COST/RESOURCE MODEL

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Abstract

The Cost/Resource Model is a simulation model intended for use in management decision-making. The model portrays the impact of proposed new business or changes in existing business on company resources including labor, equipment, facilities, material and money.

INTRODUCTION

A simulation model has been designed for use as a management tool in planning resource requirements and allocations. The model permits determination of the impact on a company of changes in existing contract schedules or product requirements, addition of new contracts to the company's business level, or cancellation of existing contracts.

When a request for a proposal is received, the estimated characteristics of the proposal are examined and its demands aggregated with the requirements of all contracts currently in house to determine what effect this new business will have on company resources. The model can also examine the effect of possible revisions to contracts or proposals currently in house. Individual contracts may be expanded, reduced, deleted, stretched, advanced or delayed. The model then determines the impact on company resources caused by any of these eventualities.

The model permits the forecasting of costs and resources for five years into the future for a medium-sized manufacturing division of a major aerospace company. The model is deterministic and is based on resource data that exists within the company. Considered in the model are all the resources necessary for company operation: labor, material, machines, facilities and money. Another factor considered is other direct costs which includes costs that may not be charged to any of the resources.

A vital aspect of the model is its quick-response capability. Anticipated turn-around time for the model is one day. The model is programmed in Fortran IV in the batch world. Design of the program is modular to permit ease in removing the influence of one or more resources. A given resource may also be isolated simply by zeroing out the inputs for all other resources. Outputs include: headcount per month by type of personnel, total headcount required per month, machine hours required by work center, shortages or surpluses of labor and machines, space requirements per month, resource costs and money requirements. Additional outputs are available as required.

The model was designed specifically for the El Segundo Manufacturing Division of the Hughes Aircraft Company, a manufacturer of complex electronic equipment, but its generality makes it applicable to other companies with a minimum of revision.

STATEMENT OF THE PROBLEM

Management in any company must make decisions affecting operations several years into the future. Some of these decisions concern whether or not to pursue new business opportunities; others concern expansion or contraction of resources such as facilities. To enable management to make these decisions most profitably, adequate information must be accessible concerning resource availability, resource demand and cost of operation.

Under rapidly changing environmental conditions, how is management to determine within a brief period how much manpower will be needed each month for the next five years, how much space these people will occupy, how much machine time will be required and how much money will be needed? How can management adequately ascertain the potential impact of possible new business on manpower, machines, facilities and money. Another problem management faces is revision of contracts currently in house. What would happen to the resource outlook if a contract were stretched out, deliverable items were added or deleted, or a contract were terminated?

Because of this type of question, Hughes El Segundo Manufacturing Division management requested that the tools of management science be used to analyze company operations and develop a model that would provide answers with a minimal lapse of time.

PURPOSE OF THE MODEL

The Cost/Resource Model calculates and portrays the impact of potential new contracts, changes in existing contracts, cancellation of an existing contract, or the effects of changes in resource parameters such as wage rates, holidays, capacity of machines and space, and interest rates. The purpose of the model is to permit management to ask "what if" questions and to see the simulated impact of its decisions so that this information can be incorporated into decision-making strategies.

Use of the model for planning purposes makes it essential that it have a quick-response capability. Anticipated turn-around time is one day or less. This means that answers can be obtained and new alternatives considered in the short time span characteristic of this type of decision-making.

DESCRIPTION OF THE MODEL

The Cost/Resource Model is a deterministic simulation model that forecasts resource requirements and costs by month for five years into the future based on projected resource demands.

The model first aggregates requirements of all contracts currently in house and outstanding proposals which are expected to be captured. A new request for proposal may then be selected for study of its potential impact. Its basic requirements are generated and the resulting demand for resources is superimposed upon the requirements of contracts and proposals currently in house.

Another function of the model is to determine what will happen to resource requirements if a contract or proposal currently in house is terminated or revised. Six options for revision are available: the delivery schedule of end items in one or more contracts may be slipped, advanced, reduced, expanded, deleted or stretched. Under the reduction option, a contract may be reduced by a specified percentage or certain end items may be deleted. In the same way, an expansion to a contract may be effected by adding a percentage or adding a specified number of end items. The effect on resources and costs of changes to parameters such as wage rates, capacity of machines or space, and interest rates may also be determined.

The results of these possible changes are shown in reports showing requirements for manpower, material, space, machines and money. Costs of operation are determined and displayed along with projected revenue and gross earnings. Other additional output options are available at the discretion of the modeler.

Structure of the model is modular to permit revision of the program for estimating one resource without affecting the other resources. A separate module exists for each of the resources: labor, material, machines, facilities and money. Another module is provided for a category of costs called "other direct costs" which are direct costs that cannot be applied to any resource. Separate modules are also provided for spreading the requirements of a new proposal and for revising existing contracts and proposals.

Characteristics of the model are shown in Figure 1. Inputs include requirements for a new proposal, revisions of existing contracts, and parameter changes. Other inputs are data for existing contracts and proposals which involve manpower, machine and material requirements. These requirements are input for each contract;

the model aggregates the requirements, following applicable revisions of the contracts, into total requirements per month.

Shown as circular forms in Figure 1 are the submodels for the resources. These submodels, or modules, summarize the requirements for the resource per month and the costs of the resources per month. Each of these submodels is a program which calls the revision program and the spread program as needed.

A flow diagram of the program relationships is shown in Figure 2. Activity originates in the main program which calls each of the submodels, or programs, in sequence. The first program called is the resource spread program which spreads the resource requirements for the new proposal under consideration. Control then returns to the main program and the first of the resource submodels is called, the material summary model, or program. This program in turn calls the revision program which alters the material requirements per month of a specified contract. For certain types of revisions, it is necessary for the revision program to call the resource spread program to attain the desired revision of resources. Following revision and aggregation of the resulting material requirements over all contracts, control is returned to the main program. Subsequently, each of the resource submodels is called in turn. Requirements for that resource are read from tape or a disk file, revisions are made as required, the resulting total resource requirements per month and resource costs per month are displayed and control is again returned to the main program. Following completion of all programs, the main program calculates total costs and displays gross earnings. Outputs of the model are shown in Figure 1 below the respective submodels.

Submodel Characteristics

Resource Spread Model: The first of the submodels accessed by the main program is the resource spread model, or program. The function of this submodel is to determine resource requirements of a new proposal or contract. This submodel takes as input the total lump-sum requirements for resources for the entire new proposal. It also takes as input the schedule for end item delivery, setback and makespan, the distribution according to which the work is to be spread (eg. according to a learning curve), and the performance factor as shown in Figure 3. The resource spread program spreads the requirements and outputs the direct labor requirements per bid category per month, work center (machine) hours required per month, other direct costs per month and material requirements per month for the new proposal. Output of the resource spread program is stored on disk files and becomes input to the resource submodels.

Material Summary Model: Second of the submodels accessed by the main program is the material summary model Figure 4. The function of this submodel is to determine the requirements (in dollars) for material per month.

Inputs to this model include the material requirements per month for each existing contract and proposal. Also input to this submodel are the monthly material requirements for the new proposal which are an output of the resource spread program. Another input to the model could be a parameter change or a contract revision requirement. The material summary model revises the specified program and aggregates material requirements per month over all contracts and proposals. It then calculates the material burden rate according to the following equation:

$$MBR=\frac{[\frac{a}{12}+\frac{.032}{12}(\text{mat'l req per mo})]x[1.0+\frac{.04}{12}]^{12y}}{\text{material required per month}}$$

where: MBR = material burden rate

a = minimum cost for the materiel function

y = number of years since the base year

Material burden rate is the ratio of the cost of acquiring material to the cost of the material itself. Material burden costs are then calculated as follows:

Procurement Costs = (A)(MBR) (Material required per month)

Receiving Inspection Costs = (B)(MBR) (Material required per month)

Receiving Costs = (C)(MBR)(Material required per month)

Finance Costs = (D)(MBR)(Material required per month)

where A, B, C, and D are distribution factors specified for the company.

These functional relationships were derived by conventional management science techniques. The material submodel then calculates the total costs per month for material and material burden and displays this output.

Other Direct Costs Summary Model: The next submodel, Figure 5, considers other direct costs (ODC), which includes those direct costs that cannot be charged to any of the resources. Inputs to the submodel are the ODC per month for the new proposal and the ODC for each existing contract and proposal. As in the material model, requirements for revision of contracts and parameter changes are input to the submodel. The submodel makes the required changes to the existing contracts or proposals and aggregates the ODC requirements per month over all contracts and proposals. This aggregate monthly value is then output to the computer printer.

Machine Summary Model: Machine requirements are considered in the next submodel, Figure 6. Again the inputs include the output of the resource spread submodel (machine requirements per work center per month for the new proposal), machine requirements per work center per month for each existing contract and proposal, and contract revision and parameter change requirements. The machine summary submodel makes the necessary revisions to existing contracts and proposals, then aggregates the machine requirements per work center per month over all contracts and proposals. The monthly requirements are compared with the machine time available (working hours in the month) to provide a statement of the surplus or shortage of machines per month by work center. Whenever a shortage of machine time occurs in a given month, it is necessary to "off load," or subcontract, that portion of the work that the shop cannot handle. The machine summary submodel determines whether subcontracting is required in any work centers for each month. It then determines the number of hours that must be subtracted from labor requirements for that month and calculates the cost of subcontracting. Subcontracting costs involve procurement, receiving inspection, receiving and finance costs similar to material burden costs and are calculated in the same manner as material burden costs. This submodel then takes as input the costs of new machines that it is anticipated will be purchased in each month and the costs of subcontracting that was planned in advance (as distinguished from "off loading"). New machine costs, planned subcontracting costs and "off loading" costs are then aggregated to provide machine costs per month over the five-year time span. Outputs from this model include machine requirements per work center per month, surplus or shortage per work center per month, and total machine costs per month.

Labor Summary Model: Next in the sequence of operation of the Cost/Resource Model is the labor summary submodel, Figure 7. Inputs to this submodel include the manpower requirements per month for the new proposal (output of the resource spread submodel), manpower requirements per month for each existing contract and proposal, and revision data. Manpower requirements are input to this submodel according to the type of personnel involved. The designators for types of labor are called "bid categories." The submodel revises the necessary contracts, then aggregates the manpower requirements (hours per bid category) over all contracts and proposals for each month in the five-year span.

Headcount for each bid category for each month is then obtained by dividing the hours required by the hours available in the month. This headcount is compared with the headcount currently available to determine projected shortage or surplus of manpower in each bid category for each month. Total direct labor requirements per month over all bid categories are then obtained. Next the submodel determines the indirect labor headcount required by the following equation:

$$\text{Indirect labor headcount} = A + C_1(DLH) - C_2(DLH)^2$$

where: DLH = direct labor headcount

A = indirect labor headcount with zero direct labor headcount

C_1 & C_2 are empirical constants

Indirect labor includes all personnel who are not charging their time directly to a contract. The submodel then adds the direct labor headcount and indirect labor headcount to obtain total headcount per month. Total headcount, direct labor headcount per bid category and shortage or surplus of labor by bid category are printed out by the submodel for each month of the five-year span.

Labor burden costs are then calculated by this submodel. Equations for labor burden costs have been derived through regression analysis on historical data. Included in labor burden are indirect labor costs, fringe benefits, utilities, operating costs other than those charged directly to the contracts, indirect data processing, depreciation, taxes and insurance, rent and leasehold costs, and plant upgrade.

Costs for direct labor per month are then calculated by multiplying the direct labor hours in each bid category by the anticipated average wage rate for that month for that bid category. Total labor costs per month are then obtained by adding direct labor costs and indirect labor costs. An estimated labor burden rate for each month of the five-year time span is calculated by dividing labor burden costs by direct labor costs. This estimated labor burden rate is printed out by the submodel. Other outputs are the components of labor burden, total labor burden and total labor costs for each month.

Facilities Summary Model: The facilities summary submodel is the next program in the sequence. This model takes as input the direct labor headcount per bid category per month and indirect labor headcount per month from the labor summary model as shown in Figure 8. Space requirements per person for each category are input to the model and are multiplied by the appropriate headcount to determine total space requirements per category. A shift factor is included in this calculation to account for the number of people working on the night shifts. These people would occupy the same space occupied by the day shift personnel; consequently, no space is allocated for the second and third shift people.

These space requirements are then aggregated and added to special space requirements, which are input to the model, to obtain total space requirements per month. These requirements are then compared with the anticipated space available, also an input to the model, to determine the shortage or surplus of space for each month over the five-year time span. The submodel then outputs space required for each category per month, total space requirements per month and the shortage or surplus of space over the five-year time span.

Parking space requirements are also calculated by the facilities submodel. The direct labor headcount is modified by the shift factor and then added to the indirect labor headcount. This sum is then divided by a "car pool" factor of 1.2 that accounts for the average number of people riding to work in one car to give the number of parking spaces required per month. This figure is printed out by the model and is compared with the parking spaces available for each month to determine the shortage or surplus of parking spaces.

Another input to the model is planned capital expenditures for new plant for each month of the future five years. These expenditure figures are the facility costs for the time span under consideration and are used in the money summary submodel to calculate total costs.

Money Summary Model: The money summary submodel is the last of the modules in the Cost/Resource Model. Inputs to this submodel are the outputs from the other submodels: the costs per month of labor, machines, material, facilities, and ODC. Labor costs are reduced by the amount of depreciation. This submodel aggregates these costs per month to obtain the net money requirements per month. Revenue per month for the new proposal and for each existing contract and proposal is the input to the submodel. These revenues are summed and compared with the net money requirements to determine whether money must be borrowed each month. The money borrowed is multiplied by the current prime interest rate to determine the cost of money for each month. This cost is added to the net money requirements to obtain the total money requirements per month. Money borrowed, cost of money borrowed and total money requirements per month are printed out by the submodel. The submodel then aggregates over all months in the five-year timespan money requirements and total revenue per month for all contracts. Total money requirements and total revenue for the entire period are then transferred to the main program.

In the main program, depreciation is added to money requirements to obtain total costs. The total costs and total revenue are then compared to obtain gross earnings over the time span under consideration. Total costs and gross earnings are then printed out by the model. These values enable management to compare probable earnings figures for different combinations of contracts and proposals. If the goal is to find the roster of contracts that will provide the greatest earnings, this figure is available from each run of the model with different contracts and proposals included in each run.

USE OF OUTPUTS OF THE MODEL

Predicted resource requirements generated by the model enable management to plan effectively for the future. If manpower available is at a high level at the present time, the model will indicate when a surplus of manpower will occur and the kinds of manpower involved. Generally, contracts in house phase out after a few years and valleys occur in resource requirements. Management must know where those valleys will fall so that new business may be obtained to take up the slack. This model will provide management with this information.

On the other hand, the company may have a large backlog of business with an expected shortage of resources. A request for proposal may come in and management must know whether to bid on it or not. It is important to know over what time span the proposed business would demand resources. If it comes at the peak period, it would be most politic not to submit a bid since the company could not show a capability for performing. It is also necessary for management to know when to start enlarging the work force to accommodate the peak work load. Or, it may be desirable to work overtime for a period rather than to staff up and a few months later have to lay off. It is essential to know how large the gap is between requirements and resource availability to determine whether overtime in lieu of adding workers is feasible.

Space requirements are another important factor in management planning. Will we be short of space for a certain peak period? Will we need to expand space for the long run? Can we change the shift factor and increase the sizes of the night shifts to effect better utilization of space? Management must know when peaks occur, what the trend of space requirements over the long run will be, and when valleys in space utilization occur so as to plan efficiently for adding facilities, planning additional leasing of facilities, or phasing out presently held leaseholds.

The model will provide all of the information required for management to make these types of decisions. The Cost/Resource Model is an effective tool for management in planning resource allocations and determining the most profitable new business to be acquired.

The model also provides management with a view of what resource allocations would be if a contract currently in house were revised or terminated or if a proposal currently under consideration by a customer were slipped or advanced or changed in scope. Management must be able to react quickly under these circumstances to provide the customer with an estimate of the cost of the proposed revision.

Quick-response is one of the characteristics of the model. Most of the input data are stored on disk files and updated quarterly through the time-sharing terminal. Manpower data are stored on tape which is updated quarterly. Input data which must be prepared at the time the model is run involve requirements for a new proposal, revision requirements for an existing contract or proposal and requirements for planned subcontracting and new machines. Two files are involved with this data. One additional file must be revised when a new proposal or contract revision is under consideration: the revenue file. This state of preparedness and minimization of data preparation at model-run time provide the quick-turnaround time essential to management decision-making.

VEHICLE FOR THE MODEL

The Cost/Resource Model is programmed in Fortran for the batch world of the Honeywell 635 computer. Memory required for the program is 65K. An overlay technique is used to keep program size down as much as possible. Running time for the model is six hundreths of an hour, or three and a half minutes.

Fortran was chosen as the language for the model because the original intention was to operate the model in the timesharing mode and none of the simulation languages were available at that time in the timesharing mode of the 635 computer.

Design, programming and testing of the model have required two years of one person's time. Approximation of the current level of Division activity has also been accomplished within that two-year time span.

DATA COLLECTION

Data for the model were intended to come from sources already available within the company. A previously issued report which has been updated quarterly provides manpower data in the form of hours required per contract, per type of direct personnel, per month, per department, per phase in the contract (implementation, production or production support phases). This report is on tape. Material requirements are obtained from a currently produced report which provides information in the form of material dollars per month per contract for a two-year time span. This report is not presently in a form suitable for direct input to the computer. It must also be extended to a five-year term.

Machine information is obtained from an eight-year forecast of machine requirements. It is anticipated that rather than updating this forecast, a new technique will be used of applying actual times to contract requirements. Space requirements have been analyzed to determine the amount of space occupied by each type of person. Areas not occupied by people, such as warehouses, are input as special space requirements. This information is currently available within the company.

Revenue per month from each of the contracts is obtained from the Finance Department. Other data than those specified here are obtained from various reports and manuals prepared by the company. Included are man/machine ratios, number of machines in each work center, average wage rate for each type of personnel, costs of new facilities per month and subcontracting rates.

Data are stored on tapes or disk files depending on their sources. Disk files are generated in the timesharing mode and are translated to BCD files through the Cardin system, which is the interface between timesharing and the batch world.

MODEL VALIDATION

The model will be validated by using actual data as inputs for a given month or series of months. Total actual requirements will be known for each resource for those months. It will then be possible to verify that the results obtained by the model correlate with the real world.

STATUS OF THE COST/RESOURCE MODEL

Design and programming of the Cost/Resource Model have been completed. All options of the model (with a new proposal, without a new proposal, with each of six revision options) have been tested successfully. One run has been made with partial real data. The model is now running and ready for implementation in a production mode. It is awaiting acquisition of the data necessary for production operation.

GLOSSARY

End Item - The deliverable equipment item specified in the contract

Make Span - The period of time required to manufacture the item

Set Back - The date on which production must begin (obtained by subtracting the makespan from the last end item delivery date)

Gallagher Distributions - A series of six distributions that represent experience in manufacturing effort over the makespan (derived by Paul Gallagher, Hughes Aircraft Company)

Selected Increment distributions - The makespan is divided into twenty equal increments, and the proportion of effort for each increment is specified

Turn-Around Time - The period from receipt of new proposal input data and contract revision information to submittal of resource reports to management

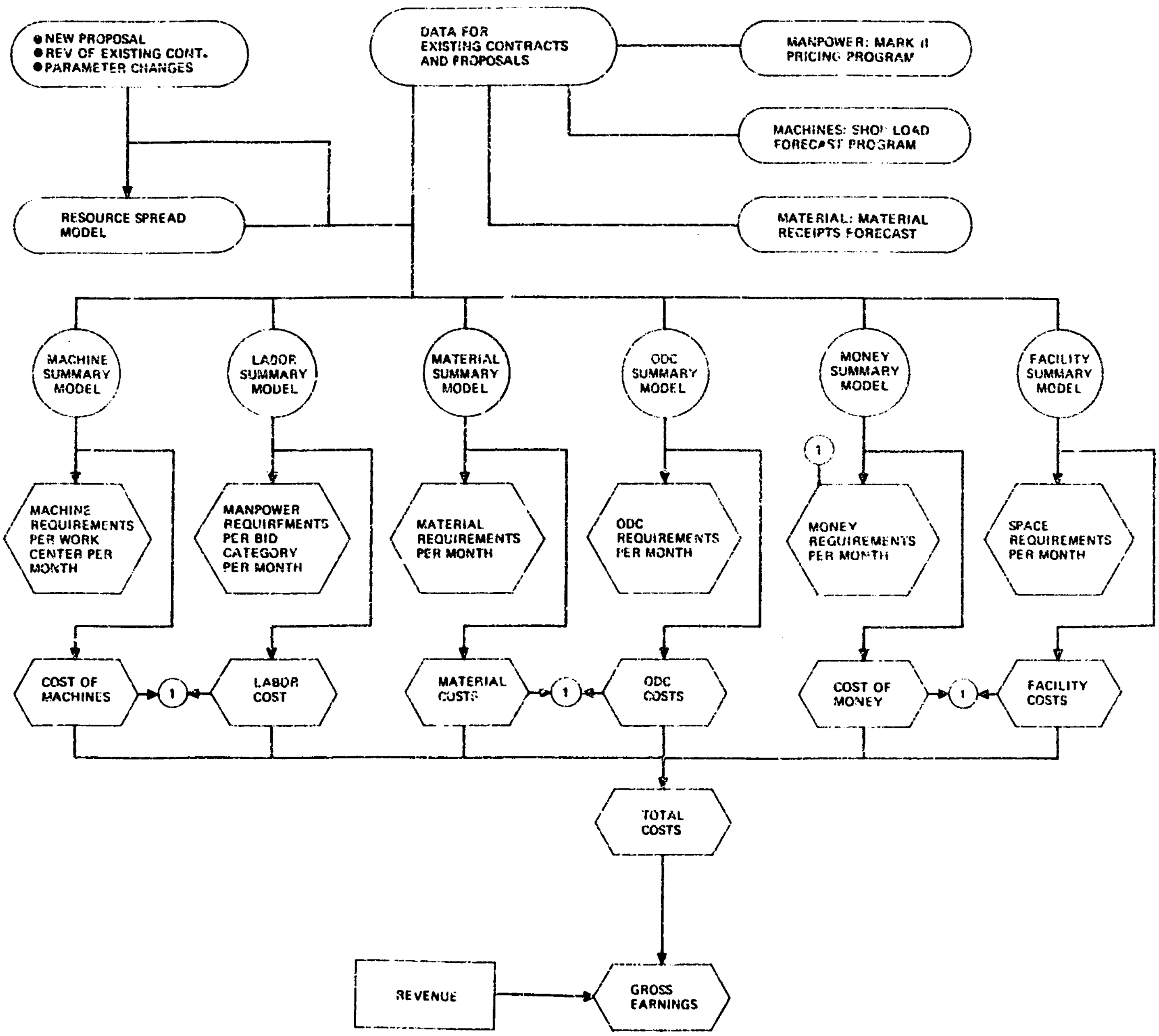

FIGURE 1. COST/RESOURCE MODEL

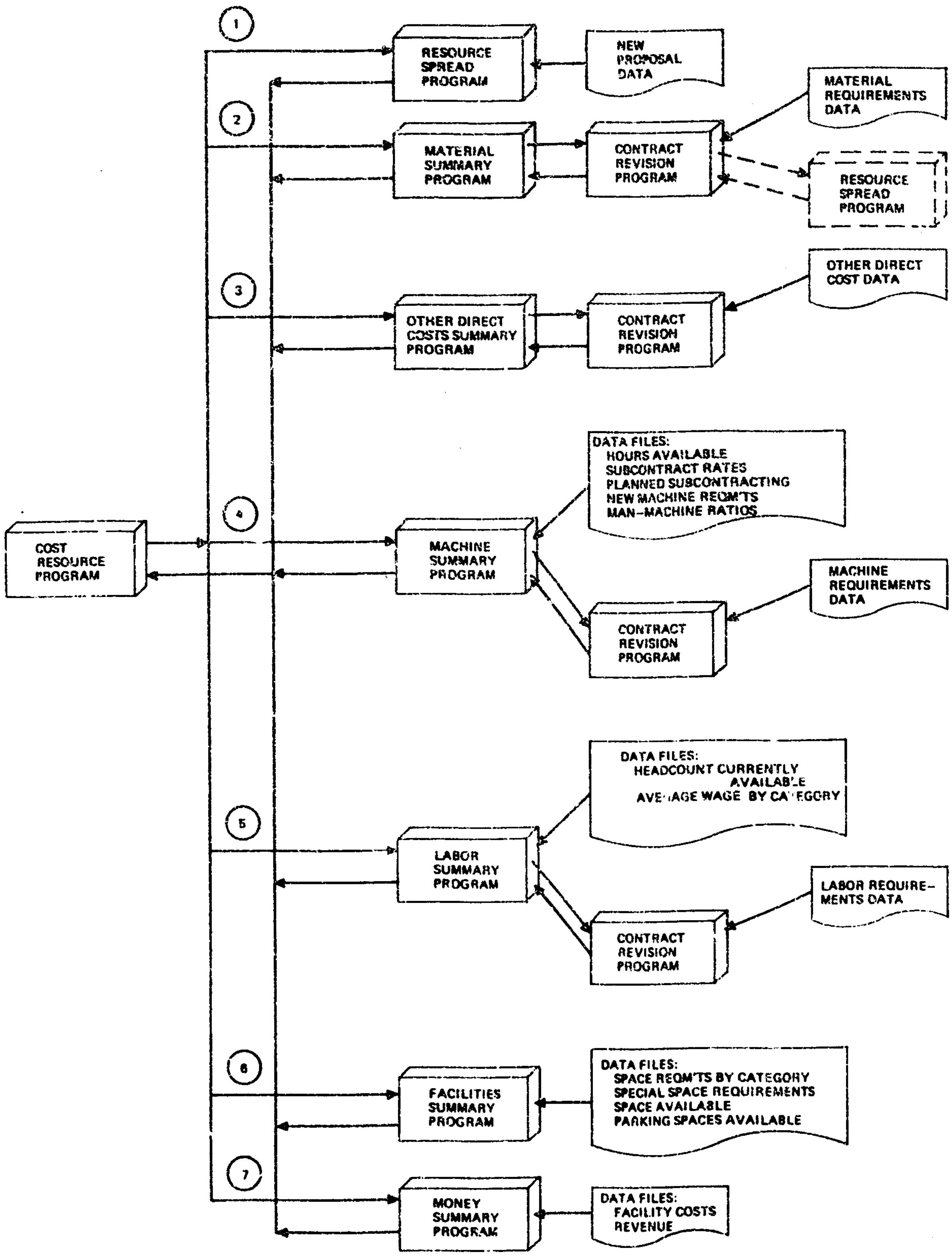

FIGURE 2. SEQUENTIAL FLOW DIAGRAM

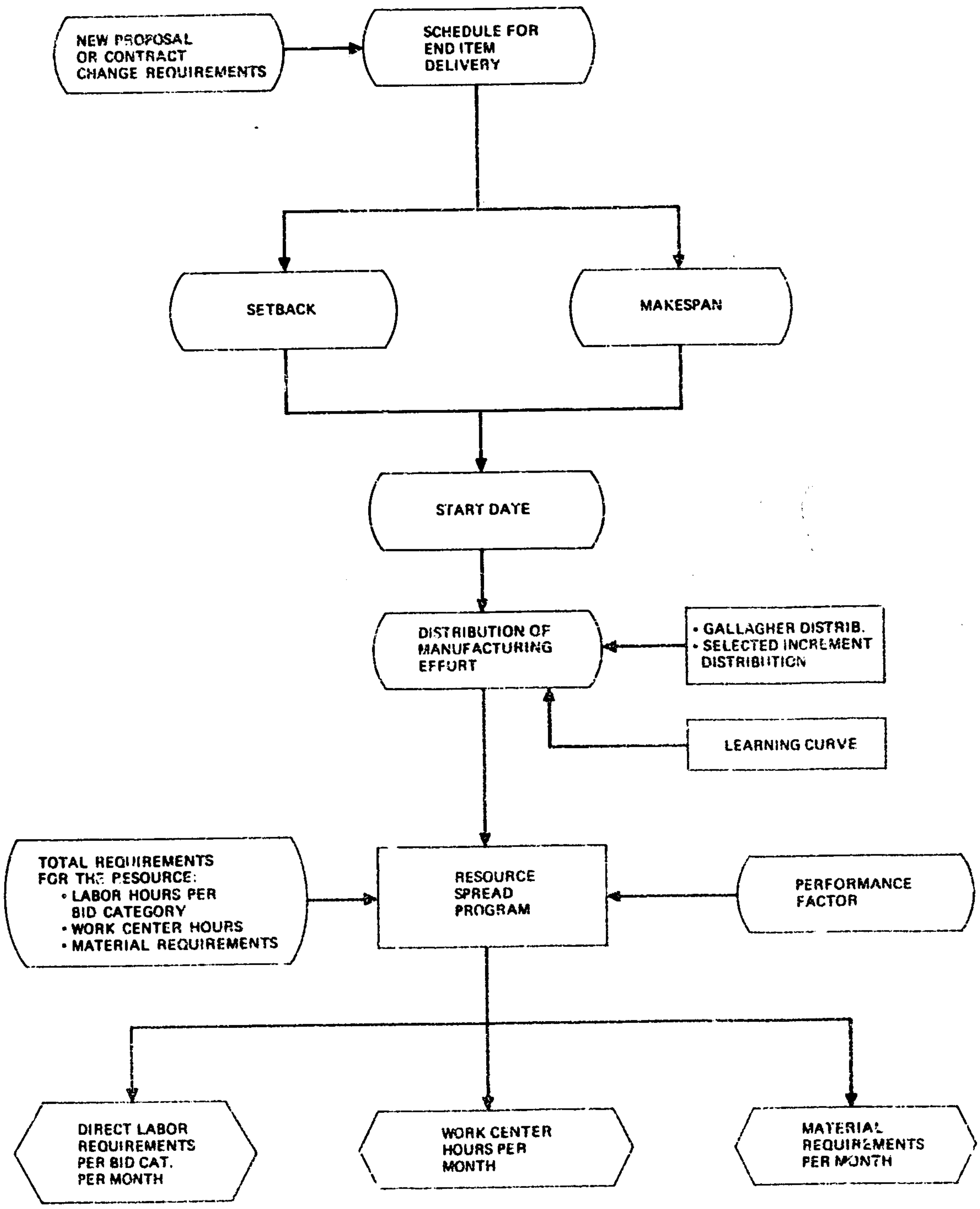

FIGURE 3. RESOURCE SPREAD MODEL

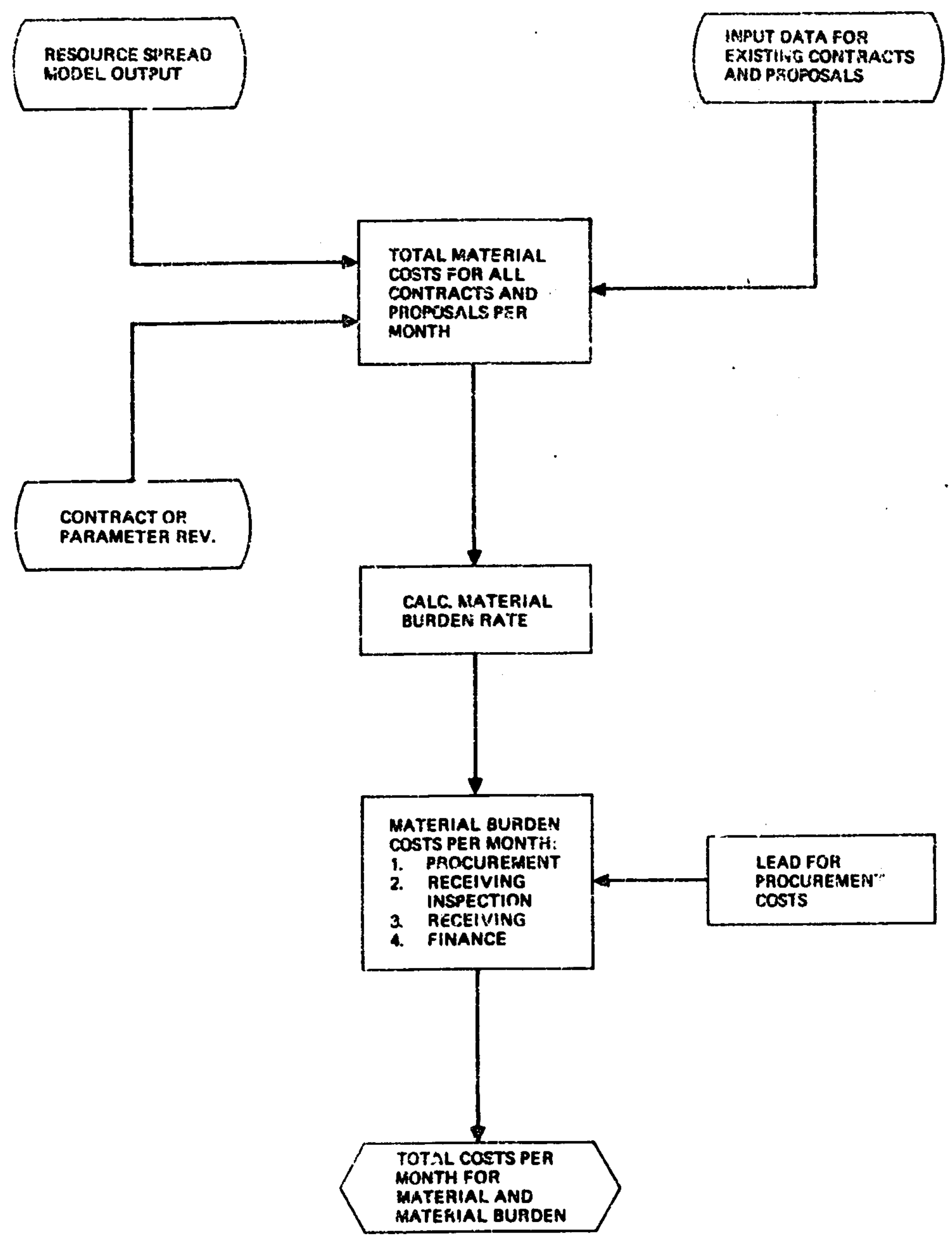

FIGURE 4. MATERIAL SUMMARY MODEL

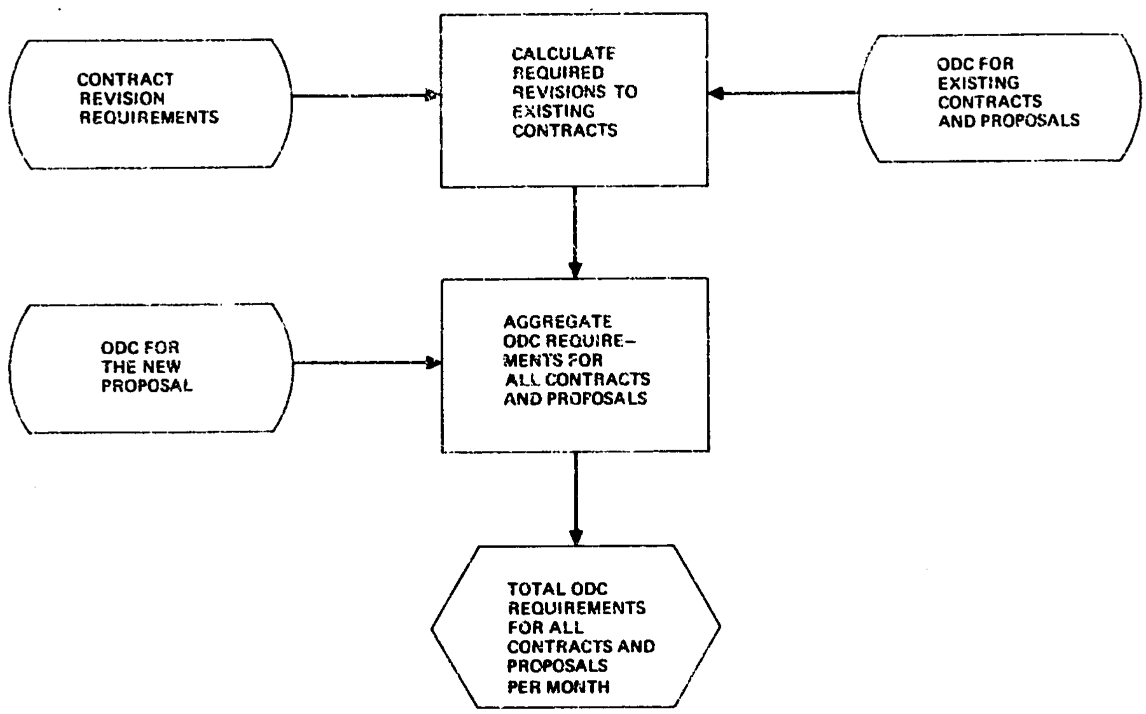

FIGURE 5. ODC (OTHER DIRECT COSTS) SUMMARY MODEL

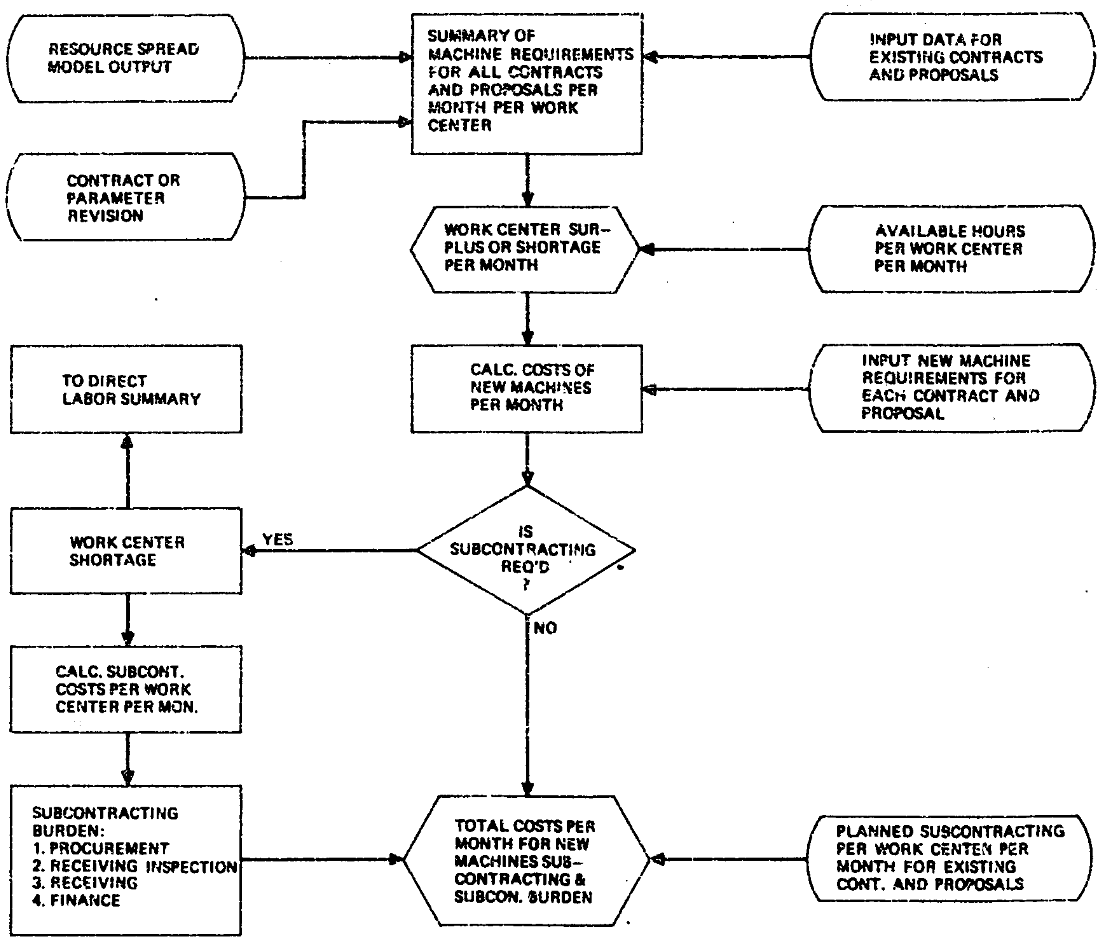

FIGURE 6. MACHINE SUMMARY MODEL

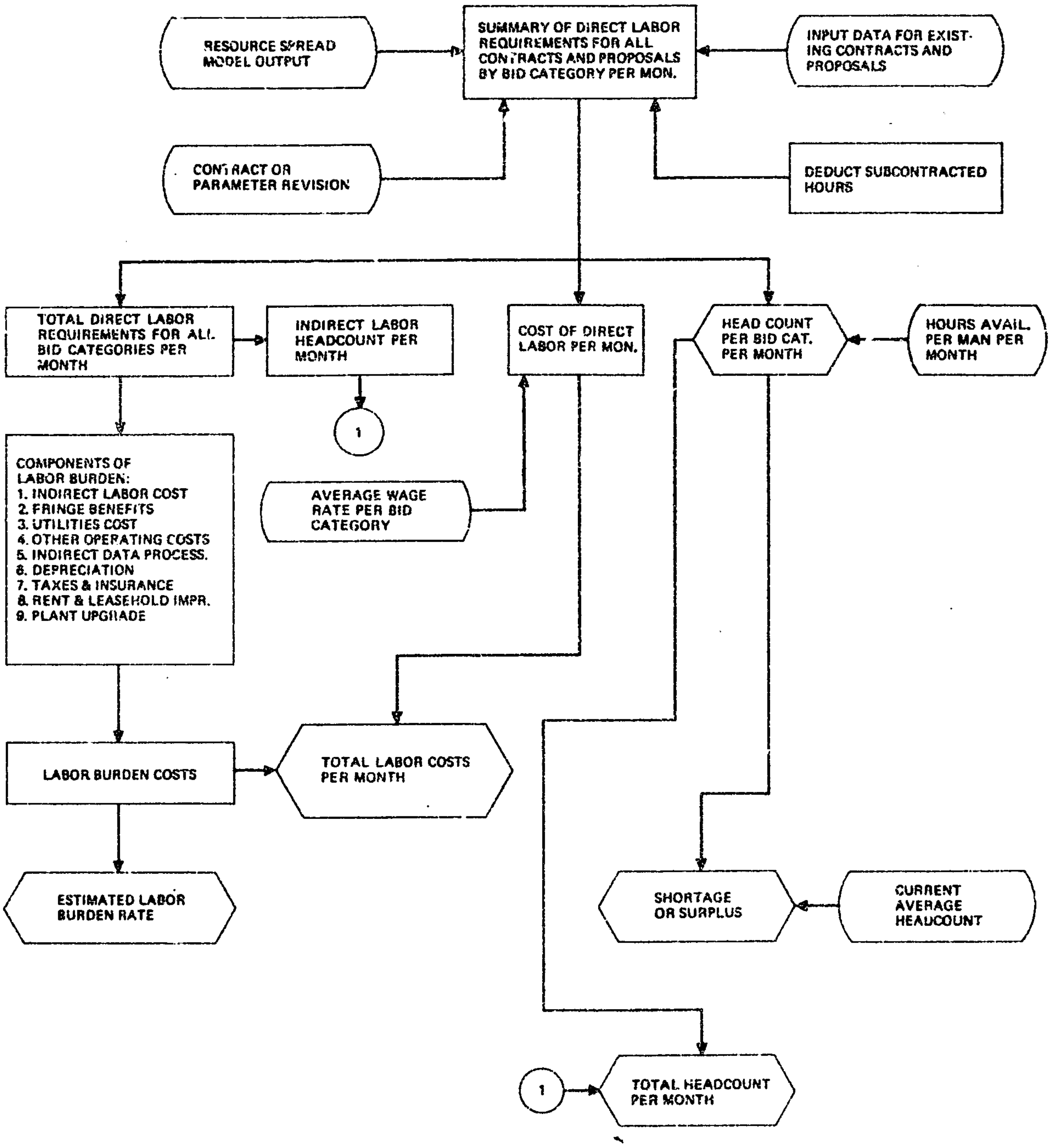

FIGURE 7. LABOR SUMMARY MODEL

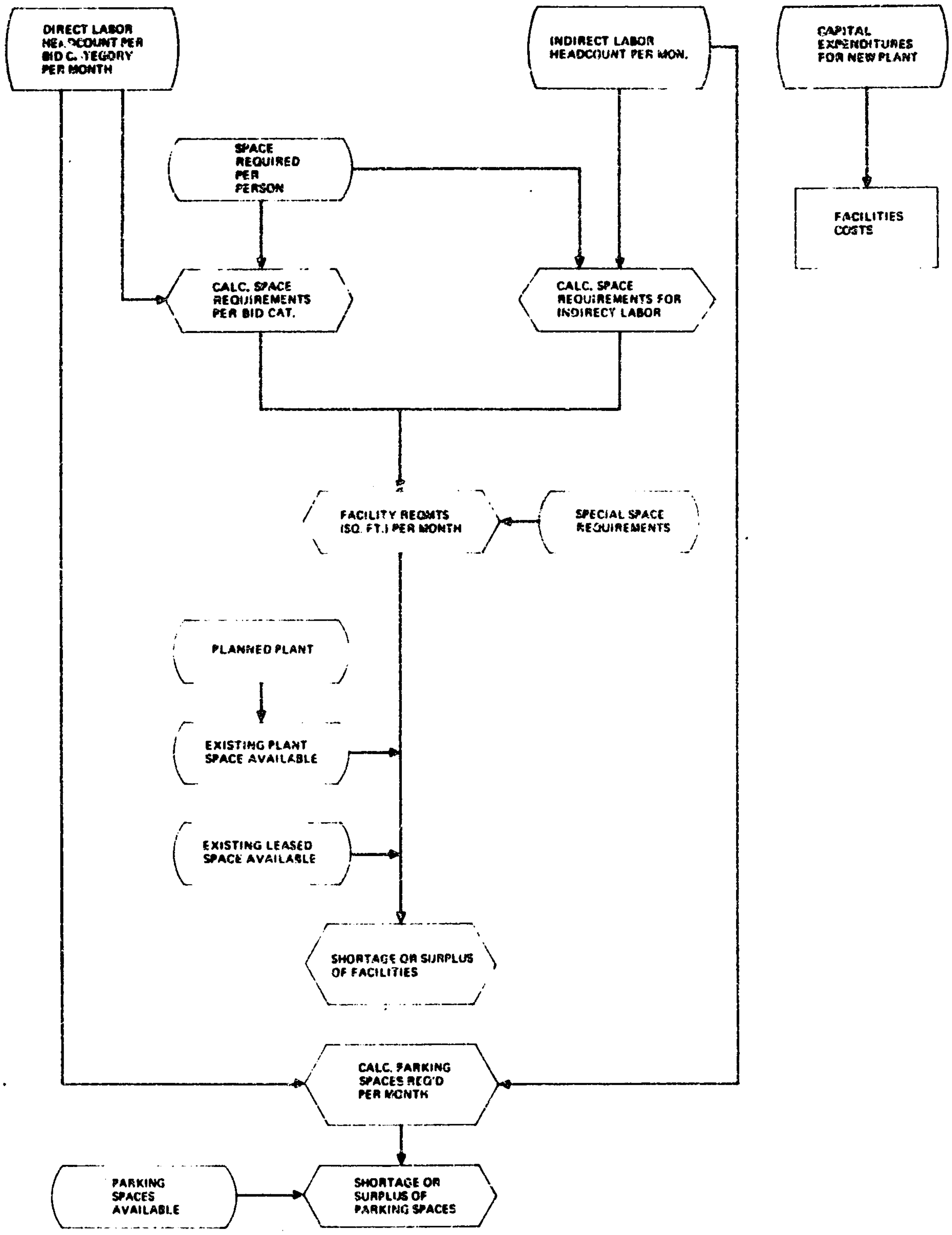

FIGURE 8. FACILITIES SUMMARY MODEL

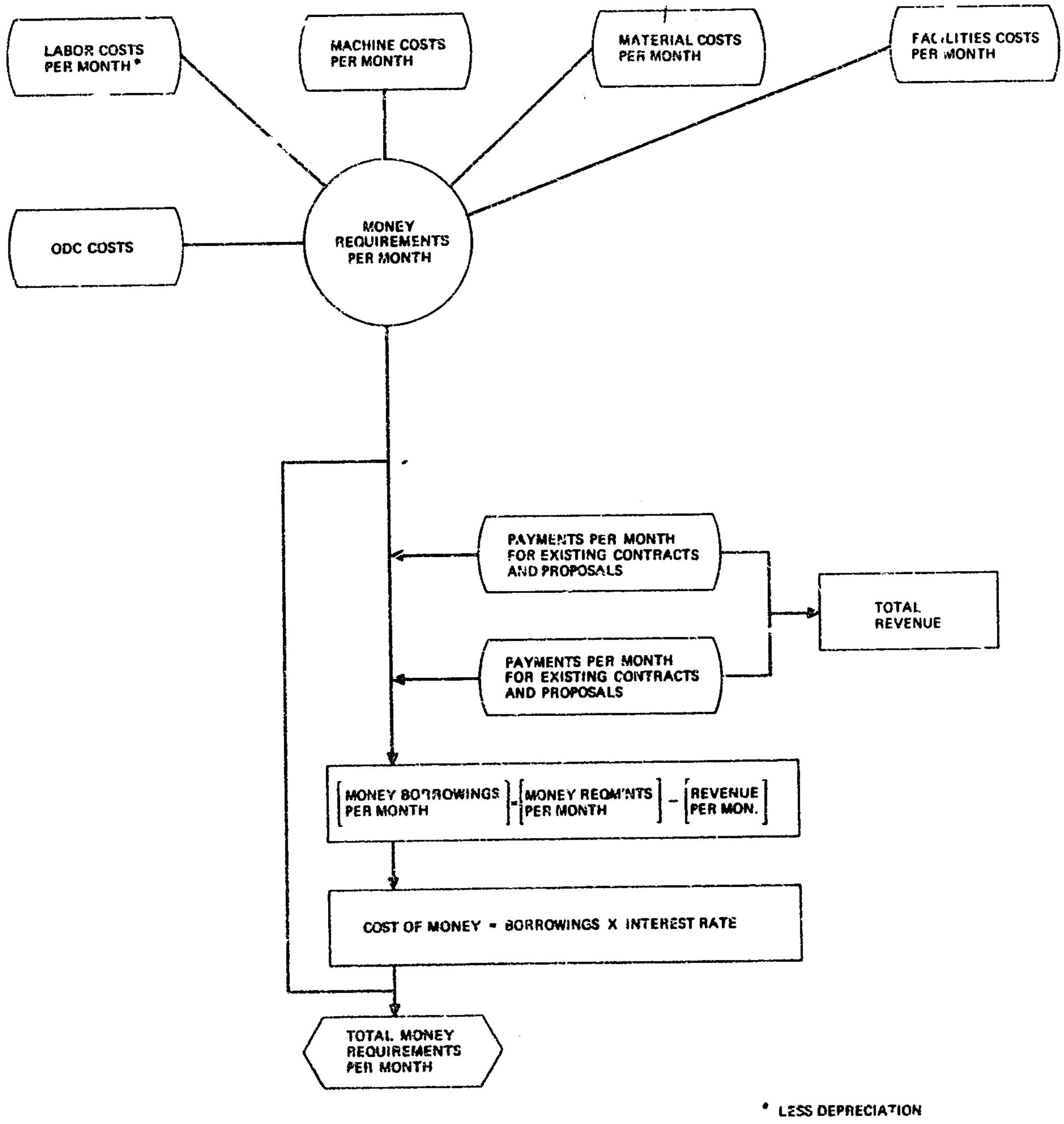

FIGURE 9. MONEY SUMMARY MODEL