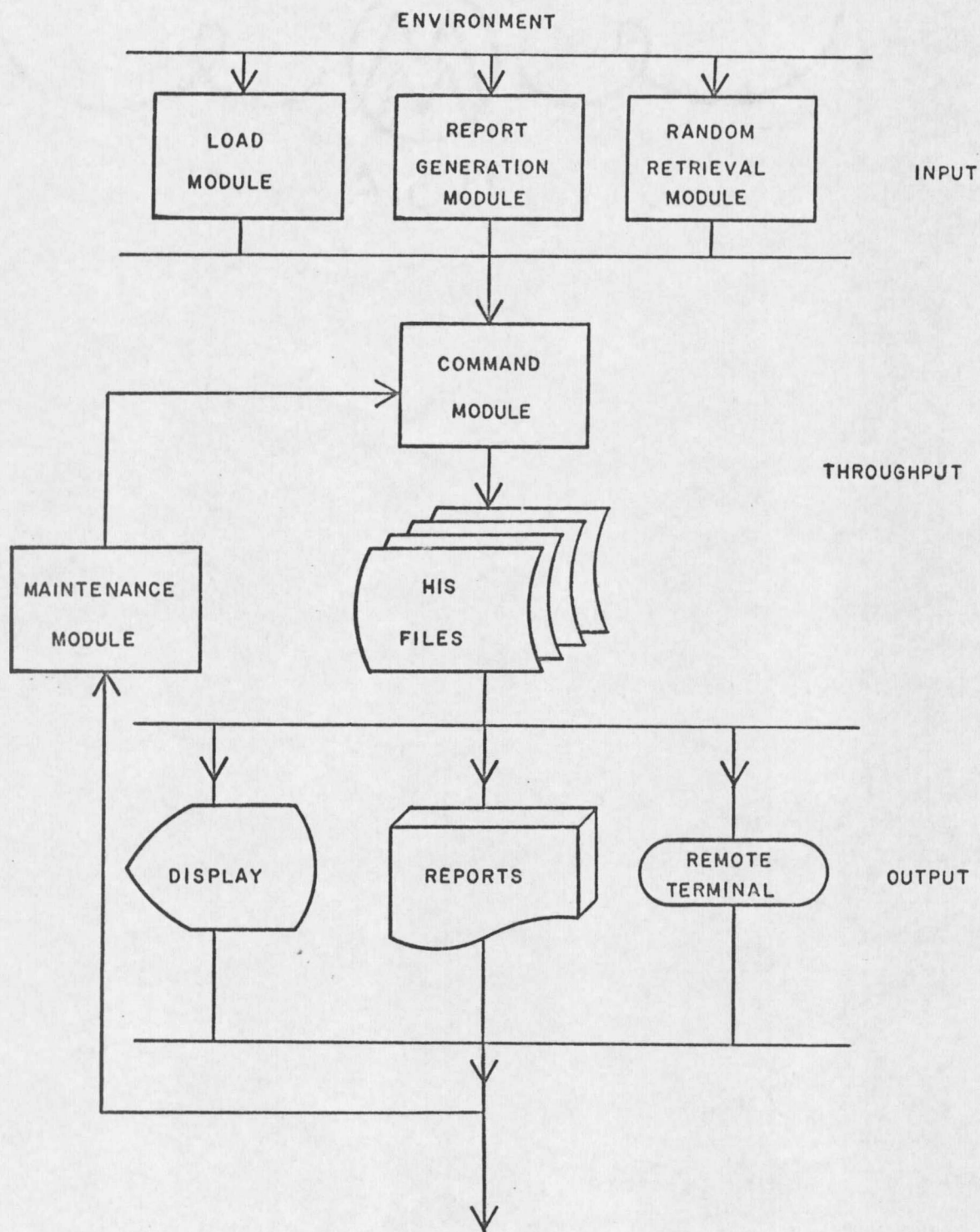


Figure 5. HIS generic view.

Equipment Selection -- The main criteria in selecting equipment are:

- a. Performance-cost ratio.
- b. Machine backup facilities.
- c. Programming systems and application programming support.
- d. Service support in machine maintenance and customer education in using and operating the equipment.
- e. Availability of trained operators.
- f. Delivery schedules.

Table IV is a summary of the current medium-sized computers available along with their characteristics.

Systems Optimization -- The foregoing is a general discussion of formulating alternatives. The systems analyst has yet to select the alternative that shows the most promise. Some of the decision theories available are:

- a. Decision under certainty:
 - 1) The principle of expectation.
 - 2) Dominance principle.
 - 3) The most probable future principle.
 - 4) The aspiration level principle.
 - 5) The expectation-variance principle.
- b. Decision under uncertainty:
 - 1) Laplace principle.
 - 2) Minimax principle.

-45-

This table is extracted from "Data Systems News", June, 1970.

- 3) Hurwicz principle.
- 4) Savage principle (minimax regret).
- 5) Game theory.
- 6) Linear programming.

7) Mathematical tools such as calculation of maxima and minima of function, and the calculus of variations to find functions which optimize some physical and economic quantity.

It is unlikely that the analyst will be called upon to use all the above listed principles to select the best system. It is recommended that the analyst present figures to justify his arguments and choice of action in his report. Once his recommendations are accepted by management, his decision represents a major investment in implementation, site preparation, training, equipment, contracts, commitments; etc. Capital investment decisions are extremely complex. It requires the advice and counsel of financial experts.

In the development planning phase of HIS, the study team did not have to go through systems or equipment selection. The sponsoring agency already had an S360/40 DOS computer in operation. The analyst tailored HIS within the limitation of the Disk Operating System. It is unlikely that any highway department will invest money to install new equipment just for the sake of accommodating a data bank system, unless, of course, the present system is outdated.

Implementation

Implementation deals with the actual design of the system. It starts after the study team has clearly defined the objectives and system requirements, and ends with at least a prototype operational system.

Programming Assignment -- A critical function in planning and controlling progress is the assignment of personnel to the various activities. The number of people involved depends on the the complexity of the application. There are three ways of assigning manpower for writing programs. One method is to assign a given application program to one person from start to finish. This method has the advantage of preserving one single train of thought without diversification. A second person, however, may check his logic from time to time.

There is some psychological effect in giving an individual a project which becomes his responsibility. It gives him an important goal to work toward, one with which he can honestly identify himself and toward which he will therefore strive.

A second method is to assign one application project to two or more individuals, a team, whose members will work together to develop the program. A person is normally appointed as the team leader. The associated advantages are:

1. Dependence on the presence, ability, and knowledge of one person is eliminated.

2. Progress toward completion is usually faster.

3. Better programs will normally be produced when more than one person has thorough knowledge of the application.

This team method is to be highly recommended, particularly during the initial stage of programming development. After the effectiveness of the various individuals has been assessed, the programming team should be regrouped. By this time more will be known regarding such matters as specific ability of each individual and the availability, the job complexity, the size of the programs and how long will they take to write, and the extent to which problem definition has been fulfilled.

A third method is to have one person, the section leader, do the defining and flowcharting and have the other members do the programming, coding and testing. For example, senior programmers or systems analyst could turn over their definition and flowcharting to junior programmers for less responsible work. This method requires definition and flowcharting to include extensive details and accompanying notes from the senior programmers to the junior programmers.

There is no fixed rule of thumb for assigning personnel. In the development of HIS all three methods were used at different stages.

Detailed Design -- Detailed design is concerned with providing the precise information required for programming and operation. As a rule, some preliminary systems analysis is performed during problem definition and then refined in the detailed systems design.

Guided by the information as provided in the development planning phase, the programmer prepares an overall flowchart of each run.

In HIS, a data checking program was written to check the validity, range, field, and sequence of data. The load program was written based on the requirements of ISAM. Test data were prepared for testing the program. After the program had been successfully assembled and compiled, it was cataloged into the core-image library for easy execution. The entire Roadlog data were then prepared and checked before being loaded onto a permanent file. The program was then tested with live data and the program then required modification several times before declared ready for production use.

Programming Language -- Selection of a programming language is a function of equipment choice or the equipment already in use, the nature of the problem (whether it is I/O oriented or computation oriented), and the versatility of the compiler.

The ability to produce programs more quickly, the speed of debugging, and the lower cost of maintenance make writing in a high-level language, such as COBOL, FORTRAN, or PL/I very desirable. The desirability of a high-level language is particularly suited for an organization of open-shop nature. In case of a closed-shop

organization, such as a large commercial house, more efficient programs may be written by a group of professionals using a more machine-oriented language.

PL/I was used as the programming language in HIS because of its versatility in I/O and interchangeability of files.

Documentation -- Effective documentation accomplishes a number of things:

1. It defines the scope of the programs, identifies the method used, and indicates changes from previous operations.
 2. It aids in communication between the programmer and the users.
 3. It provides flexibility in personnel assignment. Changes in personnel can be handled with a minimum of difficulty when the work has been documented.
 4. It facilitates program modification and implementation.
- Thus adequate program documentation is of prime importance in the planning and operation of an installation. Documentation standards vary from place to place. For the data bank design the following methods of presentation are recommended:

Overview: This gives an overall picture of the system. The potential readers are generally department heads, or application engineers whose knowledge of computer systems may be limited. This method of presentation should be in narrative form, avoiding the use

of "systems jargon," and the emphasis should be placed on applications and benefits.

Systems View: The expected readers of this portion of the documentation are data processing managers or supervisors whose interests are not confined to detailed programming. The readers are interested in the system concept, abstracts of the programs, and the associated usage of the hardware.

Detail View: The detail view serves as the communications between the programmer and the user who is interested in installing and modifying the system. Detailed flowcharts, attributes, field and range of variables, and I/O should be emphasized in this portion of the documentation.

User's Manual: The communication between the programmer and the user is the User's Manual. The stress should be on inputs of data such as coding and forms of output. "Set-up" for job execution should be well illustrated.

Conversion -- Conversion is the gradual change from old procedures of data processing. Some of the specific tasks involved in conversion are:

1. Gathering real data for the system.
2. Editing the files for accuracy and correct format.
3. Provisions for tracing personnel in the department that will supply source data and receive processed data from the data processing system.

4. Planning for pilot or parallel operation.
5. Establishing the schedule for implementing the new processing system.
6. Checking the results of processing by the old and the new systems.

Where new procedures are replacing old ones, two basic approaches may be taken at the moment of conversion. The first is called parallel operation. This involves the processing of current data by both the new and the old systems simultaneously. Parallel operations should be carried out through a complete run rather than fragments to give an overall evaluation of the new system.

A second method is called "pilot operation." A full-scale operation, using the data from a previous period, should be attempted to back-check the accuracy of the existing system. Basically, a pilot operation tests the new procedure, and accuracy of data testing verifies that an individual program is performing as desired. In the pilot operation of HIS a series of commands were set up to invoke the cataloged procedures to produce the 1969 Road Log Report. The results were compared with those of the actual report. In the first pilot run, many misconceptions in programming were clarified. And, in the process, the run uncovered a few discrepancies in the existing way of compiling reports.

Pilot operation provides operational training for data processing personnel, because complete applications are run under much the same conditions as will be encountered in actual production runs.

Pilot operations will be repeated as long as there are some "bugs" in the new system. This process continues until the results and performance of the new system are acceptable to the management.

Systems Design Summary

Systems design covers exploratory planning, development planning, and implementation phases of the systems engineering framework. Systems design starts with problem definition, progresses through the mechanics of setting objectives, systems synthesis, and systems analysis in order to select a set of objectives to be followed. The recycling process of converging on systems requirements involves activity-module transform, system elements analysis, compatibility determination, generic system description, system selection, equipment selection, and systems optimization. The implementation entails programming assignment, detail design, programming languages, documentation, and conversion.

With reference to our case study, and the problem definition (which reads "to devise a computer-based information system for the Planning Survey Division which will keep current and available information necessary to produce reports as required by FHWA"), it can be seen that the set of qualitative factors has been transformed into some viable entities. ISAM files on DASD are computer-based; update procedures in the Maintenance Modules keep data current; Random Retrieval Modules render information readily available; Report Generation Modules satisfy FHWA requirements; and the

Command Module facilitates easy handling of the system.

The transformation of conceptual requirements of a proposed system to some viable entities is the end product of systems engineering.

CHAPTER V

A LOOK TO THE FUTURE

The objective of this thesis is to heighten the awareness and understanding of systems engineering as a process, and in particular to focus on the approaches to the design of an "ideal" data bank system for highway planning.

The growing recognition of the need for systems engineering over the past decade has been attended by the birth of such systems as ICES and PERT. Also the past decade has witnessed the emergence of using a data bank system for information retrieval purposes. It would appear that systems engineering is here to stay in order to help make systems of greater complexity more efficient, and to bridge the gap between demand and supply in all disciplines of data.

This thesis does not provide all the materials for effective systems engineering. For one reason, effective systems engineering is dependent on careful coordination of processes, human relations and equipment utilization. Such coordination can only be learned from clinical experience in dealing with the environment.

The author is limited to his own environment and experience in designing a specific data bank for the Montana State Highway Commission. There remains the experience of designing similar systems under different environments.

It is of interest to note from the survey of the current state of the art discussed in Chapter II that:

1. 85% of the state highway departments are using IBM equipment of about the same capacity and modularity;
2. 94% of the state highway departments do not have a data bank system, but seem eager to install one in the near future; and
3. reports to be submitted to the Federal Highway Administration by all of the state highway departments generally cover the same topics.

It would, therefore, seem reasonable for the Federal Highway Administration to promote a universal data bank system.

APPENDIX A

Data Bank Survey
(Sample cover letter)

Dear Sir,

We are in the process of developing an integrated computer-based data bank for highway planning for the State of Montana.

The main features of this data bank are:

1. Information is stored on a direct access storage device using indexed sequential files.
2. Data can be kept current through updating activities such as rewriting, deleting and adding records.
3. Reports can be generated as required via a command processor, providing, of course, that the command processor has been written.
4. Facilities are provided for rapid-access random retrieval purposes.

We are eager to know if we have overlooked any important steps in our systems development. Your completion and return of the enclosed questionnaire will not only provide us with valuable information, but will also serve as a cooperative effort in a national survey of the current state of the art in data bank design.

We will be pleased to send the compiled results to you as soon as they are available.

Truly yours,

.....

Data Bank Survey Questionnaire

1. Configurations of your computer.
2. Do you have a data bank system similar to that described in our letter?
3. State your common base of reference for cross-referencing your files.
4. State the total number of files in your system that are operational.
5. What programming language did you adopt for your programs?
6. What is the design "life" of your system?
7. Did you make use of the existing format or design a new format for the data of your records?
8. Was the system fully documented?
9. Indicate the approximate time, if applicable, you spent on the following:
 - a. Systems studies(interview, study reports, etc.)...months
 - b. Systems design(writing programs, logic flows).....months
 - c. Programs debugging and testing.....computer-hours
 - d. Documentation.....months
 - e. Implementation.....months
 - f. Data preparation for files.....months
 - g. Total project--Professional.....man-days
Subprofessional.....man-days
10. Did you include a "straight-line diagram" file(this file can be digitized into a geometrics file) in your data bank?
11. What other applications did you use for your data other than routine reports generation and random retrieval purposes?
12. Is your department considering setting up a data bank in the near future?
13. State the major reasons for not having a data bank operational to date?

REPORTS ACTIVITIES						
	Road Log	Traffic by Sections	Accidents by Sections	Sufficiency Rating	Bridge Listing	Other Reports
DATA						
Card						
Tape						
Disk						
Drum						
Datacell						
Other ¹						
UPDATE						
Manually						
Programming						
Weekly						
Monthly						
Yearly						
Other ²						
PROCESSING						
Manually						
Semi-manually						
Direct Listing						
From Tape Files						
From DASD Files						
Remote Terminals						
Visual Display						
Indexing Microfilms						
Other ³						

Specify:

*
Other¹
Other²
Other³

Other Reports

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 cop.2 Design of a computer-
 based information
 retrieval system for
 highway planning

NAME AND ADDRESS	
4-23-71	305 Nelson Hwy Wayle, Okla
4-29-71	Frank Yu CT Dept
5-11-71	Railroad 90 S 5'
	Shams'
	315 E
LINE 5	107 RAL

77.378
 Y89
 Cap 2