



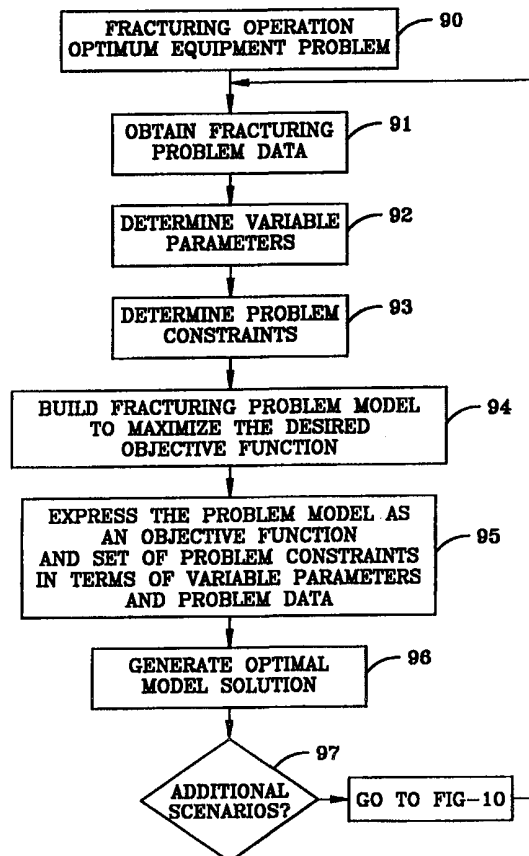
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(54) Title: OPTIMAL EQUIPMENT ALLOCATION

(57) Abstract

A method for optimally allocating equipment to jobs at multiple geographic locations to maximize utilization of scarce and expensive resources needed for oil-well fracturing operations (90). The computer implemented method obtains fracturing problem data (91), determines variable parameters (92) and problem constraints (93) and using an algebraic modeling language, builds a fracturing problem model (94) for optimally allocating fracturing equipment to fracturing jobs at multiple geographic locations. The model is expressed as an objective function (95) and a set of problem constraints (95). An optimal solution (96) is generated for the model using a solver software problem to satisfy the problem constraints (93) and optimize the objective function (94). The model can be rerun for different oil-well fracturing operations (90) scenarios and optimal solutions (96) generated for each scenario to determine optimal equipment.



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TITLE OF THE INVENTION

Optimal Equipment Allocation

This application claims the benefit of United States Provisional Application No. 60/065,168, filed on December 5, 1997.

BACKGROUND

This invention relates generally to optimally allocating equipment for fracturing operations or oil-well stimulation operations by applying operations research methodologies. More particularly, the invention is a method for optimally allocating equipment to jobs at multiple geographic locations to maximize utilization of scarce and expensive equipment resources needed for fracturing operations. The optimal equipment allocation problem is formulated and solved using operations research and mathematical programming techniques.

Oilfield Services are a multibillion-dollar industry with well stimulation or "fracturing" accounting for a large fraction of this revenue. Fracturing consists of pumping complex water based fluids under high pressure into boreholes to make cracks in the geological formation. These cracks are held open by solid particles transported by the fluid and deposited in the cracks. Fracturing a well can typically improve the long-term oil flow from a well by a factor of two by increasing the local permeability of the geological formation. This is done by pumping special water based fluids containing small particles (sand) at high pressure (approximately 5 to 15,000 psi) into the well. The high pressure fractures the formation, ideally creating long cracks leading away from the borehole, which are kept open by the particles deposited in the cracks long after (years) the well stimulation. Control of fracture formation is critical to the success of the stimulation and is partly controlled by the rates at which the fluid is pumped into the well, as well as the design and dynamic control of the fluid properties. These pumping operations may last anywhere from 20 minutes to 12 hours in exceptional circumstances, but are typically from 1 to 2 hours. Equipment setup and takedown is time consuming and must be performed carefully given the potentially hazardous nature of the operations. This adds a total of 1 to 3 hours to the total on site time.

Fracturing operations involve a variable number of pumping trucks ("pumpers") together with a control van and ancillary equipment for fluid and sand storage and

blending. The most expensive pieces of equipment are the pumpers and the control van, with a pumper costing about several times as much as a control van. Given the expense of this equipment, there is only a small amount of it at any particular depot. Several depots may cooperate via equipment and job sharing. Jobs may be spread over a geographical area with many different geological formations. Clearly they are within a certain range suitable for trapping oil but may be heterogeneous with respect to specific requirements.

Fracturing operations are a service industry. Jobs are typically requested some weeks in advance for a specific day, although there is wide variation in the actual details of client-provider interaction. These jobs are designed with the help of specific software simulating the details of the stimulation. However, managers typically have "comfort levels" for given operations so will send more equipment than is required by the job design, either to guard against equipment failure or to satisfy customer preferences or in case the design has to be changed at the job. Also the demand for fracturing services is not constant but depends on many macro-economic variables.

SUMMARY

The present invention optimally allocates the fracturing operation equipment (pumpers and control vans) to jobs in order to obtain the best return on investment possible for this capital equipment. The results of the optimal allocation are an improvement over any optimal allocation that can be obtained without using operations research tools. There is considerable flexibility in the present system in scheduling aspects at the initial client contact to matching equipment to job requirements, inter-Depot cooperation, and the comfort levels of the local managers. The optimal allocation of equipment may take place at current or increased demand levels.

In a typical problem example, potential customer sites are spread around some number of equipment depots with the depots having some number of control vans (TCV's) and pumpers. A heterogeneous pumper fleet has three different pumper types. Not all depots have all pumper types. Actual fracturing operations could involve only single depots for very small oilfields. Equipment is usually used on 1 to 2 jobs each day depending on job length and location.

The present invention increases equipment utilization in fracturing operations carried out in one organizational area (called a fracturing Area) under current demand and

under increased demand scenarios without losing significant market share. Using the method and system of the present invention, equipment allocated to Depots under supply-demand matching can be reduced with optimal allocation for little loss of market share. Alternatively market share may be increased with the same amount of equipment. The term "increase" implies an increase relative to some pre-existing situation. The term "market share" means the number of jobs done relative to all jobs done by all companies within the fracturing Area. Changing management strategies, for example equipment sharing, also has major impact on increasing equipment utilization.

In the examples discussed regarding the present invention, a hypothesized typical organization of a fracturing Area is utilized. In specifying this hypothetical organization, the management criteria under which the Area was set up are clearly defined. In actual practice, an Area's organization may be mostly historically based, rather than the result of management choices.

The models described herein capture the main aspects of the optimal allocation problem. The models do this in two ways. Firstly, by making the management decisions for setting up the original Area explicit. Secondly, by illustrating the potential changes in equipment utilization possible by further management decisions helped by an optimal equipment allocation procedure using mathematical programming.

The present invention comprises a computer implemented method for optimally allocating equipment to jobs at multiple geographic locations to maximize equipment utilization. The method comprises the steps of inputting the jobs to be completed within a specified time period, determining job requirements of each job specified in terms of an amount of equipment needed to perform each job, inputting supply equipment available for supplying to the jobs and optimally allocating the supply equipment to the jobs. The optimal allocation step comprises formulating an equipment allocation problem for allocating the supply equipment to each job based on the jobs to be completed, the job requirements and the supply equipment available, modeling the equipment allocation problem as an objective function and set of constraints and optimizing the objective function to generate an optimal solution for allocating the supply equipment to the jobs to be completed to maximize jobs performed within the specified time period. The jobs may comprise fracturing operations. The supply equipment may comprise pumpers and monitor vans. The amount of supply equipment to perform each job may be determined

based on a maximum hydraulic horsepower, maximum pumping pressure and maximum rate needed for the fracturing operation for each job. The maximum hydraulic horsepower, maximum pumping pressure and maximum rate for each job is used to determine a number of pumpers needed for each job. The set of constraints may comprise that the pumping pressure capability of the supply equipment must be greater than or equal to a minimum pumping pressure needed for each job, at least one monitor van must be included in the supply equipment provided for each job and job duration must be less than or equal to a specified maximum working day duration.

The present invention comprises computer executable software code stored on a computer readable medium, the code for optimally allocating equipment to jobs at multiple geographic locations to maximize equipment comprising code for inputting jobs to be completed within a specified time period, code for determining job requirements of each job specified in terms of an amount of equipment needed to perform each job, code for inputting supply equipment available for supplying to the jobs, code for formulating an equipment allocation problem for allocating supply equipment to each job based on the jobs to be completed, the job requirements and the supply equipment available, code for modeling the equipment allocation problem as an objective function and set of constraints, and code for optimizing the objective function to generate an optimal solution for allocating supply equipment to jobs to maximize jobs performed within the specified time period.

The present invention also comprises a method for optimally solving a fracturing operation equipment allocation problem for a multiple number of fracturing jobs within a specified time period, in a computer program running on a computer processor, comprising the steps of obtaining fracturing problem data, determining variable parameters, determining problem constraints and generating an optimal solution. Generating an optimal solution comprises using an algebraic modeling language, building a fracturing problem model for optimally allocating fracturing equipment available to fracturing jobs, the model being expressed as an objective function and the problem constraints in terms of the variable parameters and problem data and then optimizing the objective function to generate an optimal solution for allocating the fracturing equipment to the fracturing jobs to maximize the number of fracturing jobs performed within a specified time period. The fracturing problem data may comprise data input by a user.

The problem data comprises job location for one or more jobs to be done each day, job equipment requirements, job location specified relative to a depot location, distance between job locations, and supply equipment available for performing the job. The fracturing problem data may be varied and an optimal solution generated for the varied problem data. The supply equipment may comprise pumpers and monitor vans.

The problem constraints may comprise time constraints or a prioritization of jobs. The prioritization of jobs may comprise scheduling jobs first that have been received first. The optimal solution generated maximizes number of fracturing jobs performed in a specified time period using the supply equipment available.

Job equipment requirements may be increased to take into account equipment breakdown. The problem constraints may allow pumpers to be shared among jobs or time constraints for completing the fracturing jobs. The problem data varied may comprise increasing the job equipment requirements to simulate increased equipment demand. The job equipment requirements for each job may comprise maximum hydraulic horsepower, maximum pumping pressure and maximum rate for each job.

The problem constraints may comprise that each job must be performed once, pumper total maximum hydraulic horsepower for each job must be greater than the maximum hydraulic horsepower required for each job, pumper total rate for each job must be greater than or equal to the maximum rate required for each job, pumper minimum pressure for each job must be greater than or equal to the maximum pumping pressure job required for each job, each pumper must be utilized and at least one monitor van is needed for each job.

The optimal solution may comprise using a solver software program to solve for the variable problem parameters that satisfy the problem constraints and optimize the objective function. The order of determining the variable parameters may be prioritized prior to generating an optimal solution for the model. The method may further comprise determining fracturing job acceptance based on available equipment, determining an equipment sharing strategy for optimally sharing fracturing equipment between the fracturing jobs, increasing job requirements for each fracturing job based on manager comfort level and determining job scheduling and prioritization.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, aspects and advantages of the present invention will become better understood with regard to the following description, appended claims and accompanying drawings where:

Fig. 1 shows a typical fracturing area geography, job locations and depot locations.

Fig. 2 is a table that shows customer job data for each job location depicted in Fig. 1.

Fig. 3 is a table showing the geology of the job area depicted in Fig. 1.

Fig. 4 is a table showing the implied parameters of lognormal distributions describing the geology of Fig. 3.

Fig. 5 is a table showing the depot locations and equipment levels.

Fig. 6 is a table showing the equipment specifications with the capabilities of different pumper types.

Fig. 7 is a table showing the resulting supply versus demand balance for the job requirements based on maximum hydraulic horsepower (HHP).

Fig. 8 is a flow diagram for the optimal equipment allocation problem.

Fig. 9 is a flow diagram for a fracturing operation optimal equipment problem.

Fig. 10 is a flow diagram for additional what-if scenarios for a fracturing operation optimal equipment problem.

Fig. 11 is a table showing the resulting percentage of pumper utilization for different equipment levels.

Fig. 12 is a table showing the resulting percentage of job completions expressed in terms of their required HHP if there is no sharing of pumpers or monitor vans.

Fig. 13 is a table showing the resulting percentage of pumper HHP utilized with different equipment levels if there is a sharing of pumpers only.

Fig. 14 is a table showing the resulting percentage of job completions expressed in terms of their required HHP if there is a sharing of pumpers only.

Fig. 15 is a table showing the resulting percentage of pumper HHP utilized with different equipment levels if there is a sharing of pumpers and monitor vans.

Fig. 16 is a table showing the resulting percentage of job completions expressed in terms of required HHP if there is a sharing of pumpers and monitor vans.

Fig. 17 is a table showing the resulting percentage of pumper utilization for different equipment levels based on increased demand with no sharing of equipment.

Fig. 18 is a table showing the resulting percentage of job completions expressed in terms of required HHP based on the increased demand with no sharing of equipment.

Fig. 19 is a table showing the resulting percentage of pumper HHP utilized with different equipment levels based on increased demand with a sharing of equipment.

Fig. 20 is a table showing the resulting percentage of job completions expressed in terms of their required HHP based on the increased demand with a sharing of equipment.

Fig. 21 is a table showing the percentage of pumper utilization for difference equipment levels based on current demand, increasing equipment by 25%, and sharing of pumpers only.

Fig. 22 is a table showing the percentage of job completions expressed in terms of required HHP based on current demand, increasing equipment by 25%, and sharing of pumpers only.

Fig. 23 is a table showing the percentage of pumper utilization for different equipment levels based on increased demand, increasing equipment by 25%, and sharing of pumpers only.

Fig. 24 is a table showing the percentage of job completions expressed in terms of their required HHP based on the increased demand, increasing equipment by 25%, and sharing of pumpers only.

DETAILED DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a typical fracturing area geography. The Area 10 consists of four Depots of equipment 11-14 (each indicated by an "X") serving a total of 20 customer locations. In the example fracturing Area 10 considered, twenty potential customer sites are spread around the four equipment Depots with five control vans (TCV's) and twenty-three pumpers. A heterogeneous pumper fleet has three different pumper types. Not all Depots have all pumper types. Actual fracturing operations could possibly involve only single Depots for very small oilfields, or probably $\pm 50\%$ of what we have considered here. Detailed information is not available from the major companies. Equipment is used on 1 to 2 jobs each day depending on job length and location. Depot 11 serves six customer locations indicated by the six occurrences of the number 1. Depot

12 serves four customer locations indicated by the four occurrences of the number 2. Depot 13 serves 4 customer locations indicated by the four occurrences of the number 3. Depot 14 serves six customer locations indicated by the six occurrences of the number 4. Each Depot 11-14 is constructed by matching supply with demand independent of other Depots in the Area. Each Depot has enough equipment to be able to meet most of the job requests in terms of their size in maximum hydraulic horsepower (HHP) and in terms of the number of jobs. This matching is calculated below.

The demand in the optimal equipment allocation problem consists of twenty customer locations (indicated by the numbers 1-4) spread out over the Area 10. Each customer requests fracturing jobs independently of all the other customers according to a Poisson process. The requirements of the fracturing job are maximum hydraulic horsepower (HHP), maximum pumping pressure (Psi) and maximum rate (rate) at which fluid is pumped into each well. The relationship between HHP, rate and pressure is given by: $HHP = \text{rate} \times \text{pressure} / 40.8$ but the maxima of each will not necessarily occur at the same time. The distribution of these quantities will be taken as a joint lognormal distribution. This distribution is suitable for describing quantities that depend on the product of many factors which is certainly the case with oil well geology and oil recovery. Four different geological formations are assumed, each with its own specific joint distribution. Each customer has wells of one formation type. The time required on site will be modeled with a normal distribution independent of the other job requirements. Travel times are deterministic and proportional to straight line distance, with a factor of 1.15 to allow for road geometry and an assumed speed of 50mph.

The supply in the optimal equipment allocation problem consists of four Depots 11-14. Each Depot has a specific number of pumpers and control vans. There are three different types of pumpers with different capabilities in terms of HHP, Psi and rate.

In terms of supply versus demand, the Depots 11-14 are equipped in order to satisfy the following equations:

1. Job numbers

$$E \left[\sum_c n_{c,d} \right] \approx cv_d$$

where

$n_{c,d}$ average number of job requests from customer c to Depot d per day.

c index for the customers.

cv_d number of control vans in Depot d .

Note that approximately two jobs per day can be done by each control van and that the number of job requests has a Poisson distribution (being the sum of Poisson processes).

Note that approximately two jobs per day can be done by each control van and that the number of job requests has a Poisson distribution (being the sum of Poisson processes).

1. Job requirements

Pumper capacity in terms of HHP is matched to job HHP requirements.

$$E \left[\sum_c \sum_{n \in N_{c,d}} hhp_{c,n,d} \right] + 2 S.D. \left[\sum_c \sum_{n \in N_{c,d}} hhp_{c,n,d} \right] \approx \sum_p hhp_{d,p}$$

where

$hhp_{c,n,d}$ HHP required by job n from county c requested from Depot d .

$N_{c,d}$ set of jobs n requested by county c from Depot d .

$hhp_{d,p}$ HHP available from pumper p in Depot d .

Fig. 2 is a table that shows customer job data for each job location for the twenty customers of Fig. 1. Job rates are per day and are Poisson distributed. Geology is defined in terms of one of four formation types present. X and Y coordinates are in miles relative to the location of the center Depot. The Depot serving the customer is shown in the last column of Fig. 2.

Fig. 3 is a table showing the geology of the job area. Characteristics of each formation present in the geology are shown in terms of effect on job requirements. The requirements of the fracturing job are maximum hydraulic horsepower (HHP), maximum pumping pressure (Psi) and maximum rate (rate). Note that the mean and standard distribution of the marginal distributions are given, *not* the parameters of those distributions (which are uniquely determined by these values and given below). The correlation matrix is symmetric with the unit diagonal so only three entries for each formation need to be specified. Note that there is no particular relationship between different formations.

Fig. 4 is a table showing the implied parameters of lognormal distributions describing the geographical formations of Fig. 3. Parameter 1 is the mean of the log of the distribution and Parameter 2 is the standard distribution.

Fig. 5 is a table showing the depot locations and equipment levels. The X and Y coordinates represent the miles relative to Depot 1. The equipment present at each level is also shown.

Fig. 6 is a table showing the equipment specifications with the capabilities of different pumper types in terms of maximum HHP, pumping pressure and rate.

Fig. 7 is a table showing the resulting supply versus demand balance for job requirements based on maximum HHP calculated using the equations above for the fracturing Area as depicted in Fig. 1.

Operational data for a fracturing area such as that shown in Fig. 1 with organization and supply versus demand structure (as shown in Fig. 7) must be obtained so as to be able to model the operations and predict how the operations may be changed or would react to different circumstances. However operational data is collected, there must be a way of validating it. There is a need to be able to find the accuracy of the collected data, and the size of the data population. It is unrealistic in most operational situations to suppose that it is possible to collect a complete dataset. Thus one needs to be able to define how much of the data have been sampled and, if possible, to identify what sort of a sample has been obtained. The collected data must also be checked before the collection is finished. The most sophisticated and simple way to implement this is via forms on a specially constructed set of web pages that specify the required data. Some databases, have the potential for "live" web connections built in. This requires connectivity of the remote sites with the analyst/data collection site. If this is not possible, stand-alone PC's with spreadsheets formatted for data entry can be used. In the case of stand-alone PC entry, individual datasets can be emailed to the analyst for fast checking by on-site company personnel.

The optimal equipment allocation for the fracturing operations problem is formulated as a Mixed Integer Problem and is formulated as shown in Table 1.

<i>Modeling Sets/Indices:</i>	p pc m date j,k jc rc c,cc d x,y	pumpers {p1, ..., p31} pumper characteristics {Depot, hhp, psi, rate} monitor vans {m1, ..., m9} list of days {d1, ..., d30} jobs with the first one being a dummy for stay at home {j1, ..., j20} job characteristics {Depot, hhp, psi, rate, customer, t_travel, t_pump, t_site} job requirement characteristics {hhp, psi, rate} customer characteristics {c1, ..., c20} Depots {Depot1, ..., Depot4p, pumpers {p1, ..., p31} coordinate locations
<i>Data</i>	pump(p, pc) mon(m) jobs(j,jc) daytime p_time(p,j,k) m_time(m,j,k)	pumpers and their characteristics locations of monitor vans jobs and their characteristics length of a working day time for pumper p to do jobs j and k (pumpers and monitor vans do up to two jobs a day) time for monitor van to do jobs j and k
<i>Variables:</i>	Real z Binary done1(j) done2(j) x(p,j,k) y(m,j,k) SOS1 used1(p,j) used2(p,j)	objective which jobs are done first second which pumps do which jobs and when similarly for monitor vans which pumps are used on jobs done first second

Table 1

The objective is to maximize the total maximum hydraulic horsepower (HHP) of the jobs done. This objective is used rather than maximizing the utilization, as this is a more natural target and prevents pathological solutions, for example, with no equipment and all of it is always fully utilized.

Note that all the equations are written in terms of subsets of jobs, pumpers, etc. This is so that each problem solved is as small as possible and unneeded variables are not used. These subsets are:

- $s_j, sk \subseteq j$ subset of jobs currently available
- $ssj = sj \setminus j1$ no job (stay at home)
- $ssk = ssj$ scheduling
- $sp \subseteq p$ subset of pumpers currently available
- $sm \subseteq m$ subset of monitors currently available

Fig. 8 is a flow diagram for the optimum equipment allocation problem 80. The current number of jobs to be completed in a specified time period are input 81. The job requirements of each job are determined and specified in terms of an amount of equipment to perform each job 82. An equipment allocation problem is formulated based on current jobs, job requirements and supply equipment available. 83. The equipment allocation problem is modeled as an objective function and a set of constraints 84. The objective function is then optimized 85.

Fig. 9 is a flow diagram for a fracturing operation optimum equipment problem 90. Fracturing problem data is obtained 91. Variable parameters are determined 92. Problem constraints are determined 93. A fracturing problem model is build to maximize the desired objective function 94. The problem model is expressed as an objective function and set of problem constraints in terms of variable parameters and problem data 95. The objective function 95 is expressed as:

$$\text{Maximize } z = \sum_{sj} (done1_{sj} + done2_{sj}) jobs_{sj,hhp}$$

subject to the following constraints 93:

1. Do jobs, except "stay at home" (job 1, "do nothing"), at most once:

$$done1_{ssj} + done2_{ssj} \leq 1 \quad \forall j \neq do\ nothing$$

2. Meet the requirements for each job that is done.

2.a. The additive quantities of HHP and rate:

$$\sum_{sp} \sum_{sk} pump(p, "hhp") x(p, j, k) \geq done1(j) job(j, "hhp") \quad \forall j \neq do\ nothing$$

$$\sum_{sp} \sum_{sk} pump(p, "rate") x(p, j, k) \geq done1(j) job(j, "rate") \quad \forall j \neq do\ nothing$$

$$\sum_{sp} \sum_{sk} pump(p, "hhp") x(p, k, j) \geq done2(j) job(j, "hhp") \quad \forall j \neq do\ nothing$$

$$\sum_{sp} \sum_{sk} pump(p, "rate") x(p, k, j) \geq done2(j) job(j, "rate") \quad \forall j \neq do\ nothing$$

2.b. Psi, the psi (pressure capability) of each pumper present must be greater than or equal to the pressure needed by the job:

$$\sum_k pump(p, "psi") x(p, j, k) \geq used1(p, j) job(j, "psi") \quad \forall j \neq do\ nothing$$

$$\sum_k x(p, j, k) = used1(p, j)$$

$$\sum_k \text{pump}(p, "psi") x(p, k, j) \geq \text{used2}(p, j) \text{ job}(j, "psi") \quad \forall j \neq \text{do nothing}$$

$$\sum_k x(p, k, j) = \text{used2}(p, j)$$

2.c. There must be a monitor van present at each job done (except *do nothing*):

$$\sum_k \sum_m y(m, j, k) = \text{done1}(j) \quad \forall j \neq \text{do nothing}$$

$$\sum_k \sum_m y(m, k, j) = \text{done2}(j) \quad \forall j \neq \text{do nothing}$$

3. Jobs done must not take longer than a working day (16 hours = *daytime*):

$$x(p, j, k) p_time(p, j, k) \leq \text{daytime}$$

$$y(p, j, k) m_time(m, j, k) \leq \text{daytime}$$

4. Equipment is always somewhere, either at home or on a job:

$$\sum_k \sum_j x(p, k, j) = 1$$

$$\sum_k \sum_j y(m, k, j) = 1$$

In addition to the above constraints, the following assumptions are made:

Job 1 is a dummy job for staying at home and doing nothing.

The formulation uses $O(|P| |J|^2)$ variables. There are fewer jobs on any day than there are customers so this using jobs rather than customers is parsimonious. In this formulation a pumper or monitor van can do at most two (2) jobs in a day. The constraints on time taken can be evaluated before the model is solved and the relevant variables fixed to reduce the solution space.

The objective function and set of constraints 95 are a mixed integer programming problem. Equipment must be allocated to meet as much of the demand as possible each day. Equipment utilization will be increased if the same amount of work can be accomplished with less equipment or more work can be done with the same amount of equipment. The model 95 may be expressed in an algebraic modeling language, such as GAMS and may then be optimized 96 using a commercial software solver program. An MIP model for the allocation of equipment to jobs is formulated and then run through different scenarios to identify which management choices lead to higher utilization. Since the problem is expressed as a mixed integer problem (MIP), a MIP solver such as CPLEX

may be used. This choice of the MIP solver defines the properties of some of the variable parameters 92. An alternative approach is to treat the optimal equipment allocation problem as a large Stochastic Integer Program (SIP) with an objective of maximizing the expected equipment utilization subject to retaining or increasing market share in different scenarios. Because small SIP's without special structure are hard to solve, this type of formulation is impractical for this problem because of its size.

The model 95 and optimal solutions generator may be repeatedly run using different scenarios to answer what-if questions posed. The present invention calculates equipment utilization in a chosen set of scenarios and decides from the set of "what if" experiments which strategy or strategies to recommend.

After the optimal equipment allocation for fracturing operations problem shown in Fig. 1 has been modeled as an objective function and expressed in an algebraic modeling language, different what-if scenarios are formulated and the objective function is optimized for each scenario. If there are additional what-if scenarios 97, processing continues in Fig. 10.

Turning now to Fig. 10, for additional what-if scenarios 100, the present invention considers the following strategies: the amount and types of equipment present (pumpers and monitor vans) 101; equipment sharing between Depots 102; manager comfort levels 103; and job scheduling and prioritization 104. The invention evaluates how these choices affect equipment utilization and the number of jobs done.

For the amount and types of equipment present, job acceptance relies on available equipment 101. There must be a correct ratio of pumpers to monitor vans for both to be fully utilized. Any bottlenecks must be identified. For example, one of the resource types should not be fully utilized while another is not used.

For equipment sharing between Depots 102, it is assumed that the base level of equipment sharing is of the pumpers. Other equipment may also be shared, such as the monitor vans, if it helps to allocate the equipment optimally. If equipment is shared, the size of the benefit is quantified.

Manager comfort levels 103 describe the relationship between the quantity of equipment requested/required to do the job and the "extra" that the individual manager usually sends. This "extra" may in fact be necessary due to the probability of equipment failure or may simply be to reassure the client that no such failure will negatively impact

job completion. Of course, it is possible that the equipment is sent out so that it gets some regular use and not for the above reasons. The idea of a “comfort level” describes the extra equipment sent to jobs for both objectively measurable and subjective reasons. How much must be sent for objective reasons depends on joint equipment and job failure distributions.

Two extreme cases of job scheduling 104 in a stochastic environment are examined, one having perfect information and the other having no advance knowledge. The perfect information situation is where all potential job requests for a particular day are known in advance and the manager can choose which to accept and which to reject. Managers accept requests for service and then at some later point call back the prospective customers to say which jobs will be accepted. Some delay in replying to requests may be acceptable to clients, but there will be a point at which clients reject the system. Clearly in the limit of very high demand it will be possible to have perfect equipment utilization by accepting a set of jobs that precisely match the available equipment. Also, no scheduling algorithm can possibly do better than the perfect information case so this forms an upper bound on how much a scheduling algorithm could offer.

No advance knowledge is a “first come first served” situation where if a manager accepts a requested job if the capability to perform the job currently exists. Small jobs are not refused in the hope of receiving a call for a bigger job later. This “no scheduling” approach sets a lower bound on the performance of potential scheduling algorithm benefits.

Job prioritization 104 is another strategy that can be incorporated into the optimal equipment allocation problem. Job priorities can model client importance or the preference of a manager for doing jobs in his own customer area as opposed to loaning equipment to another Depot manager.

Most problem instances are small enough to be solved close to optimality in reasonable time so use of a heuristic is not needed. However, for larger problems, these heuristics may be of interest. The optimal equipment allocation problem is similar to a bin covering problem (BCP). In the bin covering problem, the aim is to fill as many bins as possible from n items of size $\{X(i), i = 1, \dots, n\}$ such that each bin is at least completely full. Normally the bins are of unit size and each item is in $[0,1]$. This

problem is NP-hard. One can map our problem to BCP by saying that the bins are in fact jobs and the items are the pumpers. This somewhat reverses the normal formulation and changes the bins from unit size to being of random size from some underlying distribution. One fast heuristic algorithm that can be used to solve for BCP runs in $O(n \log^2 n)$ time and is called the Iterated-Lowest-Fit-Decreasing (ILFD). If $\text{MAX}(X(n))$ is the maximum number of bins that can be covered then $\text{ILFD}(X(n)) \geq \frac{3}{4} \text{MAX}(X(n)) - 1$ for any set of n items $X(n)$. This is a worst case bound. It has also been shown that the average case behavior also has $\text{ILFD}(X(n)) / \text{MAX}(X(n))$ in $[1, 4/3]$. No work has yet demonstrated a correspondence between general probability distributions and particular ranges for this ratio. Some specific results are known in the case where $X(n)$ is drawn from a uniform distribution: $E[\text{MAX}(X(n))] = n/2 + O(\sqrt{n})$ and $E[\text{NF}(X(n))] = (n + 2/e + 1 + o(1))$ where $\text{NF}()$ is the number of bins covered by the Next-Fit algorithm.

Some scheduling aspects of fracturing operations resemble various dynamic and stochastic knapsack problems (DSKP). One type of DSKP is one with deadlines where randomly sized jobs with random rewards arrive according to some stochastic process and must be accepted or rejected at once. The aim is to fill as much of the knapsack as possible within a given time. The optimal policy for a DSKP is a threshold which decreases with time up to the deadline provided that a fairly lenient consistency condition is met for the size and reward distributions. In fact, this stochastic optimization problem is equivalent in some sense to an n -stage stochastic optimization program with recourse, where n is the number of items seen before the deadline. This may be a viable approach to fracturing service scheduling as the number of jobs is quite low for each day.

One feature of fracturing operations is that a pumper can be involved in more than one job on a single day. This can be thought of, turned around, as the sojourn time of the job at the pumper. Stochastic knapsack problems have been developed for this situation where jobs occupy capacity but only for a limited time. This has been particularly developed with respect to telecommunications networks but the applicability to the optimal equipment allocation problem may be limited because the number of job requests is so different (millions for the telecommunications network versus around 10 for the fracturing operation).

Additional sets/indices, etc. are required to describe the different scenarios. The calculation of the distance matrices and some implementation issues which became relevant for reducing solution times are listed below:

Priorities 105 are used to help specify the order of selection of variables for inclusion in the branch and bound tree by the solver. These were partly derived from known results about approximations to the problem. The optimal choice for a (0-1) knapsack problem is to accept items in order of decreasing value density.

Because many symmetric possibilities make things hard for branch and bound solution techniques, slack variables are used. Thus, it is useful to introduce slack variables that contribute very slightly to the objective function and express some preference amongst these possibilities.

Dynamic sets are defined for indices and used in the formulation of the constraint equations, including the objective. This ensures that each of the problem instances solved contains only the range of indices used rather than the range needed by the largest problem to be handled.

Turning back to Fig. 9, once each additional what-if scenario has been determined as shown in Fig. 10, steps 91 through 96 are repeated to generate a new optimal model solution 96 for the new what-if scenario.

EXAMPLES

The examples discussed below show a mixed integer programming (MIP) model of fracturing operations in an organizational Area. This is compared to a pre-existing organization based on equating supply with a combination of expected demand and the variability of that demand. The Area has been set up so that individual Depots could operate independently and would have to refuse very few jobs. Using the MIP model to optimally allocate equipment to jobs is a pumper utilization of around 50% when no "extra" is sent. If "extra" is sent to allow for possible equipment breakdowns the average utilization is around 70%. Twenty percent of the pumpers could be removed for no loss of jobs and an increase of 20% in pumper utilization in both scenarios. If the demand increases by 20% then permitting Depots to share monitor vans and decreasing the number of pumpers by 20% gives an increase of 30% in pumpers utilization for <5% loss of market share (total job HHP served). This is even with sending the "extra" to allow for on the job breakdowns. The MIP optimization models consider equipment sharing

between Depots and two extremes of job scheduling. Either all the jobs for a day are known in advance and the managers can choose which to do, or they arrive in random order and are accepted on a “first come first served” basis. The model of fracturing operations concentrates on optimal equipment allocation and its consequences. By this focus, all scheduling aspects of the problem are specifically excluded. Scheduling aspects can be incorporated into the model. Scheduling these operations is a dynamic and stochastic problem. After a job is requested for a certain day, this date may be changed either by the customer who, for example, has problems with the drilling (in the case of a new well), or by the service provider, because of another client who wants to change the service date and has a higher priority than the former client. Another aspect of scheduling is that some clients may be more important than others. Rescheduling may happen more than once before a job is finally done or canceled.

In each scenario discussed below, the current equipment level is 23 pumpers and 4 monitor vans (TCV's). Total pumper HHP with 19 pumps is 33000, with 23 pumps is 43000 and with 27 pumps is 51000. Thirty simulated days were considered. In the first scenario, no sharing of pumpers or monitor vans is assumed. If there is no sharing of pumpers or monitor vans between the four Depots shown in Fig. 1, the resulting percentage of pumper utilization for different equipment levels is shown in Figure 11.

If there is no sharing of pumpers or monitor vans between the four Depots shown in Fig. 1, the resulting percentage of job completions expressed in terms of their required HHP is shown in Fig. 12.

At the current demand level, the results show there is no advantage in adding monitor vans but there does appear to be an advantage in removing pumpers (models were solved to within 10% of optimality). Four pumpers can be removed for very little loss of market share as defined by the total HHP of the possible jobs and an increase of approximately 20% in average pumper utilization.

In the second scenario, pumpers are shared but monitor vans are not. If pumpers are shared but monitor vans are not shared between the four Depots shown in Fig. 1, the resulting percentage of pumper HHP utilized with different equipment levels is shown in Fig.13.

If there is a sharing of pumpers but no sharing of monitor vans between the four Depots shown in Fig. 1, the resulting percentage of job completions expressed in terms of

their required HHP is shown in Fig. 14. From the results shown in Figs. 12 and 13, there appears to be little change with the previous situation (Figs. 10 and 11) except perhaps a decrease in the variation in Job HHP Done and an increase in the variation of pumper utilization.

In the third scenario, pumpers and monitor vans are shared. If there is a sharing of pumpers and monitor vans between the four Depots shown in Fig. 1, the resulting percentage of pumper HHP utilized with different equipment levels is shown in Fig. 15. If there is a sharing of pumpers and monitor vans between the four Depots shown in Fig. 1, the resulting percentage of job completions expressed in terms of their required HHP is shown in Fig. 16.

The results show that at the base demand level, as designed, there is no need to share pumpers or monitor vans. Also, increasing the number of pumpers or monitor vans has no effect (to within solution tolerance of 10%) on the job completions. This approximate supply versus demand matching is effective in enabling Depots to be independent and to ensure that very few jobs are not done. It is, however, wasteful. The same percentage of job HHP may be done with 4 fewer pumpers (19) if pumpers are shared between Depots.

In a variation of the above problem, the current demand level is increased by twenty percent (20%). Decreased demand levels are not considered because the idea is to plan for an increase in market share. In the first scenario, no sharing of pumpers or monitor vans is assumed. If there is no sharing of pumpers or monitor vans between the four Depots shown in Fig. 1, the resulting percentage of pumper utilization for different equipment levels based on the increased demand is shown in Fig. 17. If there is no sharing of pumpers or monitor vans between the four Depots shown in Fig. 1, the resulting percentage of job completions expressed in terms of their required HHP based on the increased demand is shown in Fig. 18.

In the third scenario, pumpers and monitor vans are shared. If there is a sharing of pumpers and monitor vans between the four Depots shown in Fig. 1, the resulting percentage of pumper HHP utilized with different equipment levels based on the increased demand is shown in Fig. 19. If there is a sharing of pumpers and monitor vans between the four Depots shown in Fig. 1, the resulting percentage of job completions expressed in terms of their required HHP based on the increased demand is shown in Fig.

20. Based on the results, it seems more effective to share monitor vans than to buy more. Sharing monitor vans results in more in total available at each site.

The next set of scenarios attempt to factor in manager comfort levels. This is perhaps the most realistic scenario if pumpers may occasionally break down. No manager is going to send only exactly what is required to a job if the possibility of a pumper breaking down and being unrepairable on site is greater than, say, 5%. For typical jobs considered here 2 to 3 pumpers are required. This means that individual pumpers would need to be approximately 97.5% to 98.3% reliable. If this is not the case, sending more equipment is reasonable from a manager's point of view.

The current demand level is as shown in Fig. 1. In the first scenario, sharing of pumpers only is assumed. Twenty five percent (25%) more equipment is also assumed. If there is a sharing of pumpers only between the four Depots shown in Fig. 1, the resulting percentage of pumper utilization for different equipment levels based on the current demand and sending 25% more equipment than needed is shown in Fig. 21.

If there is sharing of pumpers only between the four Depots shown in Fig. 1, the resulting percentage of job completions expressed in terms of their required HHP based on the current demand and sending 25% more equipment than needed is shown in Fig. 22.

In a variation of the above problem, the current demand level is increased by twenty percent (20%). In this second scenario, sharing of pumpers only is again assumed as is sending twenty five percent (25%) more equipment than needed. If there is a sharing of pumpers only between the four Depots shown in Fig. 1, the resulting percentage of pumper utilization for different equipment levels based on the increased demand and sending 25% more equipment than needed is shown in Fig. 23.

If there is a sharing of pumpers only between the four Depots shown in Fig. 1, the resulting percentage of job completions expressed in terms of their required HHP based on the increased demand and sending 25% more equipment than needed is shown in Fig. 24.

As the results show, at this higher demand level there is a benefit of having more TCV's (monitor vans). However this benefit can be replicated by simply allowing Depots to share monitor vans as well as pumpers (data not shown). Utilization of greater than 100% is possible because utilization is defined to be (Total HHP Required for Jobs

done) / (Total Pumper HHP). Thus if all pumpers did two jobs in a day there would be a utilization of 200%. The pumper HHP sent is the maximum of 25% of what the job specifies and the HHP of the smallest pumper size. This is called the HHP Required for a job.

Clearly there is a benefit to decreasing the number of pumpers even with a higher demand level and sending more HHP to a job than it specifies. The percentage of jobs lost becomes insignificant if monitor van sharing is allowed. This duplicates the effect of adding more monitor vans. Thus with monitor van and pumper sharing, approximately 95% of the job HHP can be served, compared to approximately 98% with no monitor van sharing and increasing the number of monitor vans. This also increases the pumper utilization by approximately 30% from approximately 80% to approximately 110% for the increased demand level and by approximately 20% for the current demand level.

Although the present invention has been described in detail with reference to certain preferred embodiments, other embodiments are possible. Therefore, the spirit and scope of the appended claims should not be limited to the description of the preferred embodiments herein.

What is claimed is:

1. A computer implemented method for optimally allocating equipment to jobs at multiple geographic locations to maximize equipment utilization, the method comprising the steps of:
 - a. inputting jobs to be completed within a specified time period;
 - b. determining job requirements of each job specified in terms of an amount of equipment needed to perform each job;
 - c. inputting supply equipment available for supplying to the jobs; and
 - d. optimally allocating the supply equipment to the jobs.
2. The method according to claim 1, wherein the optimally allocating step comprises:
 - a. formulating an equipment allocation problem for allocating the supply equipment to each job based on the jobs to be completed, the job requirements and the supply equipment available;
 - b. modeling the equipment allocation problem as an objective function and set of constraints; and
 - c. optimizing the objective function to generate an optimal solution for allocating the supply equipment to the jobs to be completed to maximize jobs performed within the specified time period.
3. The method according to claim 2, wherein the jobs comprise fracturing operations.
4. The method according to claim 3, wherein the supply equipment comprises pumpers and monitor vans.
5. The method according to claim 4, wherein the amount of supply equipment to perform each job is determined based on a maximum hydraulic horsepower, maximum pumping pressure and maximum rate needed for the fracturing operation for each job.
6. A method for optimally solving a fracturing operation equipment allocation problem for a multiple number of fracturing jobs within a specified time period, in a computer program running on a computer processor, the method comprising the steps of:
 - a. obtaining fracturing problem data;
 - b. determining variable parameters;
 - c. determining problem constraints; and

- d. generating an optimal solution for the fracturing operation equipment allocation problem.
7. The method according to claim 6, wherein the generating an optimal solution step comprises:
 - a. using an algebraic modeling language, building a fracturing problem model for optimally allocating fracturing equipment available to fracturing jobs, the model being expressed as an objective function and the problem constraints in terms of the variable parameters and problem data; and
 - b. optimizing the objective function to generate an optimal solution for allocating the fracturing equipment to the fracturing jobs to maximize the number of fracturing jobs performed within a specified time period.
 8. The method according to claim 7, further comprising varying the fracturing problem data and repeating steps a and b to generate an optimal solution for the varied problem data.
 9. The method according to claim 7, wherein the problem constraints comprise a prioritization of jobs.
 10. The method according to claim 7, wherein the problem constraints comprise time constraints for completing the fracturing jobs.
 11. The method according to claim 6, wherein generating the optimal solution comprises using a solver software program to solve for the variable problem parameters which satisfy the problem constraints and optimize the objective function.
 12. The method according to claim 7, further comprising prioritizing the variable parameters to be optimized prior to generating an optimal solution.
 13. The method according to claim 7, further comprising:
 - a. determining fracturing job acceptance based on available equipment;
 - b. determining an equipment sharing strategy for optimally sharing fracturing equipment between the fracturing jobs;
 - c. increasing job requirements for each fracturing job based on manager comfort level; and
 - d. determining job scheduling and prioritization.

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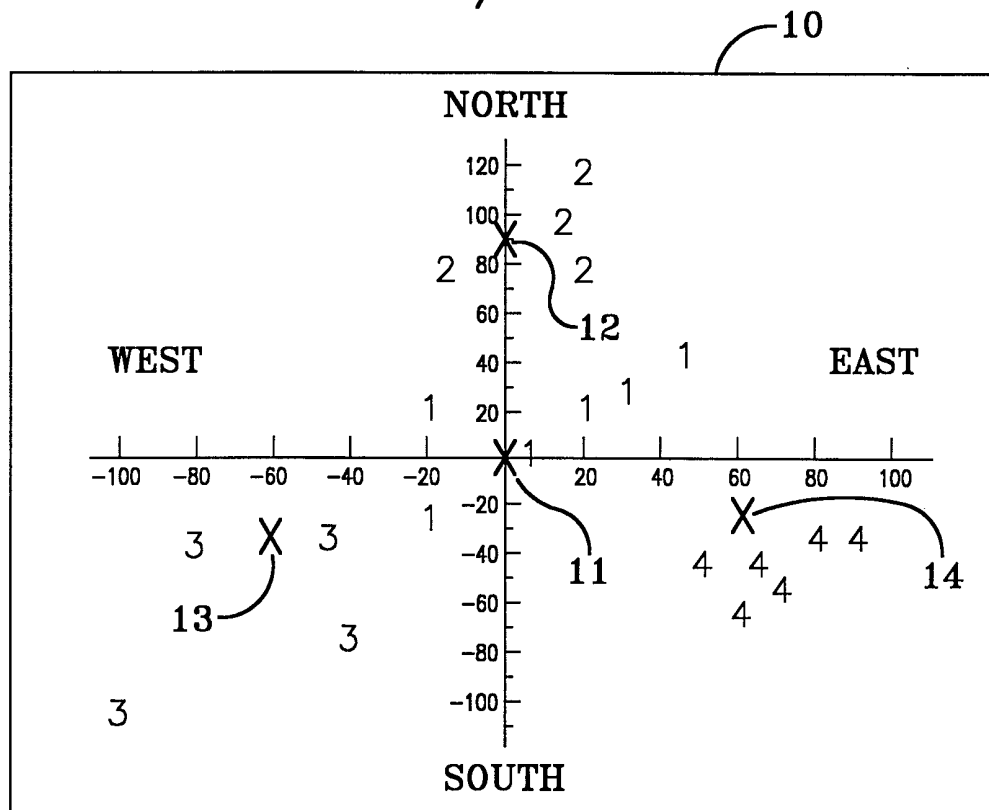


FIG-1

Customer	Job Rate	Geology	X coord	Y coord	Depot
C1	0.047	F2	20	120	D2
C2	0.278	F4	15	99	D2
C3	0.35	F2	-15	80	D2
C4	0.14	F2	20	80	D2
C5	0.2	F4	-100	-100	D3
C6	0.78	F3	-80	-33	D3
C7	0.094	F3	-45	-30	D3
C8	0.004	F1	-40	-70	D3
C9	0.03	F1	50	-40	D4
C10	0.088	F2	70	-50	D4
C11	0.095	F4	90	-30	D4
C12	0.0289	F4	80	-30	D4
C13	0.167	F1	60	-60	D4
C14	0.459	F2	65	-40	D4
C15	0.06	F3	20	20	D1
C16	0.02	F2	-20	20	D1
C17	0.058	F4	45	45	D1
C18	0.68	F3	-20	-20	D1
C19	1.2	F3	5	5	D1
C20	0.136	F2	30	30	D1

FIG-2

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Formation	Mean			S.D.			Correlation		
	Max HHP	Max Rate	Max Psi	Max HHP	Max Rate	Max Psi	Ln(HHP) vs Ln(Rate)	Ln(HHP) vs Ln(Psi)	Ln(Rate) vs Ln(Psi)
F1	3500	38	1357	1000	24	981	0.092	0.41	-0.03
F2	3000	79	4448	2000	35	403	0.2	0.05	-0.09
F3	5000	62	6089	2000	26	517	0.29	0.035	-0.44
F4	4000	27	6629	2500	3	1100	0.25	0.073	-0.12

FIG-3

Formation	Parameter 1			Parameter 2		
	Max HHP	Max Rate	Max Psi	Max HHP	Max Rate	Max Psi
F1	8.1213	3.4697	7.0028	0.2801	0.5794	0.6484
F2	7.8225	4.2798	8.3961	0.6064	0.4233	0.0904
F3	8.4430	4.0461	8.7106	0.3853	0.4025	0.0848
F4	8.1292	3.2897	8.7856	0.5742	0.1108	0.1648

FIG-4

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Depot	X coord	Y coord	# control vans	# type 1 pumps	# type 2 pumps	# type 3 pumps
D1	0	0	2	3	3	3
D2	90	0	1	4	3	0
D3	60	-20	1	0	3	1
D4	-60	-30	1	0	3	0

FIG-5

Pump Type	Max HHP	Max Rate	Max Psi
T1	1000	30	15000
T2	2000	60	10000
T3	3000	90	5000

FIG-6

Depot	Demand			Supply	Demand	Supply
	Mean HHP	SD HHP	Mean + 2 SD	Total HHP	E[# Jobs]	# Control Vans
D2	5446	2059	9564	10000	0.815	1
D1	10400	2778	15957	18000	2.154	2
D3	5184	1648	8481	9000	1.078	1
D4	2826	981	4789	6000	0.8679	1

FIG-7

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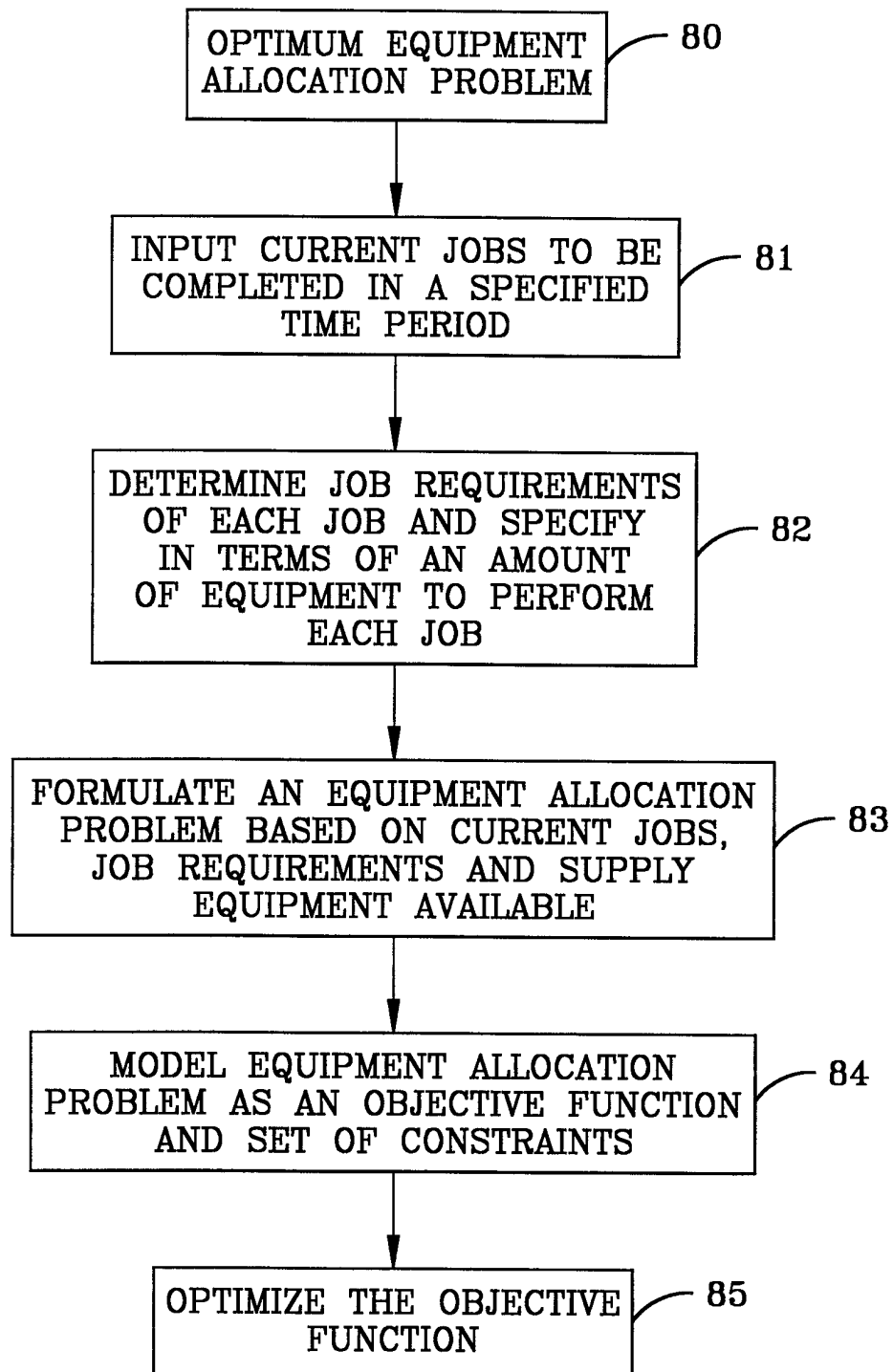


FIG-8

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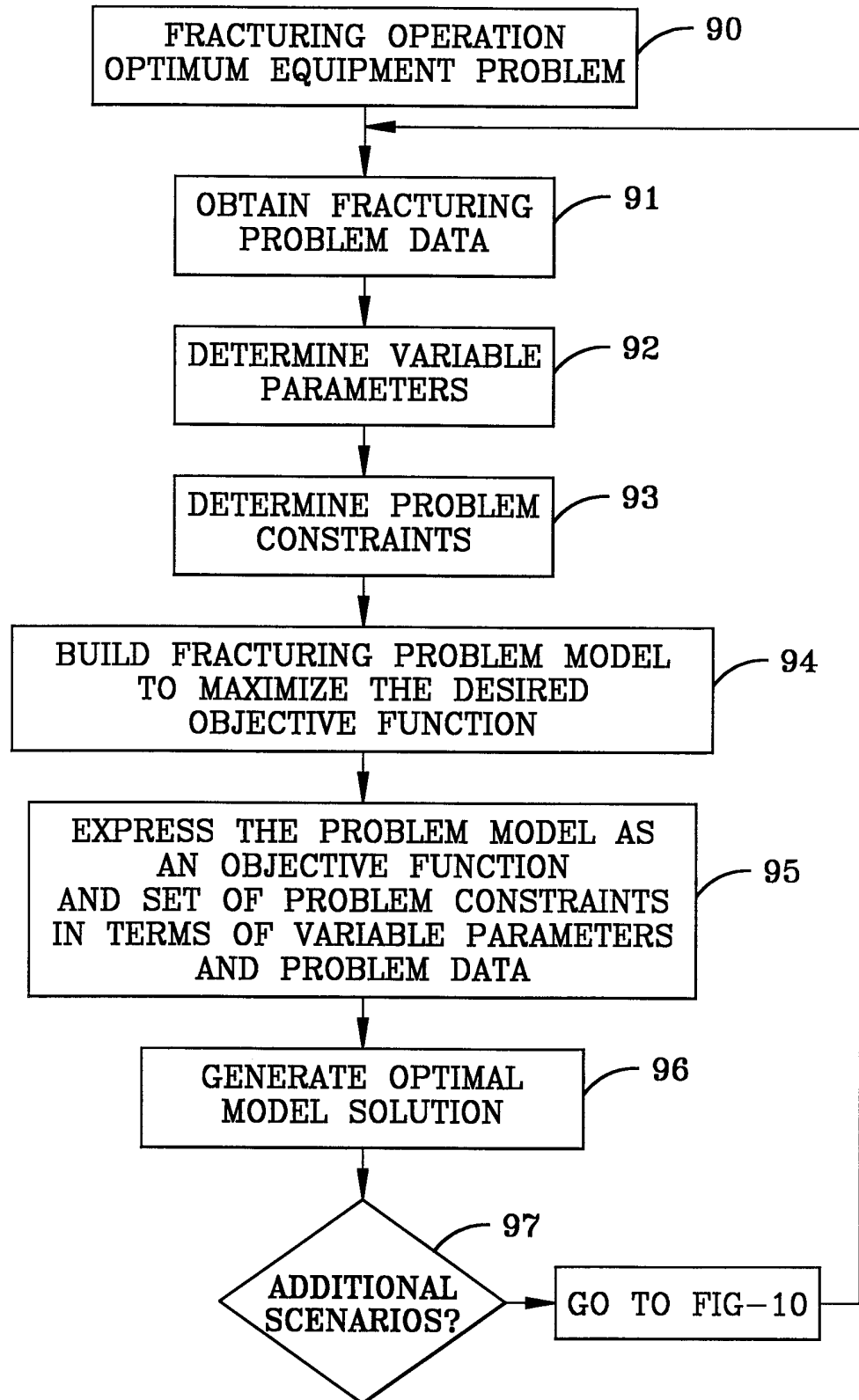


FIG-9

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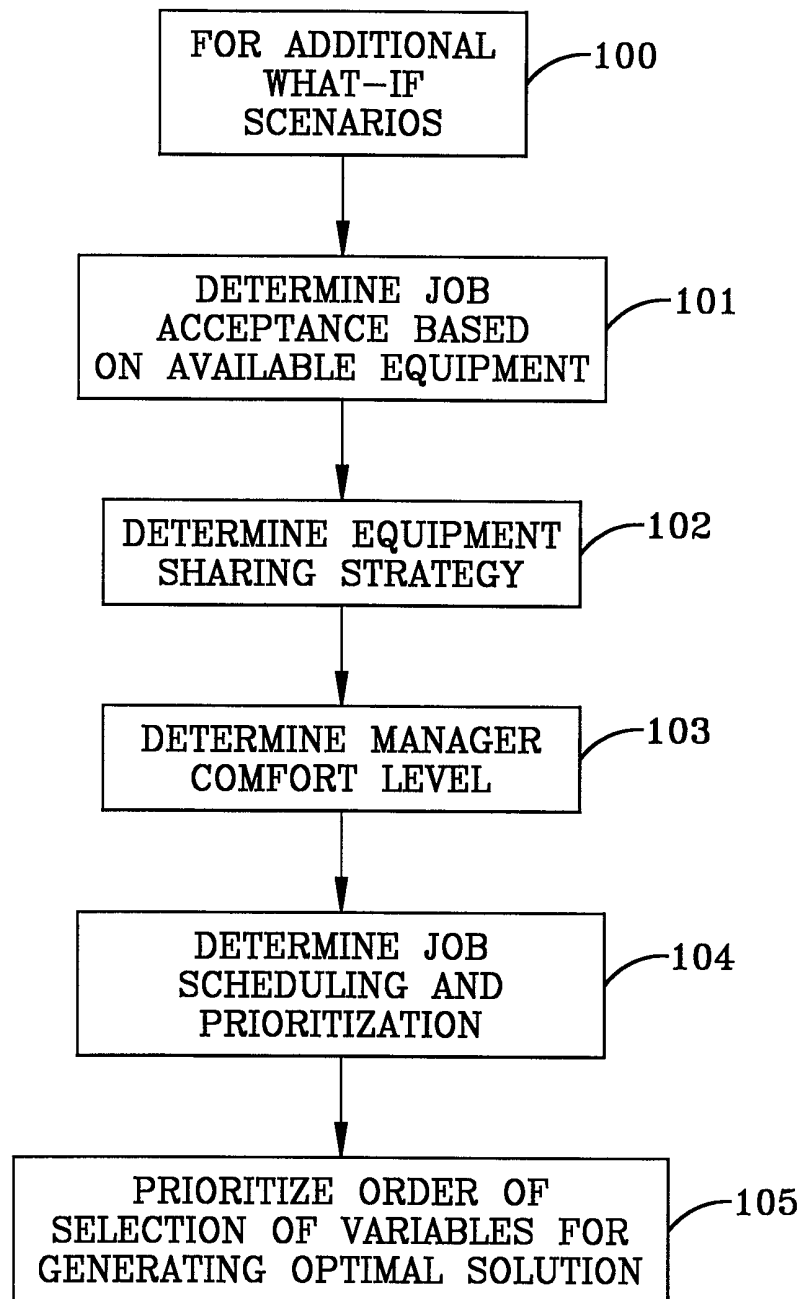


FIG-10

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	Percent Pumper HHP Utilized			
	4 TCV's		7 TCV's	
Pumps	Mean	S.D.	Mean	S.D.
19	66.6	17.7	64.9	17.3
23	53.0	16.5	52.7	15.6
27	46.2	16.4	46.6	16.9

FIG-11

	Percentage Job HHP Done			
	4 TCV's		7 TCV's	
Pumps	Mean	S.D.	Mean	S.D.
19	95.2	10.0	93.1	11.6
23	97.2	6.5	97.1	7.5
27	99.4	2.3	100.0	0.0

FIG-12

	Percent Pumper HHP Utilized			
	4 TCV's		7 TCV's	
Pumps	Mean	S.D.	Mean	S.D.
19	69.1	27.6	68.3	27.9
23	52.3	20.4	52.9	21.4
27	43.9	17.9	44.4	18.4

FIG-13

	Percentage Job HHP Done			
	4 TCV's		7 TCV's	
Pumps	Mean	S.D.	Mean	S.D.
19	99.3	2.4	98.4	7.6
23	98.3	5.2	98.8	5.4
27	97.5	6.7	98.3	6.5

FIG-14

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	Percent Pumper HHP Utilized			
	4 TCV's		7 TCV's	
Pumps	Mean	S.D.	Mean	S.D.
19	68.9	27.3	68.5	26.9
23	53.2	22.0	53.6	22.0
27	45.2	18.5	45.2	18.5

FIG-15

	Percentage Job HHP Done			
	4 TCV's		7 TCV's	
Pumps	Mean	S.D.	Mean	S.D.
19	99.2	3.9	98.7	4.6
23	99.3	3.8	100.0	0.0
27	100.0	0.0	100.0	0.0

FIG-16

	Percent Pumper HHP Utilized			
	4 TCV's		7 TCV's	
Pumps	Mean	S.D.	Mean	S.D.
19	81.2	26.2	81.0	32.2
23	64.5	21.0	67.5	24.5
27	55.0	18.7	58.8	22.5

FIG-17

	Percentage Job HHP Done			
	4 TCV's		7 TCV's	
Pumps	Mean	S.D.	Mean	S.D.
19	87.7	15.8	87.7	20.1
23	89.6	12.2	92.6	10.1
27	90.3	11.2	94.7	8.1

FIG-18

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	Percent Pumper HHP Utilized			
	4 TCV's		7 TCV's	
Pumps	Mean	S.D.	Mean	S.D.
19	91.0	31.0	91.4	32.7
23	73.0	27.5	72.0	26.4
27	61.3	23.4	61.9	23.7

FIG-19

	Percentage Job HHP Done			
	4 TCV's		7 TCV's	
Pumps	Mean	S.D.	Mean	S.D.
19	95.7	7.9	95.7	7.1
23	98.6	3.3	97.7	4.5
27	98.3	5.2	99.0	2.9

FIG-20

	Percent Pumper HHP Utilized			
	4 TCV's		7 TCV's	
Pumps	Mean	S.D.	Mean	S.D.
19	90.1	26.1	91.4	30.3
23	70.3	21.8	68.9	21.8
27	58.0	19.3	59.7	19.3

FIG-21

	Percentage Job HHP Done			
	4 TCV's		7 TCV's	
Pumps	Mean	S.D.	Mean	S.D.
19	97.7	4.4	97.9	7.4
23	98.9	3.9	96.5	8.5
27	96.0	9.0	100.0	0.0

FIG-22

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	Percent Pumper HHP Utilized			
	4 TCV's		7 TCV's	
Pumps	Mean	S.D.	Mean	S.D.
19	109.8	28.8	113.6	36.6
23	83.2	26.9	91.1	31.7
27	71.5	23.1	76.4	27.4

FIG-23

	Percentage Job HHP Done			
	4 TCV's		7 TCV's	
Pumps	Mean	S.D.	Mean	S.D.
19	90.0	13.6	95.2	8.0
23	91.5	10.4	98.4	4.1
27	92.9	7.9	97.8	5.0

FIG-24

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US98/25819

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G06F 17/00, 19/00

US CL :364/468.05, 468.06, 468.09, 468.15

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 364/468.05, 468.06, 468.09, 468.15

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS: (job or resource)(5a)(allocat? or plan?)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,630,070 A (DIETRICH et al.) 13 May 1997, see abstract and claims.	1-13
A, P	US 5,704,012 A (BIGUS) 30 December 1997, see column 2, and column 3,	1-13
Y, P	US 5,721,686 A (SHAHRARAY et al.) 24 February 1998, see entire document,	1,2,6,7, and 13
Y, P	US 5,745,652 A (BIGUS) 28 April 1998, see claims 1 and 11, also col. 3, line 1+	1,2,6,7, and 13



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"B" earlier document published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"G" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

11 FEBRUARY 1999

Date of mailing of the international search report

19 APR 1999

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