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THE FIRE MANAGEMENT SYSTEM
THE FIRE MANAGEMENT CENTRE

Preliminary Results and Design Concepts

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NOTE TO THE READER

Sections III and IV of this report present the results of an analysis of specific subsystems in some detail. Readers interested in the general design concepts may skip these sections without loss of continuity.

I. INTRODUCTION

Forest fire management has many aspects which suggest that an optimal organizational structure will involve some form of a coordinated fire management system (FMS) through which the technical expertise of experienced fire management personnel can be blended with the capabilities of electronic computers to provide efficient fire management over a relatively large land area. The results of an initial study of certain elements of such a system are presented in this paper.

The relationships between human decision makers, advanced computer algorithms, and the forest fire environment constitute the core of an FMS. In fact, one objective of the FMS is to quantify certain of those relationships so as to provide improved information regarding the environment about which the human must make his decisions. It is clear at the outset, however, that there are many situations in fire management in which the human is superior to the computer and that the final responsibility for fire management always rests with the man rather than with the machine. For these reasons, the FMS should be regarded as a relatively new, subordinate technique by which data is organized; control of the FMS, and the decision as to whether or not the FMS should be used, always rests with the humans involved.

Perhaps the most important requirement for the FMS is that it be designed with an efficient interface with the human decision makers. The system will never be judged in isolation but rather in relation to the management structure of the organization. Its acceptance by management and its ability to fit into the existing organizational structure are fundamental design criteria.

The FMS can be viewed as a set of functions arising from the relationships noted previously. For example, the obvious relationship between fire behavior and weather requires that the FMS have the capability to calculate significant fire weather indices and to predict the behavior of these indices at various future times.

Certain FMS functions can be performed by mathematical models which now exist. Others are routinely performed by current fire management agencies. The realization of other functions must await the outcome of future research. Thus, it is not possible to specify the exact nature of an FMS at the present time. Instead, we consider certain basic FMS design principles and the work steps which derive from those principles. Further results and detailed specifications must depend on the results obtained from current and future research programs.

Since an improvement in the efficiency of a fire management organization as a whole can be obtained from an improvement in the efficiency of the parts of the organization (Maloney, 1972a), it is not necessary to wait until the FMS is fully complete in all aspects before applying the system. It is our intention to proceed with FMS development in stages -- using currently available techniques to implement those functions which are feasible, while simultaneously instituting research programs designed to both increase the number of functions which can be performed and to improve the performance of functions which are feasible. With this approach, there will never be time at which the FMS is "done", like a cake or a loaf of bread. There will only be times at which further development of a function, a particular group of functions, or the whole FMS is deemed unnecessary.

Considerable effort has already been devoted to developing data bases and mathematical models useful to the fire manager. The FMS will provide a vehicle for consolidating such tools, regardless of source, in a coherent framework and for making them available to decision makers in the fire management organization.

The difficulty of predicting demand for fire control resources has become a truism of forest fire management. Thus, it will be necessary for the FMS to be anticipatory and predictive insofar as possible, and to be adaptive in the inevitable instances when expected events do not match actual occurrences.

The factors mentioned above -- stage development, inclusion of tools from many sources, and the need for adaptability -- indicate that the FMS must be highly flexible. A good way to obtain such flexibility is to build the system as a series of semi-independent "modules"; that is, to develop or implement each function as a unit which can be tested separately from the entire FMS before being tied into the system. In effect we will be building a house of blocks; at any developmental stage we will be concerned with constructing, testing, and integrating only the last block (function) rather than with re-design of the whole system.

Certain of the functions of an FMS -- particularly those requiring manipulation of large amounts of data, repeated use of similar facilities, or complex computations -- will require a physical facility or fire management centre (FMC). The FMC will provide centralized management with direct access to a large quantity of information and to mathematical models for assistance in decision making. Physically, the centre will consist of a variety of peripheral devices (Figure 1) connected to one or more large computers (IBM 360/50 or larger) on the one hand, and to the field offices of the organization on the other. The magnitude of the information flows required between the field organization, the centralized management unit, and the FMC presupposes an efficient and integrated communications network which can both receive and transmit information in a manner suitable to the needs of the system and to the sensibilities of the people involved.

The FMC is at once the most visible part of the FMS and the most difficult part to analyze. Among the questions about the FMC which can only be answered in practice are those regarding cost of operation, the structure of appropriate "test-bed" for new FMS functions, the efficiency of various computer types in solving various fire management problems, the feasibility of linking multiple computers and other devices into a single problem-solving unit, and the method by which a quantitative FMC can be introduced into fire management organization with minimun resistance and disruption. These questions require that the initial stages of FMS development include development of a prototype FMC and testing of the prototype FMC under real-world conditions.

The first section of this report is largely expository, in that it presents definitions, initial results of the process of FMS design,

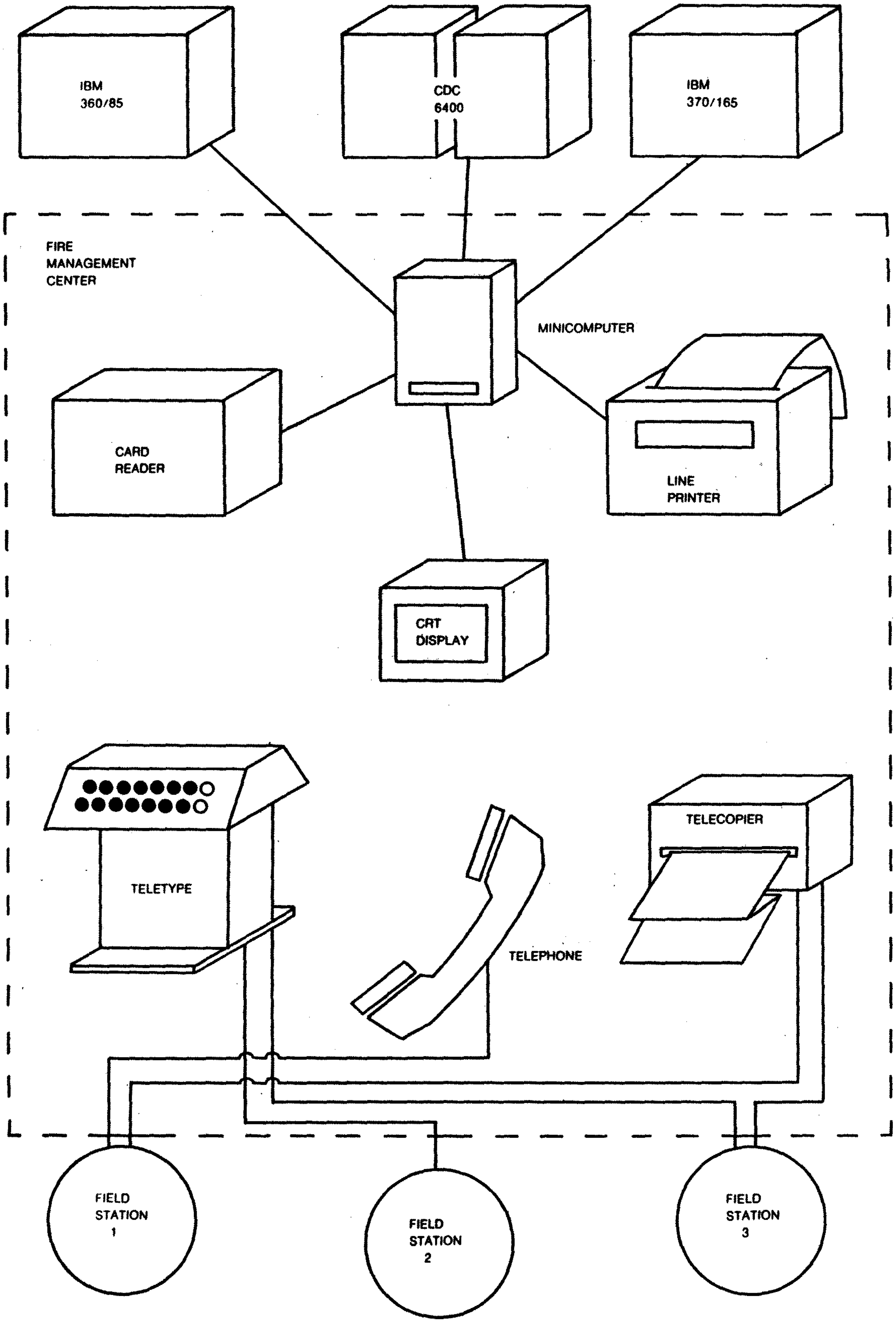

FIGURE 1 **PHYSICAL STRUCTURE OF A FIRE MANAGEMENT CENTER**

and an example of FMS operation. Report section II discusses the objectives of fire management and classifies the wide range of decisions involved. Sections III and IV develop design concepts for the two major FMS subsystems -- fire detection and fire suppression. Finally, section V presents goals for immediate implementation and recommendations for future research and development.

General Definitions:

As shown in Figure 2, the FMS consists of the natural fire environment, the fire control organization (FCO), the management decision unit (MDU), the fire management centre (FMC), and the relationships between these four parts. The FCO, MDU, and FMC are most relevant to the initial FMS design, as these are the parts of the FMS most subject to human intervention.

The FMS is intended to assist in control of resources in a relatively large region perhaps as much as 100,000 square miles. This region includes a number of stations which act as resource depots, serve as headquarters for field personnel, and provide information for the FMS. Each station is surrounded by a "dispatch zone" - an area which generates the major part of the demand for use of resources from that station and for which the station has initial attack responsibility. The aggregate set of stations, resources, and personnel actively engaged in direct field operations is the fire control organization (FCO).

The FMS also includes, and is controlled by, the management decision unit (MDU), the executive branch of the FMS. The MDU decides when the FCO and FMC are to be activated, specifies the tasks to be performed or functions to be implemented, delegates responsibility within the FMS, communicates directly with the FCO, and generally defines the state of fire management within the region at any given time. In essence, the MDU holds the operational authority and bears the responsibility for fire management within the FMS region.

We have previously noted that the FMC is the computational arm of the FMS and that it serves as a link between the human and the computer. In an operational sense, the job of the FMC is to provide information in usable form to the MDU and to process requests or data received, either directly from the FCO or from the MDU. From our standpoint, the majority of design variables in the FMS are related rather directly to the FMC and most of our initial development efforts will be concentrated on FMC design.

The relationships between the four parts of the FMS are also indicated in Figure 2. As shown, both the FMC and the FCO are under the direct control of the MDU through requests and decisions, respectively. Conversely, both the FMC and the FCO influence operational decisions by making recommendations to the MDU. Beyond this, the FMC acts as a "data filter", taking major flows of data regarding resource availability and the fire environment and modifying these data into a form useful to the MDU. The MDU can, of course, monitor data flows and can also act as a source of data to the FMC through definition of constraints, priorities, and general information revisions.

The process used in analyzing the FMS has been variously referred to as "operations research", "operational research", "management science", or even "systems analysis" (Wagner, 1969). The

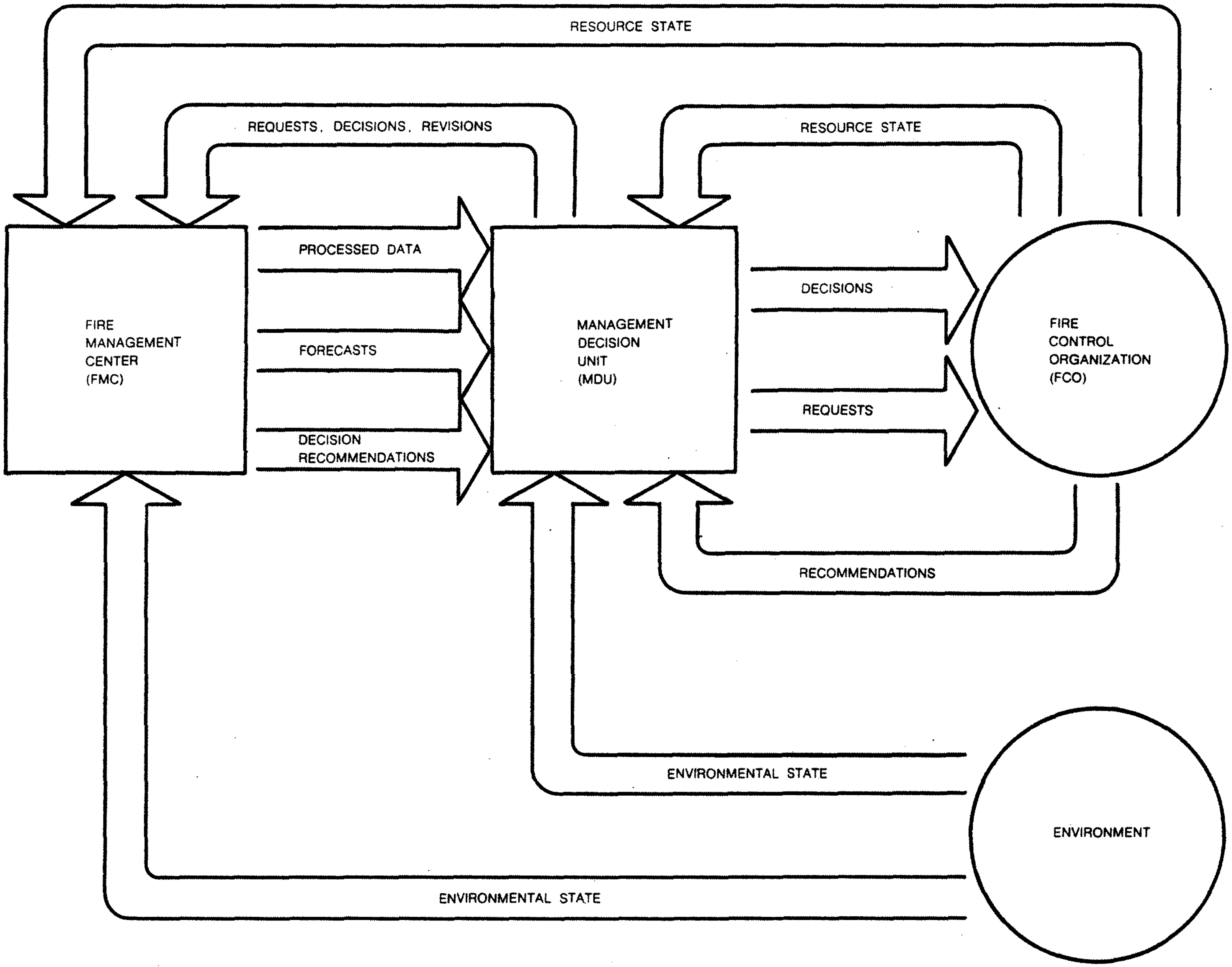

FIGURE 2 **THE FIRE MANAGEMENT SYSTEM**

basic premise is that one can specify a system (the FMS) composed of interrelated parts or "components" (the FCO, FMC, and MDU) in such a way that the components can be analyzed subject to the system interrelationships. The analysis then proceeds, component by component, with the goal of improving the efficiency of the system as a whole.

Components can generally be further divided into operational units or subsystems, each of which has a definable output or goal and for each of which one can define an appropriate performance criterion. In our case, the FMC component consists of the prevention, presuppression, detection, and suppression subsystems. As before, the components can be sequentially analyzed, subsystem by subsystem.

Finally, each subsystem is composed of a set of functions (for example, the prediction of fire weather) which must be performed if the subsystem is to produce output. Elements, including data bases, models, and physical facilities are necessary to implement functions. A function for which all necessary elements are present is a feasible function. Similarly, a subsystem for which all necessary functions are present is a feasible subsystem; feasible components and feasible systems are defined in the same manner. Figure 3 outlines the relationships between the various units involved in the analytical process.

Operations research generally involves economic analysis of system performance using mathematical models (Wagner, 1969). The selection of a criterion for this evaluation involves two factors -- theoretical correctness and practical applicability. In an ideal world, the two factors coincide, while in the real world they often diverge sharply due to a lack of significant information. In the case of the fire management system, the divergence is especially pronounced, even at the subsystem level.

The general economic factors in fire control are the revenues generated and the costs incurred. Equivalent model formulations leading to an optimal trade-off between these factors have been rigorously described elsewhere (Henderson and Quandt, 1958; Davis, 1965; Maloney, 1972b) for both the stochastic and non-stochastic case. Each formulation is a restatement of the marginal theory of the firm and each suffers from the practical limitations of that theory.

The foremost such limitations are the marginal optimization criteria. In essence, these criteria require that the revenue derived from the last unit of output produced (marginal revenue) be equal to the cost incurred in producing that last unit of output (marginal cost) for each input used. Application of the criteria requires a detailed knowledge of the production, cost, and revenue functions of the system being studied. We define the "economic model" as the evaluatory model which would be used if this detailed knowledge were available.

A second type of model can be used for economic evaluation of alternatives if only the production and cost functions of the subsystem are known. In this format, the amount of physical output generated per unit of cost is the criteria; the objective is to search among the alternatives to find the highest output-to-cost ratio consistent with the budget constraints implied by a given level of subsystem operation. A refinement of the model allows the maximum output/cost ratios to be defined for many levels of subsystem operation; the locus of such points

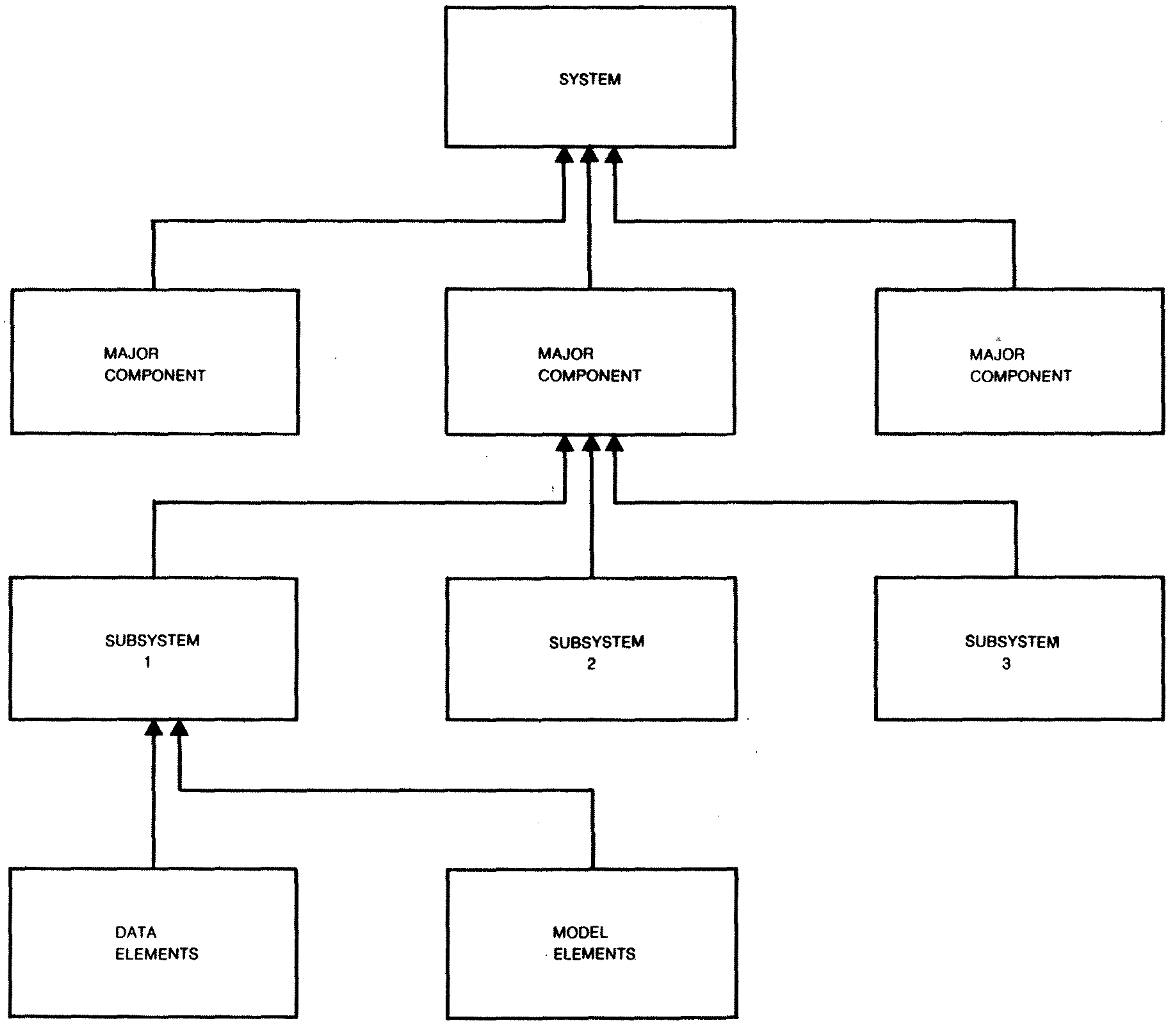

FIGURE 3 **PARTS OF A SYSTEM**

is the path of maximum physical efficiency for the subsystem. Thus, if a policy maker can set a budget limiting the range of subsystem operation, an efficiency model will indicate where the subsystem should operate within that range to achieve maximum physical output per unit of cost.

The production function for fire management is generally not well defined because output depends on what would have happened had no action been taken. A "surrogate model" is generally used in such cases; that is, some indicator variable which varies directly with output is used as a surrogate output measure. For example, the number of fires detected is usually used as a surrogate measure of the output of a fire detection subsystem. Once the surrogate measure is defined the model is essentially the same as the efficiency model described above.

All three types of models -- surrogate, efficiency[1], and economic -- are relevant to the design of the FMS and particularly to the design of the FMC. Generally, surrogate models will be used in initial FMC versions. Later, as research programs generate production and revenue information, efficiency and economic models will be substituted. Considering the magnitude of the research effort required, it is likely that the FMC will depend on surrogate models for a substantial period of time.

General Design Principles:

Within the framework shown in Figure 2, design of the FMS concept has proceeded under three basic principles. These are:

(1) The sole criterion for inclusion of a function in either the FMS or the FMC is its usefulness to the MDU as judged by the MDU. This implies:

  (a) Potential system users should be involved in system development at early stages to minimize research errors and to promote user understanding of the system.

  (b) The FMS and the FMC must be simple to operate even under difficult conditions.

  (c) No function will be added to an operating FMC until it has been documented and tested in a prototype FMC.

(2) The development of the FMC will occur in stages, beginning with currently feasible functions and incorporating other functions as these become feasible. Efficiency criteria suggest the following division of developmental efforts:

  (a) Current fire control agencies will concentrate on development of relationships and functions between the MDU and the FCO.

  (b) Fire research agencies will concentrate on definition and development of relationships and functions in the FMC and between the FMC and the MDU.

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[1] We have avoided the usual benefit/cost terminology often used for surrogate and efficiency models because: 1) the relationship between benefit and output is not clear in fire management, 2) benefit/cost models do not generally include an expansion-path search algorithm, and 3) benefit/cost models are generally used for comparison of different projects rather than for subsystem evaluation.

(3) Any FMS will be under the control of the MDU at all times.

The research steps involved in initial FMS development derive directly from the basic design principles:

(1) Specify the relationships and functions in the FMC without regard to current feasibility.

(2) Define the elements necessary to perform the functions of an FMC. Use this information to:

   (a) infer the physical structure of the FMC.

   (b) determine the current feasibility or infeasibility of each function.

   (c) establish priorities for studies necessary to provide elements for currently infeasible functions.

(3) Establish a prototype FMC, using currently feasible functions, to:

   (a) test the FMC concept in a real-world environment.

   (b) test the properties of currently feasible functions.

   (c) test the usefulness of proposed modifications to the FMC.

   (d) allow direct involvement of potential users in FMC development.

The remainder of this paper is primarily concerned with the results of investigation under work steps 1 and 2. Current FMS research at the Forest Fire Research Institute is concerned with further investigation of these steps, with development of the prototype FMC, and with work necessary to expand the set of currently feasible functions.

Basic FMC Characteristics:

As we have noted, it is not possible at this time to present a detailed description of the functions, elements, and physical facilities necessary in an FMC. However, it is useful to present an overview of the centre to put the discussion in subsequent chapters in context. Naturally, our current views may change as more knowledge is gained from further investigation and research.

The functions of an FMC may be evaluated by type or by category. In Figure 4, following, the functions are listed by type, along with the necessary data and model elements. For example, one type of FMC functions must predict expected levels of variables such as the fire weather index (FWI) or the expected rate of fire arrivals in the area protected. To do so, the centre will require both data elements (e.g., predicted weather) and model elements (e.g., fire occurrence model).

Vertical arrows in Figure 4 indicate relationships between function types. For example, the calculation and predictive functions

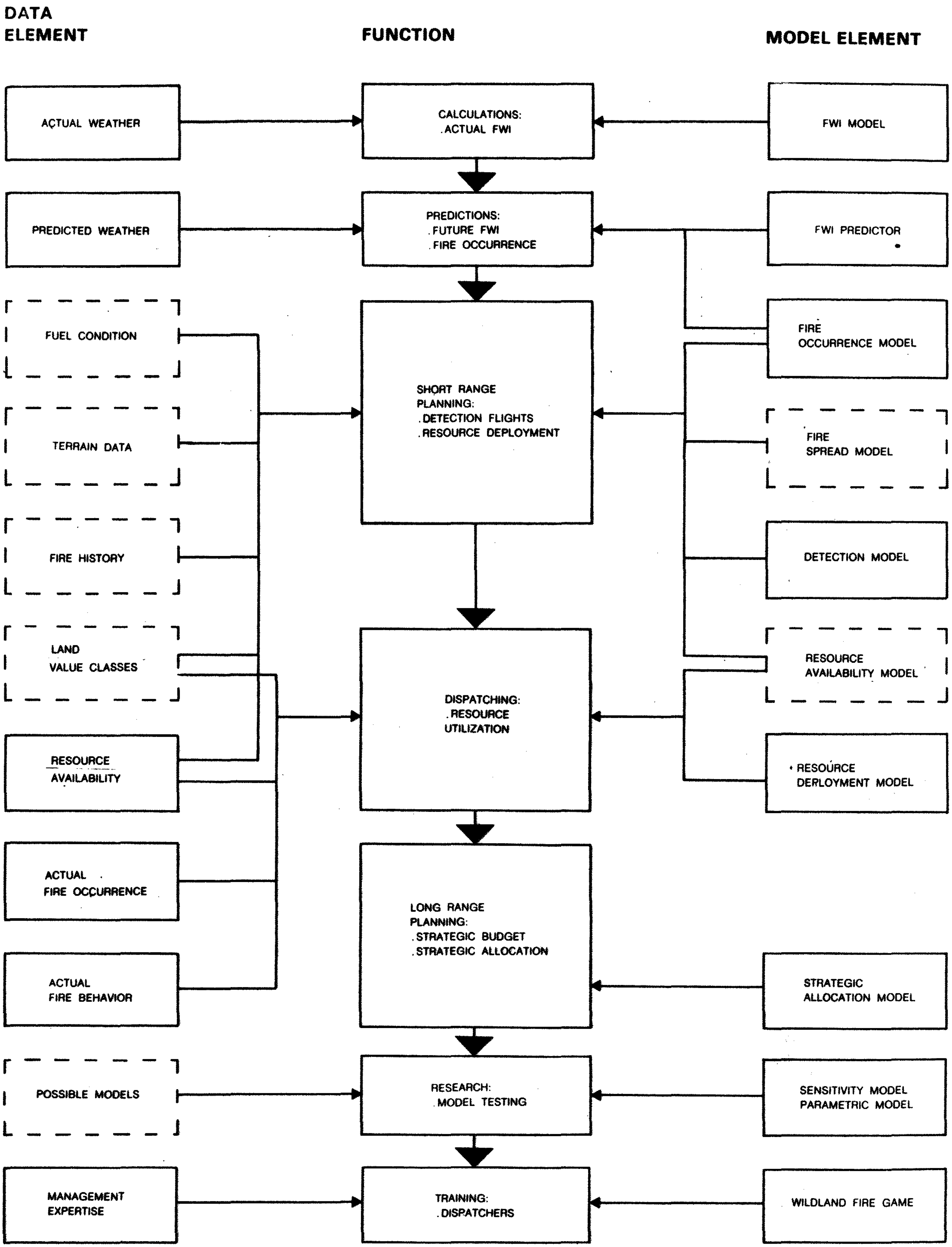

FIGURE 4 **FUNCTIONS OF A FIRE MANAGEMENT CENTER**

provide data necessary to the short-range planning and dispatch (resource allocation) functions. Insufficient information is available at present to evaluate the relationship between short-range and long-range planning functions, although conventional theory indicates that such a relationship does exist.

Horizontal arrows in Figure 4 indicate inputs and models which are necessary for the implementation of functions. Data bases and models which are currently available, albeit in prototype or surrogate form, are enclosed in solid lines; inputs and models which require future research are enclosed in dashed lines. It is evident that a substantial portion of the work necessary to establish a prototype FMC has already been done by various reseachers. It is also evident that much remains to be accomplished.

Although the physical facility is the most visible aspect of an FMC, the set of logical procedures or "computer software" necessary to implement the functions shown in Figure 4 is far more significant from a system design standpoint. As shown in Figure 5, the FMC software falls into three categories:

1) Decision models
2) Mathematical models of natural processes
3) Data elements.

A decision model is a set of procedures or computer program steps which recommends an appropriate resource control decision based on the current or predicted state of the FCO, the MDU, and the fire environment. The output of a decision model fulfills the appropriate function of the FMC.

A complete FMC would include decision models for prevention, presuppression, detection, suppression, and mop-up. However, the initial FMC will include only detection and suppression (resource deployment) models (Figure 5) as these are the activities to which the greatest share of fire management effect in Canada are devoted and the activities in which the effect of variability in demand is most evident.

Models of natural processes are intended to predict the behaviour of the fire management environment. They are the essential forecasting tools necessary to allow the FMS to be an anticipatory system rather than a passive receptor. The most significant of these models will include:

1) Fuel state prediction model
2) Man-caused fire occurrence model
3) Lightning-caused fire occurrence model
4) Fire spread model

Information requirements or data elements are a basic consideration in any management system and are certainly significant in the FMS. The information needs of the system fall into two categories: 1) data that describe relatively permanent attributes of the environment, and 2) data that describe temporary aspects of the environment and which require frequent modification. These categories are generally referred to as the "data base" and the "management information system" (MIS), respectively. Examples of data types in each category include:

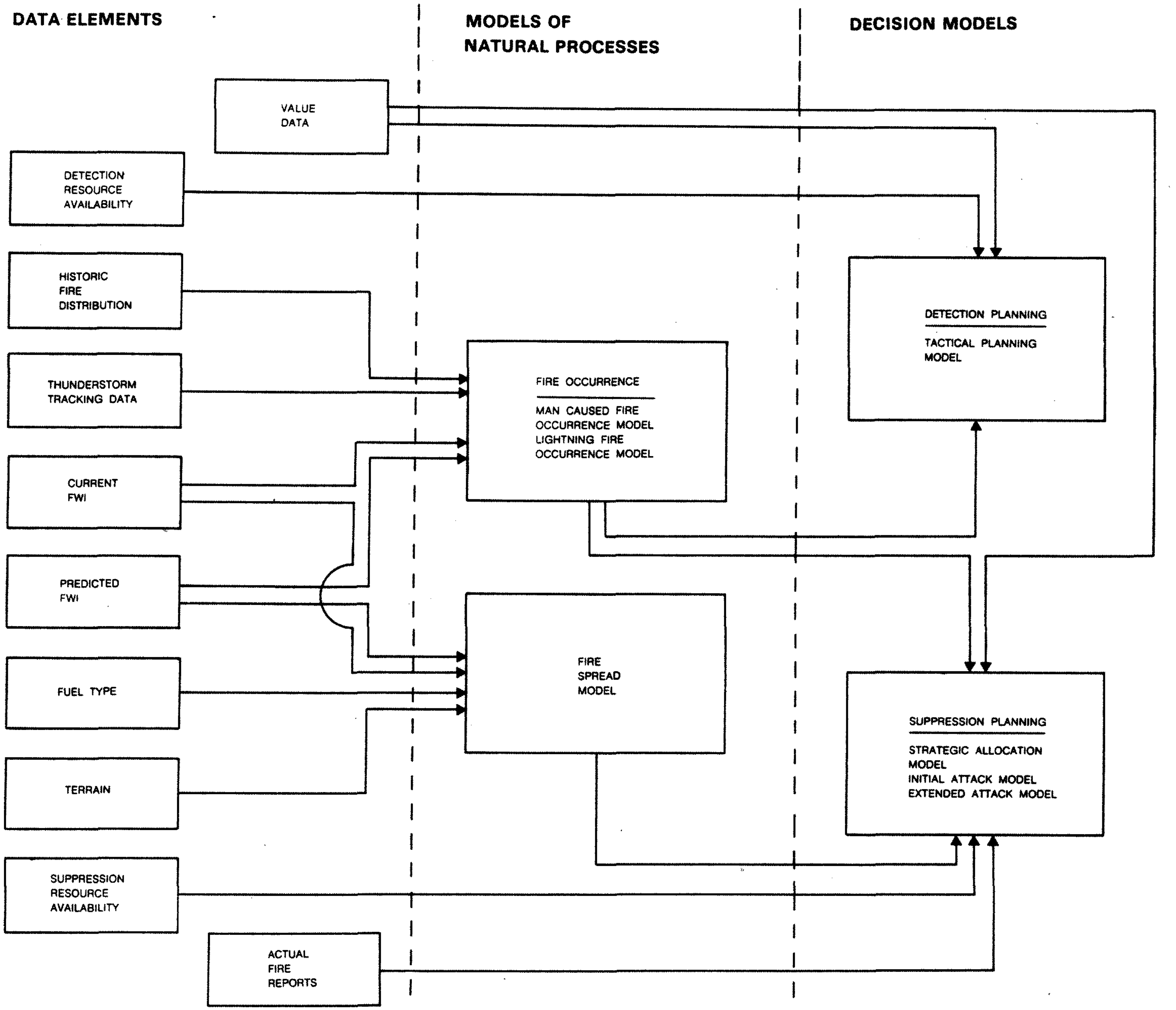

FIGURE 5 **FMC FUNCTIONS AND ELEMENTS BY CATEGORY**

1) Data base elements
    a) Fuel types
    b) Topographical data
    c) Historic fire occurrence distribution

2) MIS elements
    a) Fire Weather Index (FWI)
    b) Resource location and availability
    c) Data about current fires
    d) Thunderstorm tracking data

The relationships between the three categories of elements are shown by the connecting arrows of Figure 5. As indicated, these relationships are not simple; several data elements are common to both decision model types. It is clear that the data-handling programs must be written with sufficient flexibility to provide information in a variety of forms.

<u>An Example of System Operation:</u>

Assume that an FMS incorporating all models and data necessary for detection and suppression planning is available and that the MDU has decided that the expected fire situation tomorrow in the 70,000 square mile region being protected is sufficiently serious to warrant activation of the full FMS. The following scenario describes the operation of the FMS for the 18 hour period from 1800 hours on day one to 1200 hours on day two.

Time	Event(s)
1800 hours, day one	Decision made to activate FMS and FMC. Historic fire distributions, current and predicted FWI, and expected thunderstorm activity are used to estimate expected fire occurrence rates in the region (Fire Occurrence Model). Expected fire occurrence rates, detection resource availabilities, and land values are used to schedule and route detection flights for day two (Detection Planning Model). Expected fire occurrence rates, land values, and suppression resource availabilities are used to assign resources to particular stations in the region and to draw the boundaries of the dispatch zones for each station (Resource Deployment Model). The MDU assesses the suggestions for detection scheduling and resource distribution received from the FMC and

	issues orders to implement those suggestions found useful. The FCO makes ready to implement the MDU orders on day two.
1900 hours, day one	The MDU orders are used to modify the appropriate data files in the FMS.

The FMS is now set up to meet the expected fire situation on day two in the best manner possible, given the constraints of the system. Therefore, the FMS goes into a holding mode until the actual events of day two begin to occur.

Until this point, the FMS has functioned as an anticipatory or planning system. However, since the actual events of day two may not coincide with the events expected on that day, the FMS must also have the capability to react rapidly to divergencies between expected and actual situations. Thus, the scenario continues:

Time	Event (s)
0600 hours, day two	All predicted data is judged against actual data. Slight errors are corrected manually while major errors are corrected by models. If necessary, the MDU issues revised orders for the day. Resource transfers, if any, begin. Stations are informed of the boundaries of their areas of dispatch responsibility and of the expected fire situations in those areas. If necessary, FMC data banks are updated. The system holds.
0800 hours (Assumed)	Detection flights are initiated under the planned schedule and routing.
1000 hours (Assumed)	An expected fire is reported.
	An "automatic first dispatch" (AFD) of resources is made to the fire. While the AFD is en route, the best current data regarding the environment of the fire is fed into the FMC (Fire Spread Model). If the AFD is judged inadequate to control the fire, the MDU may authorize a second dispatch at once, thus saving substantial travel time.
1100 hours (Assumed)	The AFD arrives on the fire, begins suppression, and transmits improved

information regarding the fire environment to the FMC. A second assessment of the need for more resources on the fire is made and suggestions are transmitted to the MDU. Previous decisions are revised or maintained according to the MDU's evaluation of the new information.

1130 hours — An unexpected fire is reported. (Assumed)

An AFD is made to the fire.

The multi-stage assessment of the potential of the fire proceeds as in the case of the first fire reported; that is, the Fire Spread Model is used to evaluate the appropriateness of prior decisions each time that improved data regarding the fire environment becomes available.

Information regarding the new fire is fed into the Resource Deployment Model and used to modify expectations and to re-assess the current distribution of resources in the region protected. Suggestions regarding revisions, if any, are sent to the MDU. Data banks are updated.

1140 hours (Assumed) — A fixed wing air tanker and three unit crews are reported as unavailable for service for the rest of the day.

The information is fed into the Resource Deployment Model and revised suggestions are sent to the MDU. Data banks are updated.

The process of decision, re-valuation, decision, etc., outlined in the scenario continues throughout the day as new events are reported and new information is received. The system is, in effect, ready to change at any time subject to the actual and expected fire situations, the current system constraints, and the decisions of the MDU.

In this discussion we have outlined, in very general terms, some initial design principles and work steps involved in investigation of the FMS concept. A logical starting point for further refinement of these principles is a discussion of the role of decision making in the FMS.

II. DECISION MAKING IN FOREST FIRE MANAGEMENT

The function of the fire management system is to facilitate effective management decision making, the process of which can be conceptualized as a feedback loop (Figure 6). The MDU accepts information on the state of the real world (both that part of the real world that is under direct control of the organization and that part which comprises the environment) and, according to some established process, arrives at a decision which is intended to have some desired effect on the state of the real world.

In economic theory, decisions are classed as short-run or long-run, according to the degree to which production resources are fixed or variable, and the response time of the system feedback loop is assumed to be negligible. In the practical case, response time is an important characteristic of any decision process. In fire management the minimum necessary response time may range from minutes to years, depending upon whether the decision is made to meet rapidly changing environmental conditions or is made to alter major system components.

All fire management decisions are made subject to constraints on either the time or the resources available to implement the decision. Time constraints are often the result of the interaction between the decision maker and the fire environment; for example, the location of a fire line is partially a function of the rate at which the fire is spreading. Resource constraints are most often a function of prior decisions; for example, an airtanker can be used only if a series of prior decisions have made an airtanker available.

The nature of decision constraints and the loop response times suggest the following general classification of fire management decisions. Note that each decision type is constrained by the decisions which follow it in the list:

(1) Very short-range:

  (a) All resource quantities are fixed.
  (b) Resource mobility is limited due to short response time required.
  (c) Decisions are made in response to spread of fire or to immediate changes in fire environment.

(2) Short-range:

  (a) All resource quantities are fixed.
  (b) Resource mobility is greater than in very short range since minimum response times up to several hours are allowed.
  (c) Decisions are made in response to occurrence or spread rates of actual fires or in response to expected fire risk or hazard levels in a station dispatch zone.

  (d) Examples: Scheduling and routing of detection flights for a given day, dispatch of resources from a given station to a given fire.

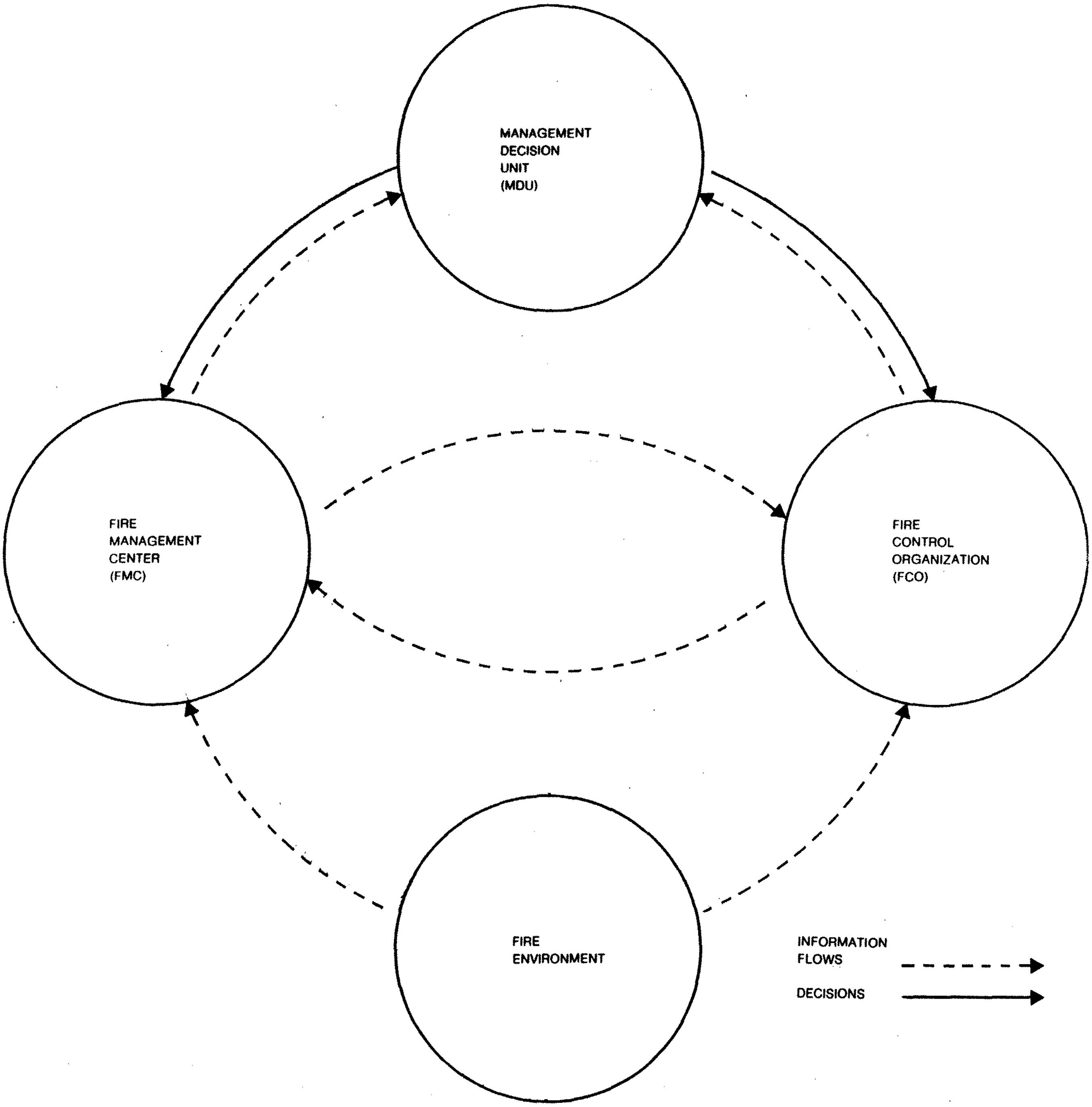

FIGURE 6 **THE FIRE MANAGEMENT DECISION LOOP**

(3) Intermediate-range:

    (a) Resource quantities are fixed for the individual stations but variable between stations within the region.
    (b) Resource mobility is complete within the region but not allowed between regions.
    (c) Decisions are made in response to expected and actual fire situations in all station dispatch zones in the region.
    (d) Example: Definition of station dispatch zones and resource levels for each station in the region for the following day.

(4) Long-range:

    (a) Resource quantities, including stations, are variable but the total seasonal expenditure is fixed for the Province.
    (b) Resource mobility is unlimited within the Province.
    (c) Decisions are made in response to expected seasonal fire situations in regions.
    (d) Examples: Division of total annual budget into specific budgets for presuppression, detection, suppression, etc., definition of the set of stations which will be activated for the coming season, definition of the initial distribution of resources between regions for a coming season.

(5) Very long-range:

    (a) All resource quantities and capital expenditures are variable.
    (b) Resource mobility is unlimited.
    (c) Decisions are made in response to Provincial and/or Federal policies regarding future fire management levels.
    (d) Examples: Conversion of detection systems from fixed lookouts to aircraft patrols, purchase of a fixed-wing airtanker fleet with support facilities.

As a concept, the FMS is concerned with all decisions made in a fire management organization. As a practical matter, however, the initial FMS, and particularly the initial FMC must be concerned with only a limited range of decisions because of the design and development workload involved.

Very short-range and short-range decisions are not prime candidates for inclusion in the initial FMC for several reasons. First, these decisions are typically made in a very short period of time and are made in response to limited information. Thus, there is neither the time nor the need for complex decision models. Second, these decisions are typically made under a large number of constraints which sharply limit the range of alternatives open to the decision maker. Again, a complex decision model is not indicated. Third, although the information required is limited, it must be very current; in effect, the decisions have a strong interactive component which limits the usefulness of predictive programs. Fourth, a substantial body of qualitative expertise exists among field personnel involved in these decisions; recent research indicates that this expertise allows field personnel to make sufficiently good decisions more rapidly than the computer (Tolin, 1969). For these reasons, very short-range and short-range decisions are excluded from the initial FMC.

Long-range and very long-range decisions may also be excluded from initial consideration. A sufficient reason for such exclusion is that these decisions usually involve structural, policy, or political objectives which are not well defined at present, but which have greater significance than the economic objectives which serve as criteria in the FMC models. Thus, one would either have to define the non-economic objectives of the system or to develop a centre which has very limited real-world usefulness. The first course would significantly delay establishment of the initial FMC while the second is patently ridiculous.

Intermediate range decisions are the best candidates for inclusion in the initial FMC. First, these decisions involve a significant range of alternatives and present an inherently complex problem in consideration of the multiple variables involved. Second, the time given for such decisions is sufficient to allow use of FMC models, if desired. Third, the budgets involved are sufficiently large to allow substantial savings due to increases in efficiency. Fourth, recent decision modelling efforts in fire management research have been primarily concerned with intermediate range decisions or with generation of the data necessary to make such decisions. Finally, inclusion of such decisions in an FMC involves the least amount of disruption of either the structure or the field operations of the fire management organization.

Intermediate-range decisions are constrained from above by both long-range and very long-range decisons. It is assumed that these constraints are adequately represented by the specific budgets assigned to various activities for the season and by the physical composition of the resources available to the decision maker. The capability of intermediate-range models to provide information useful in longer-range decisions will be considered but will not be a major design factor in the initial FMC.

Intermediate-range decisions act as constraints on short-range and very short-range decisions. As a consequence, the interface between these classes of decisions is a significant design variable. Substantial emphasis will be placed on the predictive and adaptive characteristics of the initial FMC models.

The initial goal of the FMC project, then, will be to develop and apply intermediate range models which suggest how to operate under a set of longer-range constraints and which have only limited policy implications. It is expected that surrogate models will be used during early development stages with substitution of efficiency models as these become available. The initial FMC will deal with two major subsystems - the detection subsystem and the fire suppression subsystem - and will include the several models of natural processes and data elements necessary to make the subsystems feasible. The characteristics of the two subsystems are discussed in the following two sections of this paper.

III. THE FIRE DETECTION SUBSYSTEM

The forest fire detection subsystem in Canada is composed of: (1) public or "unorganized" detection, (2) ground detection, whether by fixed lookouts or by organized patrols, and (3) visual detection from aircraft (Kourtz, 1972). In the intermediate range, we assume that the unorganized and ground detection components are fixed[2]; therefore, these components are not considered in the initial subsystem model.

With this limitation, visual detection from aircraft becomes the only variable factor in the detection subsystem. However, as indicated previously, this variable factor is manipulated subject to the constraints imposed by prior long-range planning and annual budget decisions. Thus, there are two aspects to intermediate-range detection decision making: (1) how much detection resource to use during a given planning period, and (2) how to use that resource efficiently. More precisely, there are three variables involved:

(1) the budget allocated for variable detection costs in each planning period in the season.

(2) the schedule according to which detection flights are to be made during a given planning period.

(3) the routes which detection flights will follow during the period.

The Budget Variable:

Some amount of money must be allocated to meet variable detection costs during each intermediate-range planning period in the season. Simultaneously, the total of all planning period budgets must not exceed the annual budget assigned to detection expenses. Thus, the budget variable is the vehicle by which long-range constraints are imposed on intermediate- range detection decisions.

If the data necessary for a full economic model were available, budgets for individual planning periods could be readily determined. In this case, the amount of money spent in each period would be adjusted until: (1) marginal detection revenues were equal to marginal detection costs in each period, (2) marginal detection revenues for all periods were equal, and (3) the total expenditure was less than, or equal to, the annual detection budget. Under these conditions, detection profit would be maximized.

However, the initial FMC will use a surrogate detection model in which the output of the detection subsystem is assumed proportional to the number of fires detected. Under these circumstances, the individual planning period budgets will be determined on the basis of the expected number of fires occurring within the planning period expressed as a percentage of the total number of fires expected during the season.

Specification of the budget variable requires two predictions of expected number of fires (detection demand). The first is a prediction of demand for the short planning period. Current research,

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[2] The performance of the unorganized detection network is not significantly affected by the fire management organization within the intermediate–range planning period, which ranges from several hours to several days. Simultaneously, unorganized detection does not cost the organization any significant amount of money. Expenditures on ground detection are set during the annual budgeting process and are not subject to substantial variation in the intermediate planning period.

which is referenced below, indicates that these short-term predictions can be made.

The second prediction is of detection demand for the season as a whole or for that part of the season remaining after the current planning period. Research now underway at the Forest Fire Research Institute indicates at least one model formulation which gives reasonable results in this area. Further, results from other studies in decision theory (Boyd, et. al., 1971) suggest that long-term prediction of results from such esoteric projects as seeding hurricanes is feasible. Further work in this area is now being done at the Institute.

Aerial detection involves both fixed and variable expenses. We assume that the fixed expenses (e.g., salaries, non-consumable guarantees, depreciation, etc.) can be identified and, if necessary, assigned to planning periods on a pro rata basis. Alternatively, such expenses can be subtracted from the annual detection budget prior to analysis.

To be useful in the planning process, the record of variable expenses must be quite current. Therefore, it is necessary to monitor current detection activity (probably with computer assistance) and not simply cash flow, since some expenses may be paid off some weeks after the service is rendered. Both an efficient accounting information system and accurate unit costing of detection activities are required.

The Scheduling and Routing Variables:

The budget variable, once determined, defines how intensively detection resources can be used in a given planning period. The schedule under which detection activities are undertaken and the routes which detection aircraft fly are the major decision variables which then determine the efficiency of the aerial detection system during that period.

Kourtz (Kourtz and O'Regan, 1968) has shown that the determination of the best schedules and routes for a given period is a constrained dynamic programming problem and has developed a surrogate model to solve the problem using the number of fires detected as the criterion of system performance.

His approach is to divide the detection area into a number of rectangles, each 15' of latitude by 30' of longitude, and to compute the expected number of fires in each rectangle. After those fires expected to be detected by unorganized or ground components are deleted, dynamic programming is used to schedule and route the aircraft over the largest possible number of fires. Satisfactory results were obtained when the model was tested against the performance of a highly skilled dispatcher on historical data from Northwestern Ontario.

Current and Future Status:

The present Kourtz' model requires short-term predictions of fire occurrence in the detection area in addition to readily obtainable physical statistics. For man-caused fires, a predictive model developed by Cunningham and Martell seems to meet this need (Cunningham and Martell, 1973). This stochastic model views man-caused fire occurrence as a Poisson process dependent on the Fine Fuel Moisture Code. Although information requirements are minimal, the predictive model gave remarkably good results when tested against actual data from Northwestern Ontario.

It has been generally assumed (Kourtz, 1973) that lightning fire occurence is dependent on fuel conditions, as measured by elements of the FWI, and dependent on thunderstorm occurence. Accurate knowledge regarding thunderstorm occurence is difficult to obtain; as a result, the bulk of the effort in lightning fire prediction has been devoted to thunderstorm tracking and reporting. Such reporting is already a standard procedure for field stations. In addition, experimental work by Kourtz and personnel of the Ontario Ministry of Natural Resources on remote sensors for storm cell tracking is yielding encouraging results.

Kourtz's model also requires prediction of the Fire Weather Index components for the planning period. FWI prediction has been a standard practice since 1970 (Anonymous, 1970) and is a well-known technique.

Since both the data elements required and the model required are available, there seems to be no impediment to using the Kourtz' detection model in the initial FMC. Thus, the initial centre will have the capability to schedule and route aircraft, but will be unable to suggest how intensive the detection effort should be during any planning period.

The 'how intensive' capability depends on inclusion of the budget variable in Kourtz's model. As noted previously, the budget variable requires long-term predictions of fire season severity as well as the short-term predictions included in Kourtz's present model. In addition, some modification of Kourtz's model is indicated. As the indicated modification is relatively minor and current work on long-term prediction is yielding encouraging results, the prototype FMC should have a 'how intensive' capability shortly after its inception.

Development and application of a detection model with inter-period allocation capability completes the first stage in inclusion of the detection subsystem in the FMC. There are two major lines of further development after completion of this first stage: 1) refinement of the interperiod allocatory criteria from simple number of fires or pro rata budget variables to more complex measures of inter-period fire occurrence significance, and 2) modification of the initial surrogate model into efficiency and/or economic forms.

There are a number of refinements which can be incorporated into the allocatory variables even within the confines of the surrogate model form. For example, the number of hours for which fires burn out of control per fire provides a useful measure of fire severity assuming a constant fire control organization (Maloney, 1972b). This measure, which can be estimated from historical records, could be used in place of the number of fires as a measure of subsystem performance.

Another possible refinement would be to test the significance of errors in data on the nature of the decisions suggested and, if indicated, to incorporate a measure, probably partially subjective, of the significance of data errors in the model[3]. Further development of the surrogate model could include incorporation of an adaptive prediction function for fire occurrence[4] or inclusion of relative values

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[3] As an example, standard 'least squares' regression assumes that the significance of an error is proportional to the square of the error.

[4] An adaptive or Bayesian predictive function would predict what would happen during the remainder of the season on the basis of what had already happened during the season as well as on the basis of historical data.

subject to destruction by fire as a part of the subsystem performance criteria.

The methodology for each of the refinements suggested above is either known or, in the case of determination of relative values, is being investigated at the Forest Fire Research Institute. The necessity for each possible refinement can be determined through parametric and/or sensitivity analysis of the surrogate model once the model is on line in the prototype FMC.

Modification of the surrogate model into an efficiency model presents substantial problems. An efficiency model uses output per unit cost as a performance criterion. Thus, it requires specification of an aerial detection production function - i.e., a determination of the amount of detection output obtained per unit of detection input used for a wide range of detection activity levels. It also requires a detection cost function - i.e., a relation between the amount of detection input used and the cost incurred at that level of input use.

Aerial detection output is the reduction in damage done by the fire if the fire is detected at an earlier time than it would have been had some other form of detection been used. Determination of this "what would have happened if some other form of detection action had been taken" measure involves prediction of fire spread and intensity rates under a variety of conditions. This prediction cannot be made at the present time.

A substantial amount of current research, both theoretical and empirical, is devoted to the question of fire spread and intensity. The theoretical fire spread/intensity model developed by Rothermel (Rothermel, 1972) is on line at several locations, including the FFRI, and has been extensively tested by the Aerospace Corporation (Anonymous, 1972) in Southern California. There seem to be two major impediments to field application of this model under Canadian conditions: 1) information requirements regarding fuel structure, low-level winds etc. are prohibitively high, and 2) the basic model is not structured to deal with multiple levels of fuel. It is unlikely that these impediments will be overcome in the near future.

Empirical measurements of fire spread/intensity rates or of the factors underlying such rates (e.g. , Stocks and Walker, 1972; Van Wagner, 1973; Walker, 1971) have more operational promise, at least in the short run, than do theoretical models. The basic problems in this area are the multiplicity of fuel types and conditions under which measurements must be taken and, oddly enough, the efficiency of Provincial fire control agencies (which makes measurements on free-burning wildfires difficult to obtain). A secondary problem is that of aggregating the data that has already been gathered by various researchers and subjecting the information to consistent statistical analysis (e.g., multivariate, non-linear regression). Again, the outlook for development of detection production functions from this data source in the near future is not promising.

Specification of an aerial detection cost function is possible at the present time. In fact, the cost data included in the surrogate budget model would suffice for this purpose. However, since the difficulties involved in specifying detection production functions are sufficient to preclude development of an efficiency model, there seems little point to devoting scarce research time to a detection cost analysis beyond that required on the surrogate model.

Further expansion of an efficiency detection model into a full economic model will require that the values subject to damage by fire be known for each area of concern and that the output of the detection process be expressed in terms of those values. Definition of such values may be feasible, either through analysis of historical data or through specific studies in each area of concern. Since the distribution of such values would be a useful addition to the surrogate model, value studies need not await completion of the efficiency detection model.

Summary of the Detection Subsystem:

The inputs and calculations required for Kourtz's detection model are shown in Figure 7, following. As indicated, the model requires distributions of lightning and man-caused fires as well as the Initial Spread Index and measures of prior detection activities and public detection probabilities to compute the current detection demand distribution. The demand distribution, along with information regarding aircraft availability and capabilities, detection probabilities, and visibility, is then used to schedule and route the detection aircraft to pass over the maximum number of expected fires. This surrogate model is currently on line.

The steps necessary to modify Kourtz's model to include a budgeting capability are shown in Figure 8. Cost and activity records are used to compute the total variable-cost budget available for the remainder of the season. The remaining budget, plus information on expected fire occurrence, visibility, and equipment characteristics, is used in a Periodic Budgeting Model to indicate an appropriate budget for the planning period. The budget for the period is then used as a constraint on Kourtz's basic model. Since the data necessary to make this modification are available and since the modification itself is relatively minor, the detection function of the initial FMC may have a budgeting capability shortly after its inception.

The additional elements necessary to develop an efficiency or an economic detection model from the budget-constrained surrogate model are shown in Figure 9. The efficiency model requires all data previously used in the surrogate model, a detection production function, and a detection cost function. The production function, in turn, requires a measure of detection output and fire spread/intensity rates. The cost function requires the cost data already available from the surrogate model. A lack of the information required to develop the detection production function is likely to impede development of an efficiency model for aerial detection for some time to come.

Since an economic detection model requires the full range of elements necessary to an efficiency model plus information regarding damageable values, the impediments to definition of a detection protection function also preclude the application of an economic model. However, knowledge of significant values at stake would also be useful as an allocatory criterion in the surrogate model; one study at the FFRI is currently investigating one means by which such values might be defined.

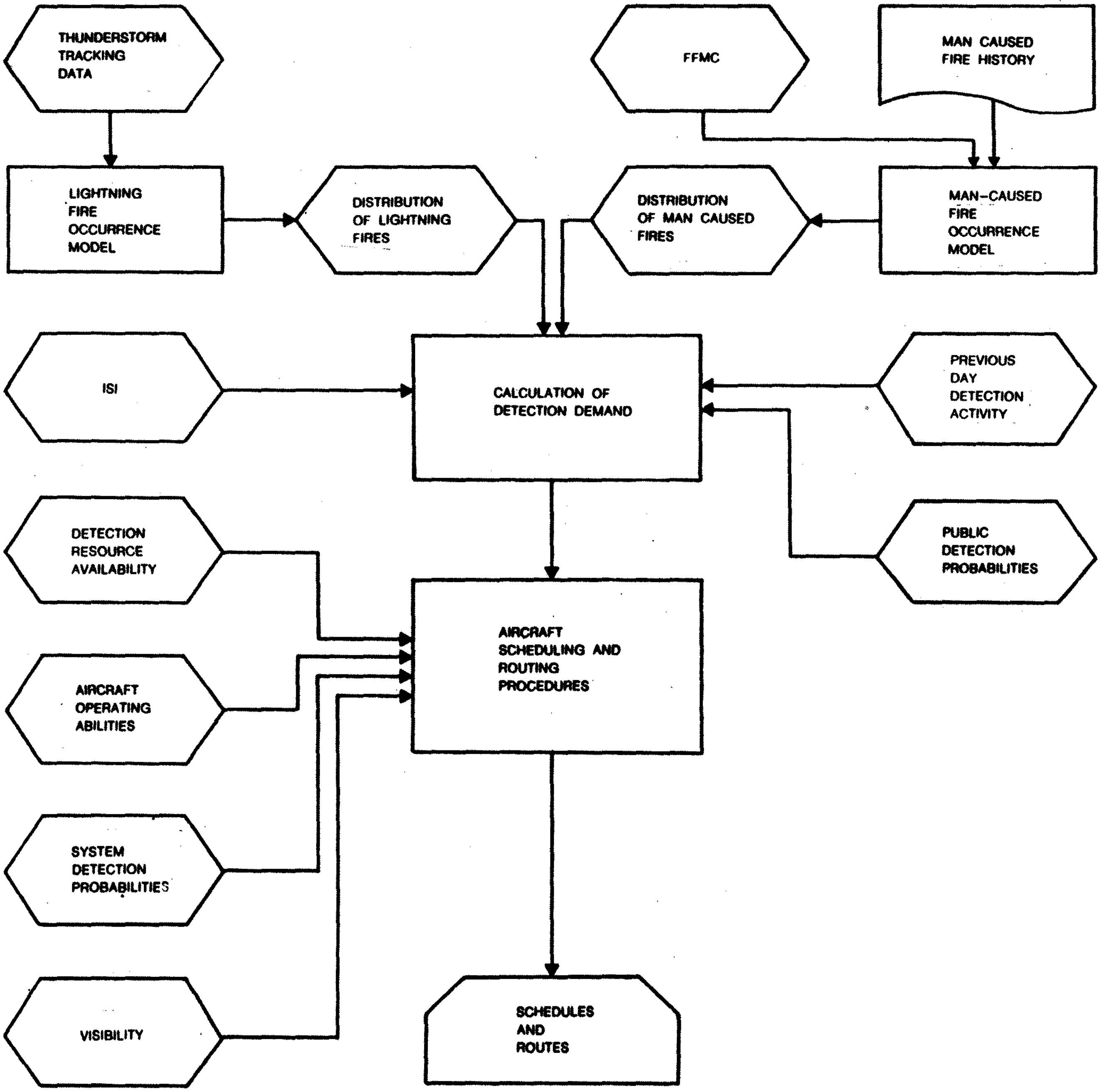

FIGURE 7 **THE SURROGATE DETECTION MODEL**

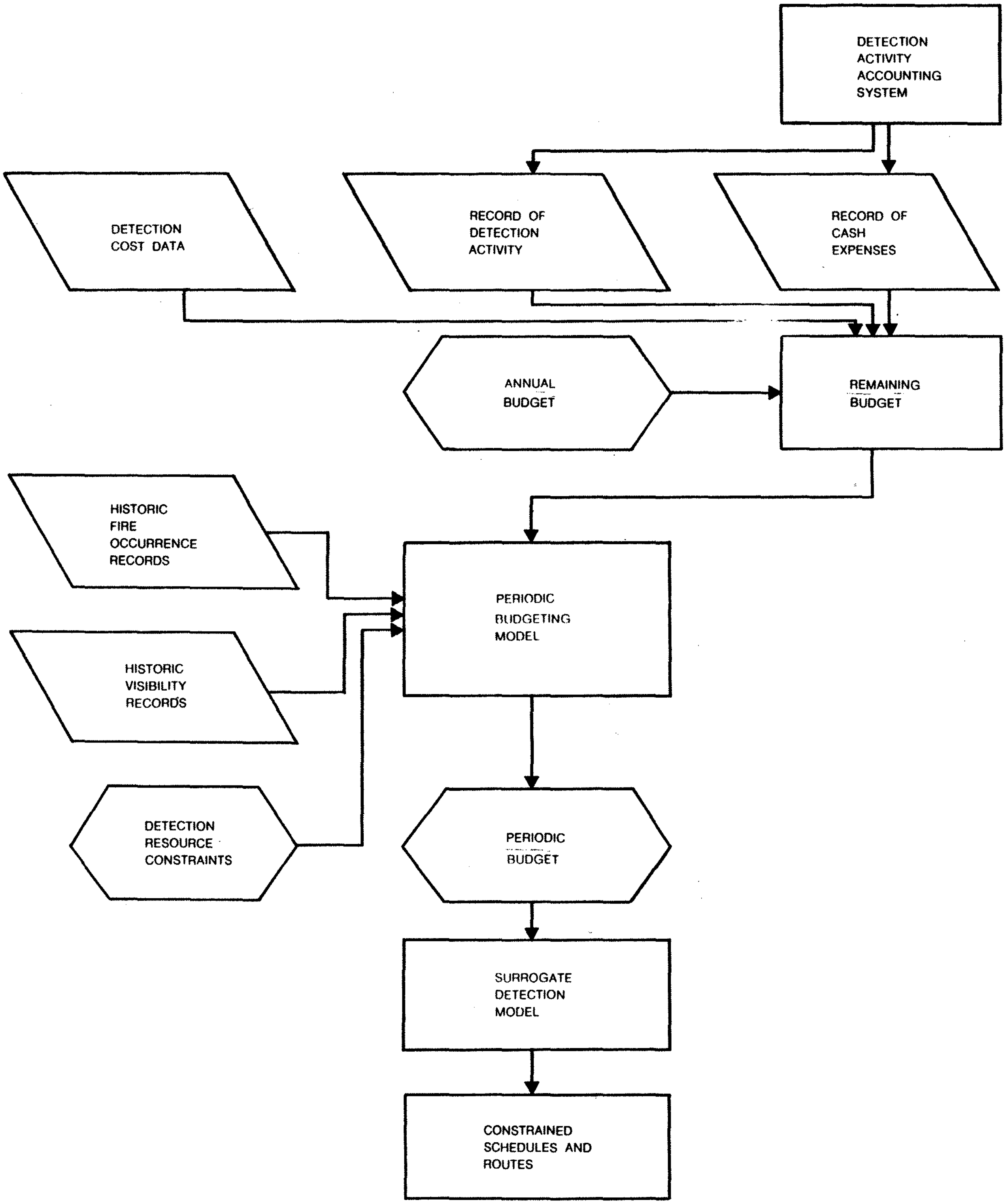

FIGURE 8 **THE SURROGATE DETECTION MODEL WITH BUDGETARY CAPABILITY**

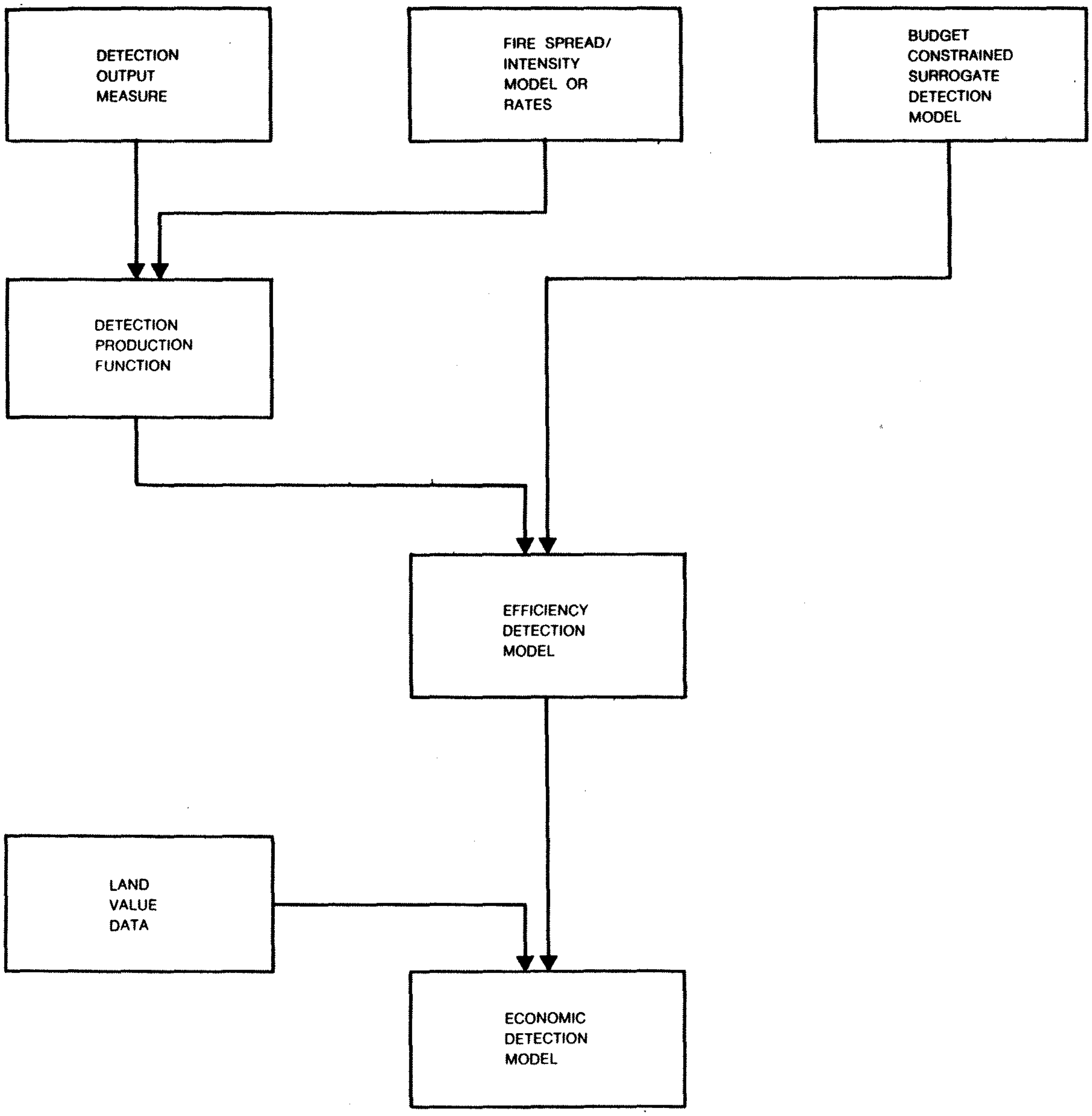

FIGURE 9 **STEPS IN CONVERTING FROM SURROGATE TO ECONOMIC DETECTION MODELS**

The analysis of the detection subsystem data elements has indicated that fairly sophisticated surrogate models are currently feasible but that the next major step in subsystem development must await definition of detection production functions. We shall return to this point, and to discussion of the implied research programs, after consideration of the fire suppression subsystem.

IV. THE FIRE SUPPRESSION SUBSYSTEM

The forest fire suppression subsystem consists of the men and equipment used in direct suppression action against wildfires, the transport equipment necessary for subsystem mobility, the stations and administrative facilities, and the group of fire executives who make the decisions which determine the state of the subsystem at any point in time. This analysis is primarily concerned with the intermediate range decisions made by the executive group. More specifically, it is concerned with the question of how to suggest ways in which the subsystem can meet some level of demand for fire suppression activity at or near minimum cost levels.

We assume that the majority of the men, equipment, and transport units which comprise the fire suppression resources are located at several stations or resource depots scattered throughout the large region for which the FMS has responsibility. The strength of any station (i.e., the ability of the station to put suppression capability into the field) at any given time is determined by the number of resource units of each type available at that station and by the alert status of those resource units.

Certain suppression resources are controlled directly by the regional offices rather than indirectly through stations (e.g., land-based air tankers, regional equipment caches). Thus, the strength of the region at any given time is a function of the number and status of regional resources as well as of the strength of each station within the region.

The intermediate-range problem faced by the suppression subsystem is similar, in many ways, to that faced by the detection subsystem. For a given planning period, the suppression subsystem must decide how much suppression strength is to be activated, just as the detection subsystem is required to decide how intensive detection efforts should be. Similarly, the suppression subsystem must decide how the desired strength levels are to be distributed among the stations in the region, just as the detection subsystem must decide on the schedules and routes for detection flights. There are, however, several significant differences between the two subsystems.

The detection subsystem is essentially concerned with a single resource type - hours of aerial detection - and with a relatively small number of locations at which that resource can be stationed. In contrast, the suppression subsystem is concerned with a number of resource types which can be distributed among a relatively large number of stations. The increased number of variables concerned in fire suppression affects both the nature of the model and the amount of data required.

The function of the detection subsystem is to detect fires; the subsystem must deal with the inherent variability of fire occurrence in a given season. The suppression subsystem must consider not only the inherent variability of fire occurrence but also the variability of fire severity and intensity. The greater uncertainty facing the suppression subsystem is reflected, in most agencies, by a provision for emergency supplemental budget allocations during critical fire periods. As a consequence, the budget variable in fire suppression acts more as an indicator of current or future needs for emergency funding than as an upper limit on subsystem expenditures.

Although there is a relationship between detection activities and the short-range situation facing the region, the detection subsystem is only peripherally affected by the current regional fire situation. In fact, the occurrence of a large number of on-going fires in a particular area of the region indicates that detection routes should avoid that area (under the assumption that suppression activities in the area will suffice to detect any new fires which may start).

In contrast, the presence of on-going fires in a given area of the region has an immediate and direct effect on intermediate-range suppression resource deployment decisions, since current fires affect both the amount of resources available for deployment in other areas of the region and the level of effective demand for resources in the area concerned. As a consequence, the suppression resource deployment model must be designed with an efficient interface between intermediate-range and short-range decisions; specifically, it must consider the current pattern of fire occurrence and severity as well as the fire pattern predicted for the planning period.

The differences noted between the detection and suppression subsystems indicate that the suppression resource deployment model will be more complex and larger than the detection model. As a consequence, the suppression model will be initially formulated as a linear rather than a dynamic program. However, the same process of surrogate model formulation, evaluation of possible improvements, and model modification as was outlined for the detection model will be followed in the subsystem model development.

A linear programming model can be completely described by specifying its variables, its objective, and its constraints. We shall use this approach in describing the salient features of the suppression resource deployment model (SRDM).

The SRDM - Variables:

In a given planning period, which may range from one to several hours or days, the expected amount of suppression activity is a function of the expected number of fires (or of a more sophisticated measure) and of the budget allocated to suppression activity. During this period, the management decision unit may change the strength of any station through transfer, change the strength of any station through changes in resource status, or change the dispatch zone -- the area for which a station has initial dispatch responsibility -- for any station. In addition, the interface between intermediate-range and short-range decisions must be considered. Thus, there are five classes of variables in the SRDM.

1. Budget variables
2. Transfer variables
3. Status variables
4. Dispatch zone variables

5. Carry-over variables

As in the case of the detection model, the budget variable is the vehicle by which long-range constraints are imposed upon SRDM decisions and also determines how intensive suppression activities are expected to be during the planning period. The initial SRDM will be a surrogate model using the same parameters of expected fire distribution as does the detection model; as more sophisticated measures of distribution are developed and tested, they will be substituted in both models.

The transfer variable specifies the quantities and types of resources which are to be transferred between stations at each run of the SRDM and also the means by which the resources are to be transferred. Similarly, the status variable denotes the alert status level for each resource type at each station. The data elements required for these variables are related to costs and constraints and will be discussed later.

The dispatch zones surrounding each station have generally been regarded as fixed areas in analytical research. On a practical level, however, the size of dispatch zone is regarded as a variable by field personnel; modification of the zone size is accomplished by transfer of resources during critical fire situations. In the extreme, when all resources at a station have been transferred out or committed to going fires, the area of the dispatch zone is zero for that station.

The SRDM explicitly considers the dispatch zone assigned any given station as a variable in the resource deployment problem. To do so, the region is divided into 30' by 30' rectangles (about 793 square miles each). Each rectangle is assigned to the dispatch zone of some station at each run of the SDRM. The set of rectangles assigned to a station on any given run is the dispatch zone for that station during the planning period.

Linear programming models can be disconcertingly cunning in finding least cost solutions. In particular if the model can defer meeting a demand for the planning period(s) considered in a given run, it will do so without consideration of the greater costs incurred in later runs.

The carry-over variables are included in the model to avoid this problem. Thus, the unfulfilled demand existing in the region at the end of the planning period(s) considered in one model run are tabulated and assigned a high cost. In this way, the SRDM is forced to consider residual demand left for subsequent model runs.

The SRDM - Objectives:

The objective of the SRDM is to allocate the various types of equipment to the various stations so as to provide the desired level of protection at a minimum expected cost. The objective function is the formula which keeps track of the costs during a given run of the model. Specification of the objective function requires that the costs associated with each model variable be known.

As a general rule, we are concerned only with the incremental costs incurred when a unit of a variable is used on a fire or is moved in anticipation of a fire. Those costs which would be incurred in any case (e.g., unit crew salaries) are significant from a budgeting standpoint but are not significant factors in the allocation problem.

Transfer costs are a direct function of the mode of transport and the round trip distance of the transfer (assuming that transferred equipment is normally returned to its home base). Such costs are estimated from the hourly operating costs of the vehicles involved, the travel rate of the vehicles, and the transfer distances. There is little problem in obtaining this information.

Status costs are interpreted as the opportunity cost of labor lost as a result of placing the unit crew on standby. Field studies will be necessary to determine the exact magnitude of this cost; it has been arbitrarily set at 10% of crew wages for trial runs of the SRDM. Field studies should be undertaken only if sensitivity evaluation of the SRDM indicates that these costs are a significant factor in resource deployment.

There are no direct costs associated with changing the boundaries of a station dispatch zone. However, if dispatch zone changes are precluded by agency policies, arbitrarily large costs could be assigned this variable in the general SRDM. Such arbitrarily large costs would prohibit use of the dispatch zone variable in any model solution.

Carry-over costs are arbitrarily set at a high level to prevent the SRDM from "putting off the whole fire management problem until tomorrow". Provided these costs accomplish this purpose, their exact magnitude is of little interest.

The SRDM - Constraints:

The SRDM must solve the resource deployment problem subject to a variety of constraints or limits which define permissable courses of action. There are two types of constraints in the model: 1) supply constraints, and 2) constraints on the demand for resource use.

Supply constraints are included in the SRDM for technical reasons and, in general, present no major data problems. For example, the total number of aircraft used by the SRDM must not exceed the number of aircraft available to the region for the planning period. The data required for such constraints are simply a description of the physical resources available to the subsystem.

The purpose of demand constraints is to specify how much suppression equipment is required to supply the demand expected in the region. Definition of these constraints poses major data problems.

The assumption of equipment interchangeability inherent in the SRDM presupposes that the relative productivity rates of the various equipment types are known. It also presupposes a common unit of measure for productivity. Neither presupposition is met at the present time.

Lindquist and others have used a square foot of fireline cleared to mineral soil as a measure of equipment productivity (Lindquist, 1969). This measure is intuitively appealing but presents certain problems in connection with airtankers, water bombers, and hose

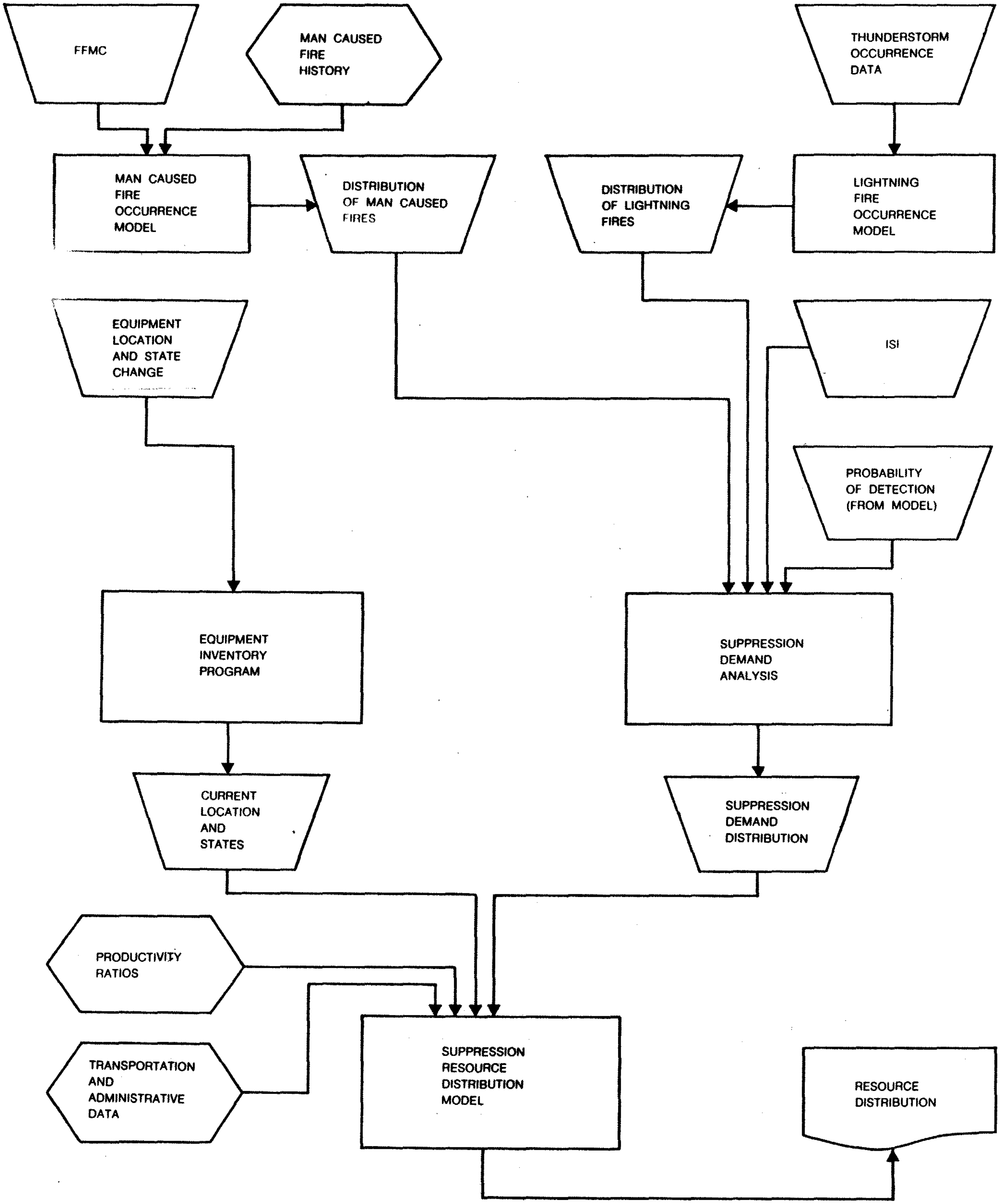

FIGURE 10 **SURROGATE SUPPRESSION RESOURCE DEPLOYMENT MODEL**

crews. Further research, probably in the area of "equivalent lottery" games, will be necessary to define the ratios between a square foot of fireline cleared to mineral soil and a square foot of fireline treated with chemicals or water.

A more substantial problem is that of relative equipment productivity rates. It is necessary to know how many units of one resource type are required to do the same job as a single unit of another type under various environmental conditions in order that the SRDM can mix equipment types to obtain an efficient solution. Productivity ratios have been obtained for limited sets of equipment types (Maloney, 1972b; Simard and Forster, 1972) but the general problem remains. Recent tests of a gaming technique have, however, indicated that initial estimates of the required data can be obtained from the subjective expertise of experienced fire management personnel. Subsequently, more conventional research can be used to refine the initial figures, if necessary.

Further research into the question of demand for resource use will also be necessary. The initial SRDM will be a surrogate model basing the demand for resource use on the relative number of fires expected during the planning period. As in the case of the detection model, later versions of the SRDM will use more sophisticated demand measures as these are developed and justified through future investigation.

Summary - The Suppression Subsystem:

The general structure of a prototype SRDM which has been developed and applied to hypothetical data at the FFRI is shown in Figure 10, following. As indicated by our prior discussion, information regarding equipment location and status is used, through an equipment inventory program, to generate supply constraints in the SRDM. Simultaneously, demand constraints are generated by an analysis similar to that made for the detection model. Productivity ratios and transfer cost data are used to establish, respectively, possible resource mixes in the final solution and the cost of attaining that solution.

The steps involved in converting the surrogate SRDM into an efficiency model and then into an economic model are similar to those involved in the detection subsystem analysis. First, alternative demand measures will be investigated and incorporated into the SRDM, if necessary. Second, the subsystem output measure will be defined and quantified insofar as possible, and, in conjunction with data on fire spread/intensity rates, will be used to define a subsystem production function. The SRDM will then be converted into an efficiency model. Finally, land value data, possibly already in use in the demand measure, will be used to convert the SRDM into an economic model. As in the case of fire detection, the suppression subsystem will likely depend on a surrogate model for some time to come.

In these latter two chapters, we have outlined certain model forms and data elements involved in the detection and suppression subsystems of the initial FMC. In the process, several data elements have been shown to be common to both subsystems and a general research framework has evolved. In the next section of this report, the organizational and research implications of that framework, and the framework itself, are explicitly discussed.

V. SUMMARY AND ORGANIZATIONAL SUGGESTIONS

General Summary:

Certain aspects of forest fire management, viewed as a system, have been reviewed in this paper. Emphasis has been placed on the initial research effort necessary to establish a relationship between active fire managers and advanced computer algorithims. In addition, we have examined the characteristics of the two major fire management subsystems -- fire detection and fire suppression -- in some detail.

The fire management system consists of the natural fire environment, the fire control organization, the management decision unit, and the fire management centre. All of these subsystem components exist, in one form or another, in operating fire management agencies. The main thrust of research into the system, as outlined in this paper, is to develop the models and data bases necessary to integrate computers and advanced data - handling techniques into the current system.

The fire management centre -- an organized grouping of peripheral devices, computer programs, and data -- is the means by which greater computational power is to be integrated into the system. Two major points emerge from our preliminary analysis of this centre. First, because of the complexity and newness of many of the tools involved in the centre, it should be developed in stages, with each successive stage dependent on prior work but improving the performance of the centre in accomplishing desired objectives. Second, because of the many unknowns regarding the centre, a prototype centre should be developed to serve as both a test unit and as a demonstrator of the concept to potential users.

Analysis of a system usually begins with a definition of analytical and system objectives. In our case, however, it was necessary to first determine if the analytical concept was possible, given current technology. The developmental work described in sections three and four of this paper has clearly shown the feasibility of the centre concept as well as providing useful models for inclusion in the prototype centre.

The prototype fire management centre will be capable of suggesting solutions to intermediate - range decision problems -- that is, problems involving the manner in which the system is structured to meet expected load levels during relatively short parts of the fire season. Related models dealing with shorter-range problems (for example, the dispatch of equipment from a single station to multiple fires) may also be developed in conjunction with the centre. In addition, the models involved in the centre may be manipulated to provide data for longer-range decisions, such as the distribution of the fire suppression budget among subsystems. However, the main emphasis in the initial centre will be on solving intermediate-range problems.

The detection and resource deployment models used in the initial fire management centre will be surrogate models -- that is, they will use an indicator of fire suppression output. As further research makes direct measurement of output and values possible, the initial surrogate models will be converted into efficiency models (which

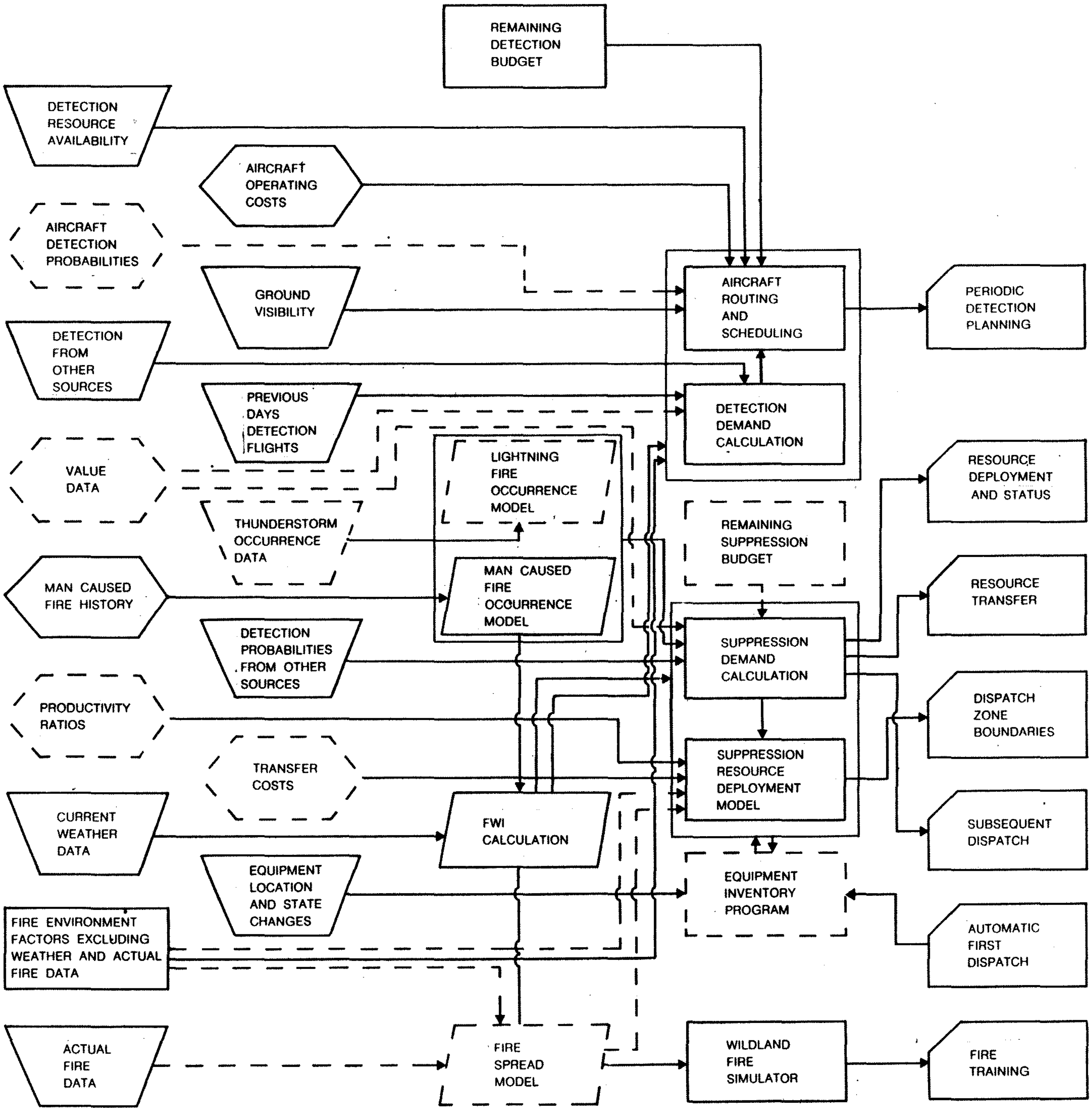

FIGURE 11 **INITIAL FIRE MANAGEMENT CENTER**

maximize output obtained per unit of cost incurred) and into full economic models.

The major data elements, models, and outputs of the fire management centre are shown in Figure 11, following. Elements which are known, although in prototype form, are enclosed in solid boxes; those which must be developed are in dashed boxes. Each arrow in the diagram represents a relationship to be defined; again, dashed arrows indicate work to be done.

The complex relationships shown in Figure 11 are summarized by categories in Figure 12, following. From this diagram, the task of initial establishment and implementation of a fire management centre can be seen to consist of three major parts -- establishment of a data base, development of the predictive and data-handling models required, and development of the allocation and training models required.

There are five substantive and interrelated questions to be answered in connection with the fire management centre. These are: 1) what is the appropriate range of data necessary to allow sufficiently accurate predictions and resource allocations to be made? 2) what consistent, central storage format can be used to make the data available to all interested parties? 3) what is the actual method by which the data can be gathered and stored? 4) what analytical techniques and models are to be developed and applied, and 5) what organizational structure will facilitate inter-institutional cooperation in seeking answers to the first four questions?

Although much work remains to be done, the analysis presented in this paper indicates that the majority of the initial development work and feasibility testing necessary for the fire management centre is well under way. Consequently, the question of an appropriate organizational structure for the Project assumes primary importance.

Organizational Considerations:

An inter-establishment Project entitled "Development of Complex Fire Management Systems" was established as a formal project of the Canadian Forestry Service on March 26, 1973. One of the initial Project goals was to suggest an organizational structure which would facilitate cooperation between institutions involved, and which would ensure coordination of related research efforts undertaken at various institutions. Although the test area selected for initial application is in Northwestern Ontario, the organizational planning has proceeded under the assumption that institutions throughout Canada would ultimately be involved.

The primary motive of the Project is to provide information and models which are useful to the Provincial management decision units. Implementation of this objective requires that Project studies be carried through a coordinated developmental process from initial feasibility testing to final field application. This latter consideration, in turn, has three organizational implications. First, the Provincial agencies, which are the user institutions in this instance, must be involved in the planning of Project studies at an early stage. Second, since the range of sequential objectives involved in each study is so broad, the Project organization must be sufficiently flexible to allow specific responsibility to shift from one institution

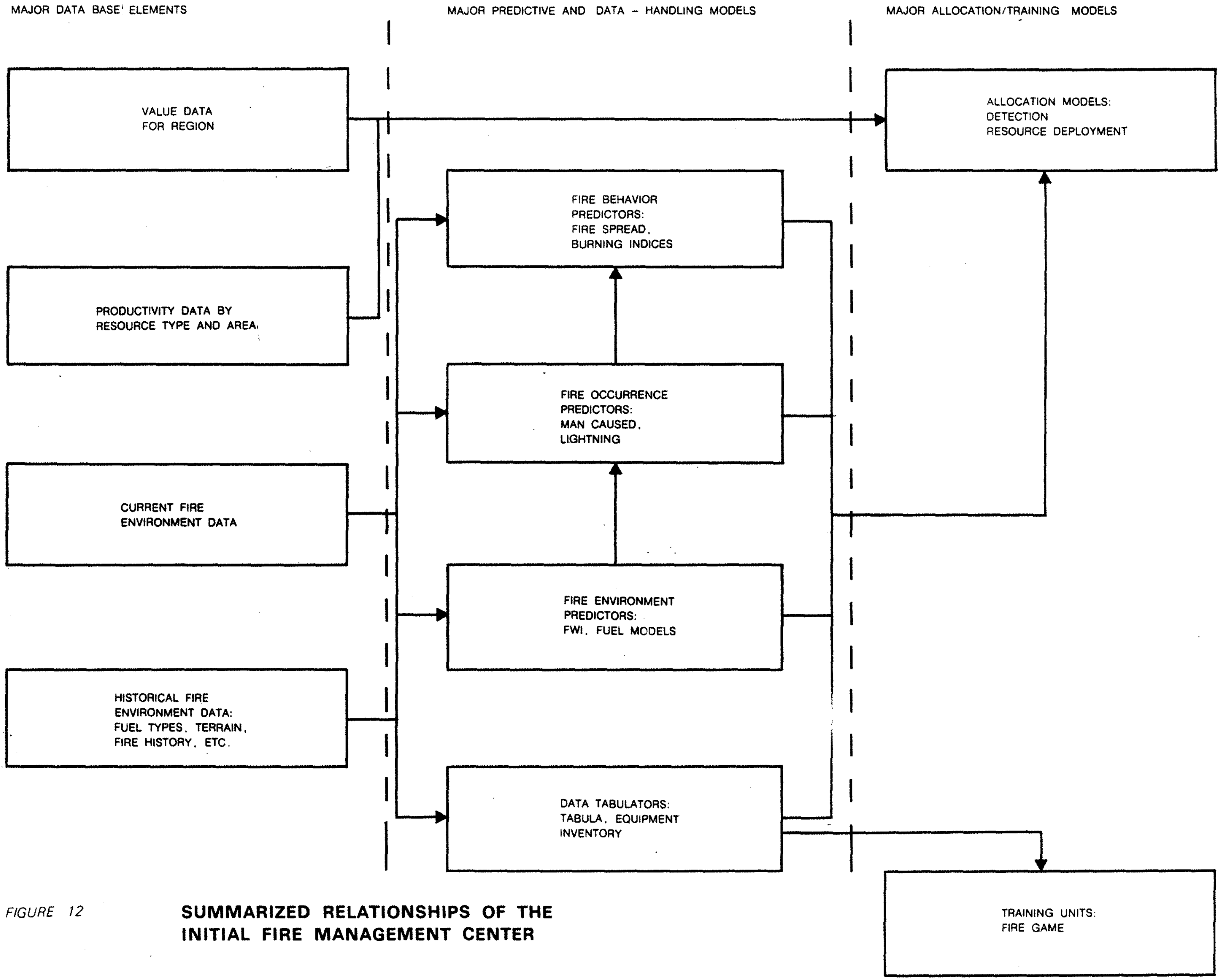

FIGURE 12 **SUMMARIZED RELATIONSHIPS OF THE INITIAL FIRE MANAGEMENT CENTER**

to another as the study progresses. Third, since the inter-study relationships to be coordinated are quite complex, the Project organization should include explicit coordinating bodies with the responsibility of establishing compatible study objectives and criteria as well as with the more usual responsibility of facilitating data exchanges.

The most immediate organizational concerns faced by the Project are those involving the major institutions -- the FFRI, the several Federal Research Centres, and the Provincial Forestry Agencies. There are three points of contact between these institutions. First, broad Project priorities must be established regarding specific study areas. Second, the detailed terms of reference for specific studies, including criteria for evaluation and means of implementation, must be defined. Third, the actual work necessary to complete a specific study must be accomplished and the study results must be integrated into the system. Each point of contact requires a different level of expertise and should involve a different contact mechanism, with overlapping memberships used to insure coordination between different contact points.

On a general level, the Project has three major functions. These are: 1) development of data bases and models necessary to the FMC, 2) creation of a central repository to facilitate exchanges of knowledge, and 3) provision of means by which application of FMC elements can be promoted. Consideration of these functions, plus the multiple contact points and the inter-institutional nature of the Project, has led to the line and staff organization shown in Figure 13, following. The composition and responsibilities of each of the organization components are outlined below.

1. Senior Advisory Committee:

    A. Composition: Senior Representatives from Regional Centres and Provinces which are actively involved in the Project, Project Leader.

    B. Function: Reviews overall Project progress, establishes Project priorities for general study areas, defines Regional and Provincial commitments, including designated personnel, for the coming period.

    C. Frequency of meeting: Annual.

2. Specifications Committees:

    A. Composition: Project Leader, functioning researchers and field personnel from the institutions as designated for specific studies by the Senior Advisory Committee, Central Repository Manager.

    B. Function: Initially, to define the scope, objectives, procedure, and implementation schedules for specific project studies and to establish specifications for documentation of data and models which will arise from the study to insure compatibility with other studies. May initiate study proposals.

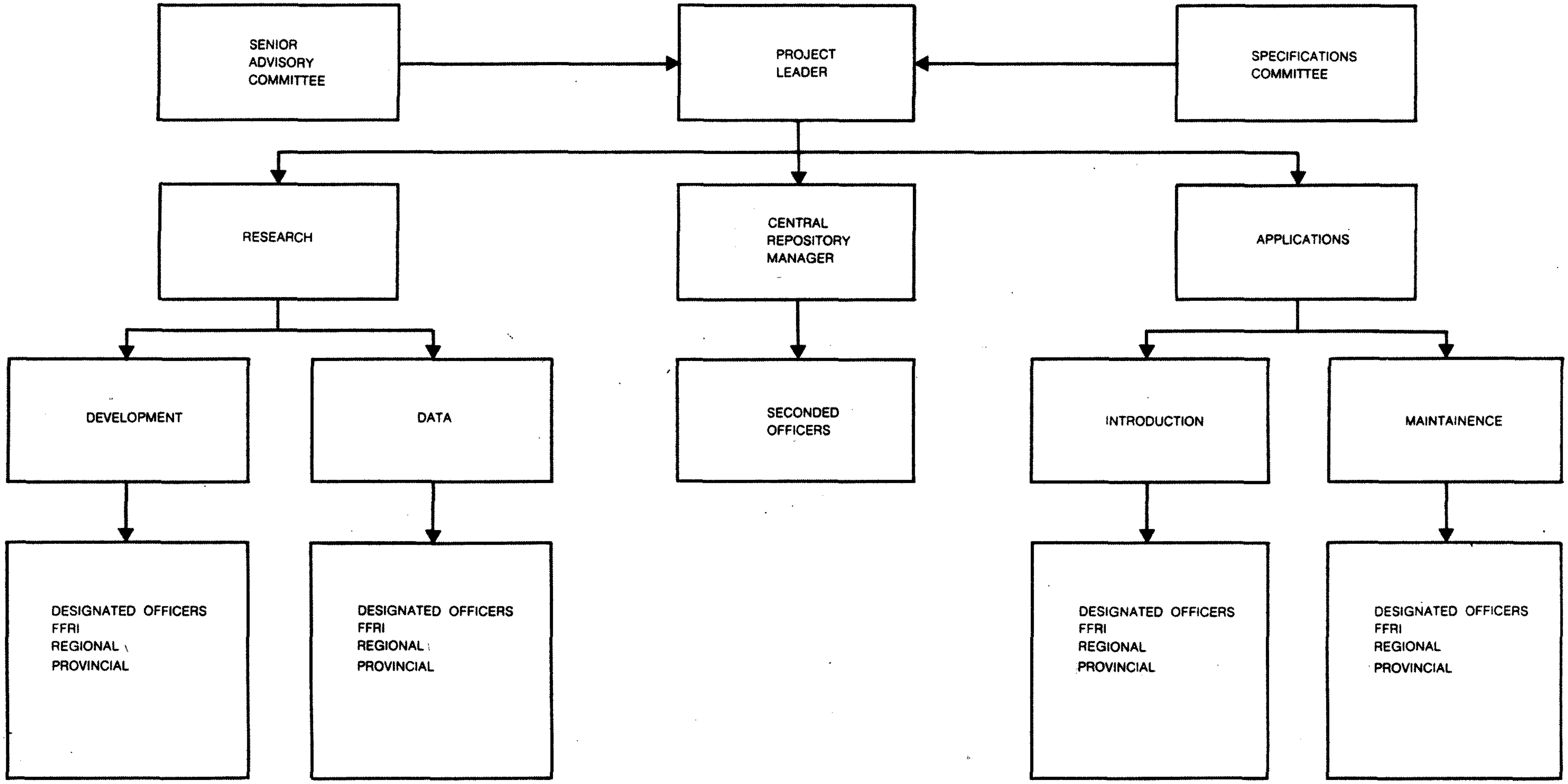

FIGURE 13 **SUGGESTED ORGANIZATIONAL STRUCTURE OF THE FIRE MANAGEMENT PROJECT**

C. Other Comments: A separate Specifications Committee is established for each major Project study and holds overall responsibility for that study. The committee disbands upon completion or termination of the study.

D. Frequency of Meeting: Variable. Quite frequent during initial phase of study definition, tapering off as basic study criteria are established and responsibility for study implementation shifts to designated officers.

3. Project Leader:

A. Composition: Individual designated by Canadian Forestry Service.

B. Function: Chief scientific officer of project. Manages both Research and Applications sections of Project. Acts as designated study officer when appropriate. Schedules Specifications Committee meetings as indicated. Overall Project coordinator.

4. Designated Researchers:

A. Composition: Research personnel from all institutions as designated by the Specifications Committee with the consent of the personnel involved and within the guidelines established by the Senior Advisory Committee.

B. Function: Participate in specification of parameters for the study to which they are designated. Act as study officers during research and development phase of specific studies. Act as consultants during application phase of specific studies. Responsible to Project Leader in Project matters.

5. Designated Applications Personnel:

A. Composition: Operational personnel from all institutions. Designated in the same manner as research personnel.

B. Function: Participate in specifications of parameters for the study to which they are designated. Act as consultants during research and development phase of specific studies and as study officers during the applications phase. Responsible to Project Leader in Project matters.

6. Seconded Officers:

A. Composition: Drawn from Designated Research or Applications Personnel upon completion of specific study phases.

B. Function: With technical assistance, enters study results into the Central Repository. Studies

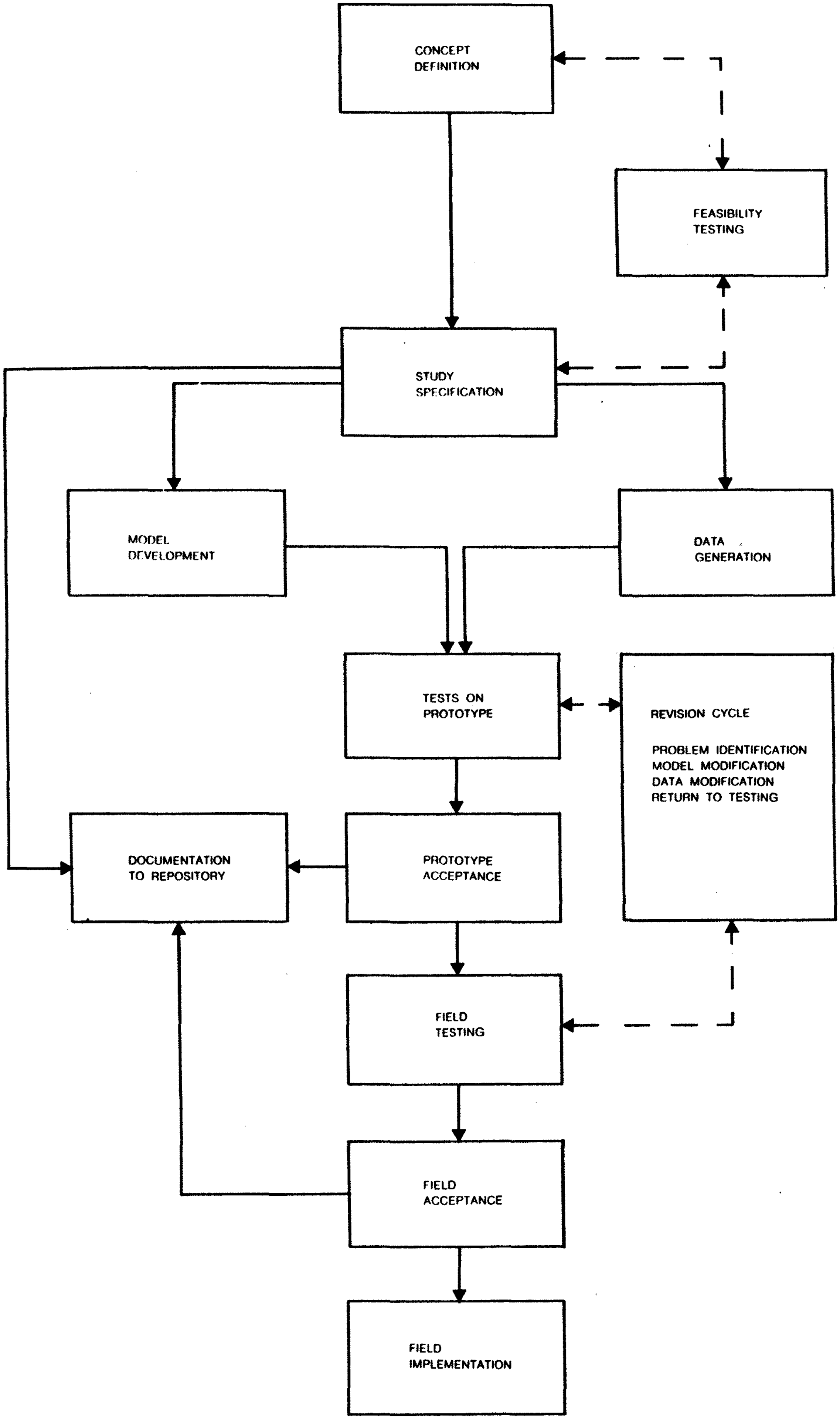

FIGURE 14 **GENERAL PHASES IN A MAJOR FMC PROJECT STUDY**

material already in Repository for familiarity. Acts as liaison officer to Regions or Provinces after completion of secondment.

7. Manager-Central Repository:

   A. Composition: Individual designated by Project Leader and Canadian Forestry Service.

   B. Function: Assists in definition of study specifications and documentations standards. Coordinates acquisition of Central Repository materials. Provides technical assistance and training for seconded officers. Assures dissemination of available data and models to interested parties.

The organizational structure outlined above is designed to be used in coordination with a multi-phase study program. This program, shown in Figure 14, is outlined by phase, below.

1. Concept Definition: The Senior Advisory Committee defines an area requiring research and authorizes further investigation through the Project Leader.

2. If necessary, a limited feasibility study is initiated by the Project Leader. If the feasibility of the study is reasonably certain, this phase is skipped.

3. An initial Specifications Committee is assembled by the Project Leader. The initial committee designates necessary researchers and field personnel and, as a full committee, establishes the study parameters. These parameters include reporting specifications, criteria for model acceptance at the conclusion of all subsequent study phases, expected study returns and output samples, and criteria for re-examination of the study. A study officer (research) is designated. The specification committee provides initial documentation to the Central Repository.

4. Model development and data generation efforts, divided among institutions as defined by the Specifications Committee, are undertaken. The results of this phase are tested on the prototype FMC and, if performance criteria are met, the model is accepted for field testing. If the model is accepted, full documentation is provided to the Central Repository.

5. Direct study responsibility shifts to the Designated Applications Officer with the onset of the field testing phase. Again, criteria previously established by the Specifications Committee are used to determine the success or failure of the model and, if the field tests are successful, additional documentation is provided to the Central Repository.

6. If either the prototype or the field tests are unsuccessful, the study enters a revisions cycle in which

the problems are identified and the necessary modifications are made. Re-specification or termination of the study may be undertaken in this cycle. Successful completion of the cycle returns the model to the testing phase at which failure occurred.

7. Documentation at the level of prototype and field acceptance is provided by Designated Personnel seconded to the Central Repository.

8. The final phase, field implementation, is under the full control of the user agency with consultation provided, as requested, by the original study team or through the Central Repository.

The organizational structure outlined above is intended for use in major project studies. Relatively minor or very straightforward studies can be accomplished without activating all organizational units or study phases. However, it is important to note that the field testing and implementation phases will be necessary in each case.

Much work has already been done on the fire management system and the fire management centre in Canada and elsewhere. There is no reason to believe that functioning FMC's cannot be integrated into field operations within the near future. The concept provides a unique opportunity for cooperation between agencies on a broad front with real gains in fire management efficiency as the result.

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