SYSTEMATION LETTER

ON THE ART OF BETTER MANAGEMENT THROUGH SYSTEMS

Number 287

BETTER SOLUTIONS WITH DECISION TREES

Many times the systems analyst is called on to assist in the decision-making process by recommending solutions to problems. Often these are not simple problems. This is because possible solutions are affected by uncertain, future events. In order to recommend *valid* solutions, the systems analyst must consider many facts at once as well as apply professional judgment to the problem.

By following a careful step-by-step plan and using decision trees to record important information, the systems analyst *is able* to select the best solution more often. These steps are:

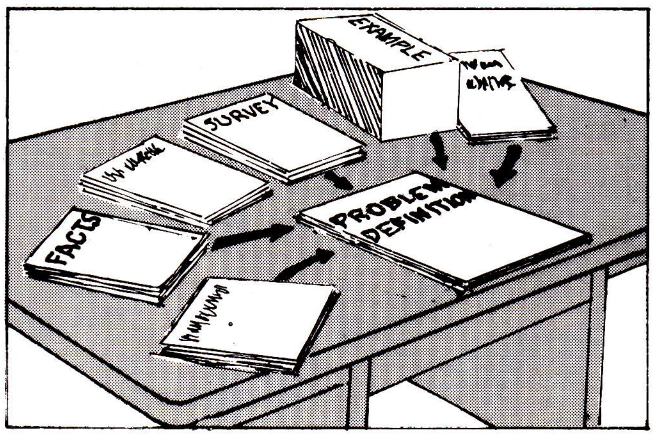
(1) Define the problem
(2) Identify the alternatives
(3) Define future events
(4) Set up a decision tree
(5) Estimate chances of future events
(6) Assign costs
(7) Perform the analysis
(8) Select the best alternative

This issue of the Systemation Letter focuses on each of these steps in the systems framework.

DEFINE THE PROBLEM

In order to solve a problem, someone must first define it. Problem *areas* may come to you, the systems analyst, from decision makers, from fellow workers, or from people in other departments. In any case, you must investigate the problem area and clearly define the problem. It is helpful to document important information such as facts, figures, examples, etc. . . . The final problem definition should be carefully summarized in not more than a paragraph. All important information should be tabularized and sorted to show the validity of the problem definition. The problem definition now serves as the basis for the remaining steps.

As a simple example, a gift store prefers to use its showroom for as many different gifts as possible. It keeps stock for each gift in the warehouse area connected to the back of the store. When a customer selects an item, a clerk writes up an order and gives it to the warehousemen. They select the desired item and send it on a long conveyor belt to the checkout



Problem definitions consist of facts, examples . . .

stands. The conveyor belt is wearing out and will have to be replaced.

The problem is obviously the aging conveyor belt. As you investigate the problem, you determine that the belt jams occasionally. Each jam takes ½ hour to repair. This leaves the warehousemen and checkers idle. Since the idle time will *cost* the gift store in non-productive wages, you record the worker and wage information as below:

WORKER	*WAGE (per hr.)*	*NUMBER*
Checker	\$2.50	4
Warehousemen	\$4.50	5
Repairman	\$7.50	1

At this point, you have defined the problem and documented the important information.

IDENTIFY THE ALTERNATIVES

Once you have defined the problem, you are ready to isolate a set of alternatives. Alternatives *may* come up during your investigation of the problem. More frequently however, you must *think out and develop* appropriate alternatives. Make up a quick list. Include anything that comes to mind. Then select those alternatives which you think have the best chance of solving the problem. Write the alternatives down and put them with the problem definition.

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For the example problem, list several initial alternatives:

(1) Have warehousemen bring up items during jam
(2) Have checkers get items from warehouse during jam
(3) Put stock on shelves in store
(4) Purchase a new belt

The first and second alternatives are rejected due to union rules and problems related to safegaurds against theft. The third alternative conflicts with the objective of displaying as many different items as possible and thus is too radical. It is not a solution for the immediate belt problem. You select the fourth alternative; however, you're not through. The best belt must be chosen.

You find that there are two acceptable conveyor belts available. One is more expensive than the other, but jams less frequently. The alternatives and associated data are tabularized below:

BELT	*ESTIMATED JAMMING RATE*	*COST*	*LIFE*
A	1 per month	$9,000	3 years
B	3 per month	$8,100	3 years

DEFINE FUTURE EVENTS

Next, let's define those future events which will influence the success of the alternatives. All decisions are affected by several events, but *only a few are important.* You therefore select the events based on their degree of importance.

In the example problem, the performance of the belts will be influenced by a jam, a total breakdown, bad maintenance, improper loading, and other future events. A total breakdown is not likely, and the effects of bad maintenance, improper loading, etc. will probably be the same for both. Thus, you decide that a jam is the only important future event to consider. You also feel.that at most, only one jam will occur per day for either belt. The future events for this problem area become either zero or one jam during a day.

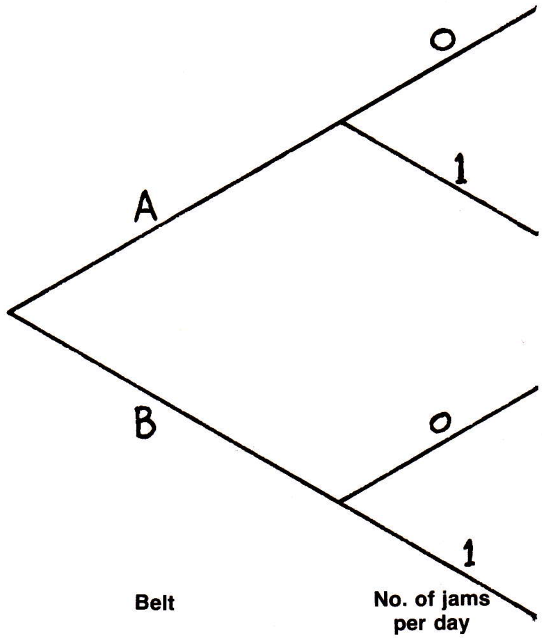
SET UP A DECISION TREE

An excellent way to record the important information in the solution of a problem is to use decision trees. In one place, (and usually on one page) decision trees:

(1) Show what the alternatives and future events are and how they relate.
(2) Provide a record of the chances of future events and what the costs are for each.
(3) Allow for rapid analysis and selection of the *best* alternative.

For the example problem, you set up the initial decision tree as shown.

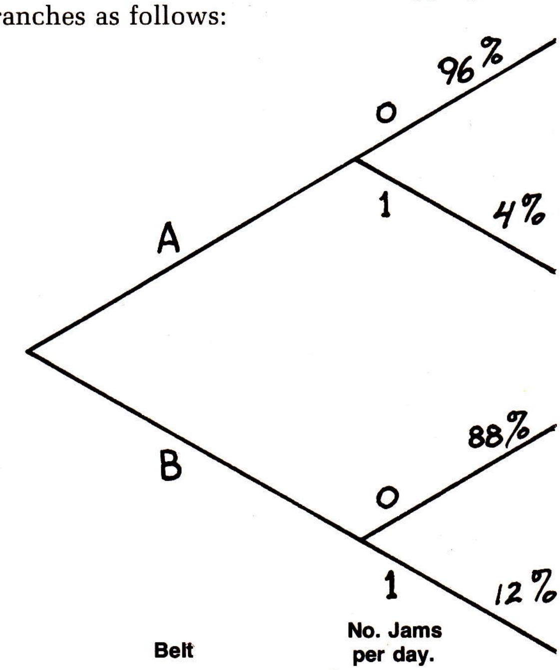
The alternatives are placed on the first "branches" of the tree. The future events (number of jams in a day) are placed on the second set of "branches" for each alternative.



ESTIMATE CHANCES OF FUTURE EVENTS

Using your professional judgment or past records estimate the chances of each future event. Much like a weather forecaster estimates the chances of rain, you estimate the chances of zero or one jam in a day.

For belt A, we have estimated that it will jam about once a month. On the basis of a six day week, this gives about a 1/25th or 4% chance of jamming on any one day; leaving a 96% chance of not jamming.* For belt B, we have estimated that it will jam three times a month. This gives about a 3/25th or 12% chance of jamming, leaving an 88% chance of not jamming. These chances are written on the appropriate event branches as follows:



Add chances of jams to the decision tree

**The sum of the chances for all possible events is 100%.*

ASSIGN COSTS

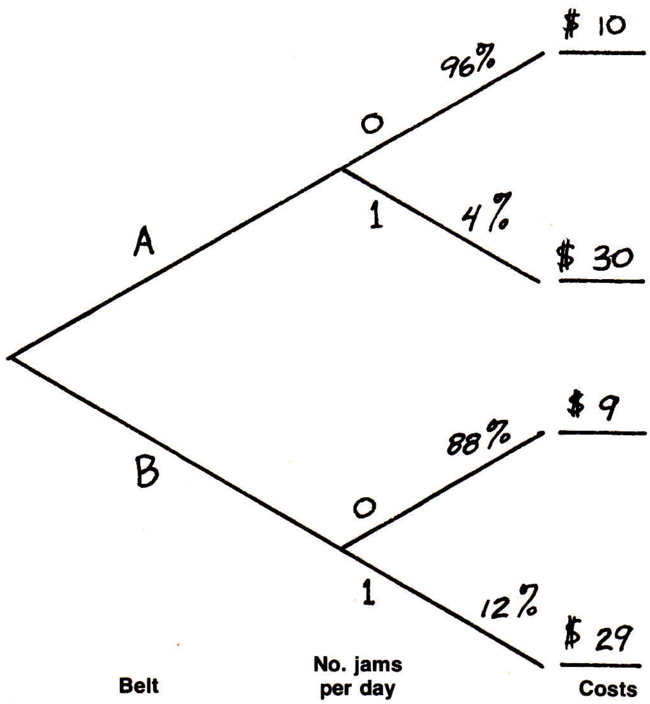
Next, you calculate the costs of each alternative. Since the jamming rates are in terms of days, you compute all costs in terms of one day. With a six day week and figuring a 50 week work year there are 300 work days in each year. Over a 3 year life (900 days), the *daily cost of the belts* is calculated as follows:

BELT	*COST*	*COST/DAY*
A	$9,000	(÷ 900 =) $10
B	$8,100	(÷ 900 =) $ 9

The *cost of a jam* can be figured as the wages wasted while the checkers (4 at $2.50 per hour) and warehousemen (5 at $4.50 per hour) are idle and one repairman (at $7.50 per hour) works for ½ hour. This amounts to:

(4 × 2.50)+(5 × 4.50)+7.50 = $40 ÷ 2 = $20

To figure the costs for one jam, add the jam cost to the belt's daily cost. For zero jams, use only the belt's cost. Write these costs on the decision tree as follows:



Add costs to the decision tree.

PERFORM THE ANALYSIS

You are now ready to combine the cost and chance estimates to get weighted costs for each alternative. You do this by (1) multiplying each cost by its chance of occurrence, (2) dividing by 100, and (3) adding the results together for each alternative:

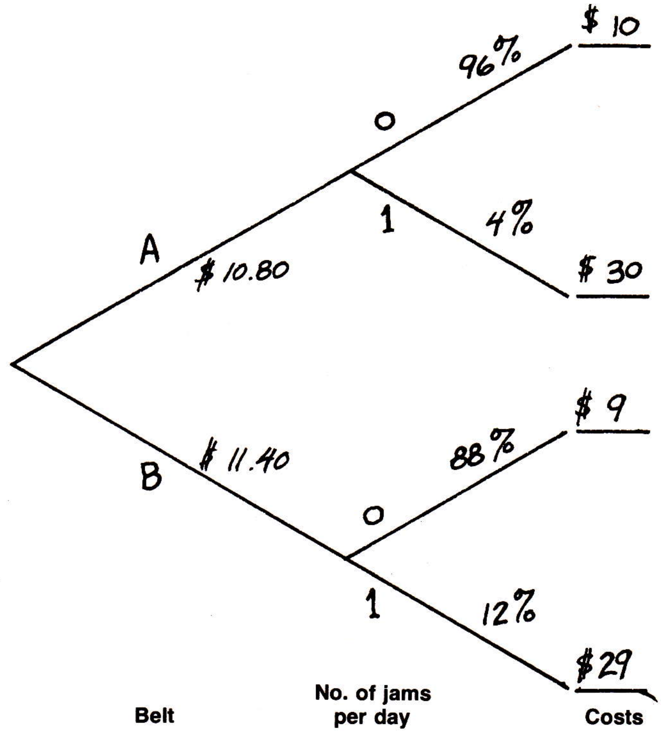
For belt A,

($10 × 96%) ÷ 100 = $ 9.60
($30 × 4%) ÷ 100 = $ 1.20
$10.80

For belt B,

($9 × 88%) ÷ 100 = $ 7.92
($29 × 12%) ÷ 100 = $ 3.48
$11.40

These results show the average cost per day for each belt. Write these results on the decision tree:



SELECT THE BEST ALTERNATIVE

The total costs over the 3 year (900 day) life of the belts are as follows:

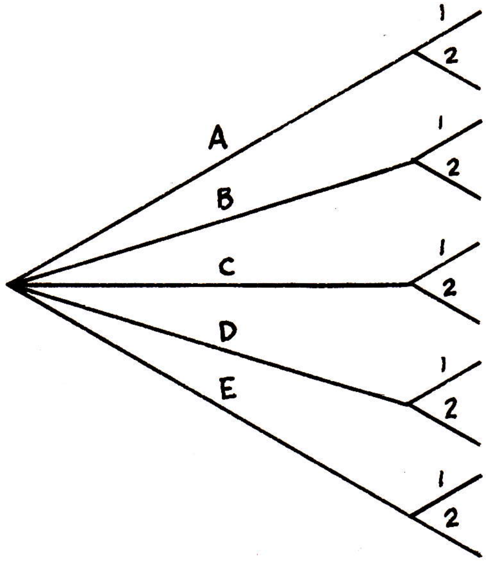
BELT	*DAILY COST*		*LIFETIME COST*
A	$10.80 × 900	=	$ 9,720
B	$11.40 × 900	=	$10,260

The difference in daily costs over a 3 year period is $540. The original purchase price of the belts is included in the analysis. Therefore, there is a clear savings of $540 if belt A is chosen. Clearly, you should recommend belt A.

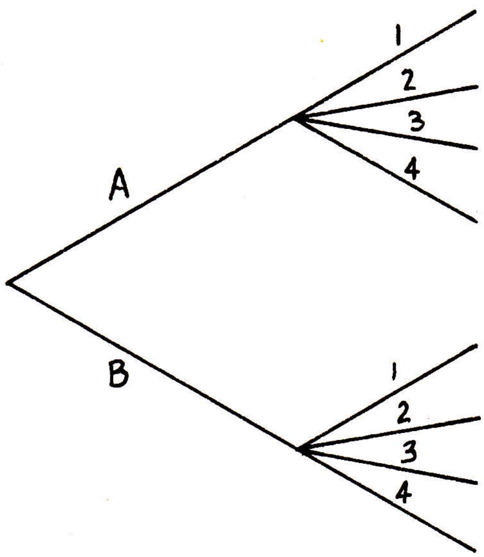
By using decision trees and the problem solution steps, the systems analyst can evaluate alternatives based on costs and chances of future events. He or she can then make better recommendations and be able to substantiate them with facts and analysis, *not guesses and hunches*. If the recommendation is not accepted, the analyst may easily re-do the analysis. Since the analysis is documented on the diagram, he may add an alternative or future event, modify his future event estimates, or change his cost figures without having to start all over.

VARIATIONS

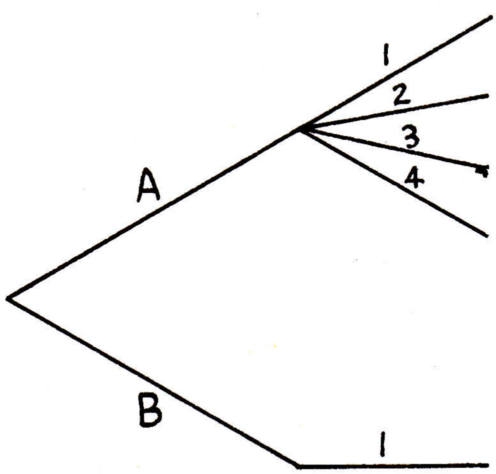
Decision trees do not always look the same. They can have several alternatives and few future events:



They may have few alternatives and several events:

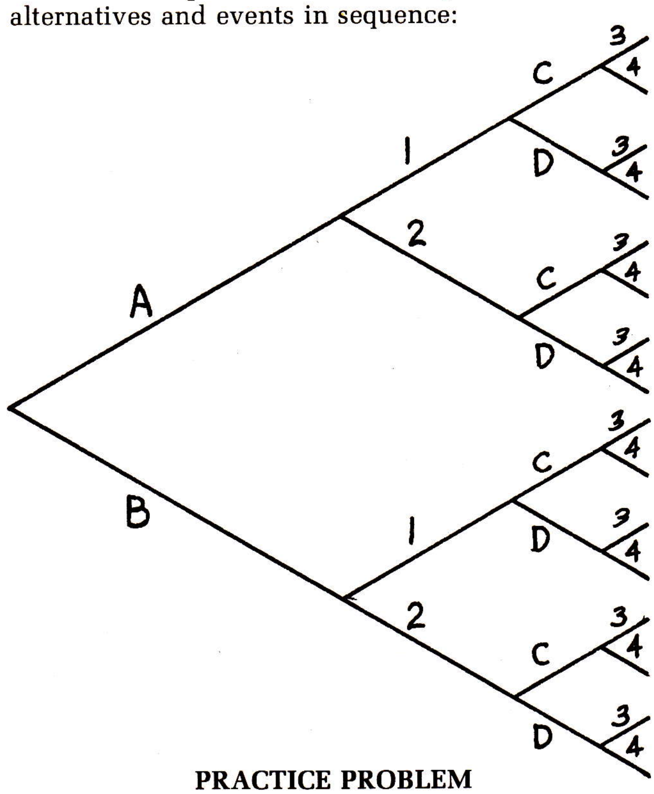


In some cases, there may be only one event associated with an alternative and several for another:



In any case, the decision tree must be set up to show all *important* alternatives and future events.

A more complex decision tree may show a series of alternatives and events in sequence:



PRACTICE PROBLEM

The EPA has ordered XYZ Refining Company to install a pollution control device. The agency has given XYZ one year to have such a device installed and working. If the device is not installed in one year, XYZ will be assessed a $500 fine each working day until the device is installed. (Assume a 250 workday year.)

It will take one year to install the only model presently available. But, there is a 25% chance that it will not work in this type of refinery. The cost of the device is $500,000. Another model will be ready for installation in one year, and it is guaranteed to work. This one will also take one year to install and will cost $500,000.

If XYZ has the current non-guaranteed model installed and it doesn't work, XYZ will have to pay fines for a year while installing the guaranteed model.

Should XYZ wait for the later model, paying the fine for a year? Or should it take a chance and install the non-guaranteed pollution control device?

Set up a decision tree. Perform an analysis and select the best alternative. If you wish an evaluation of your solution, send it to us at:

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Attn: Decision Tree
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SYSTEMATION LETTER

ON THE ART OF BETTER MANAGEMENT THROUGH SYSTEMS

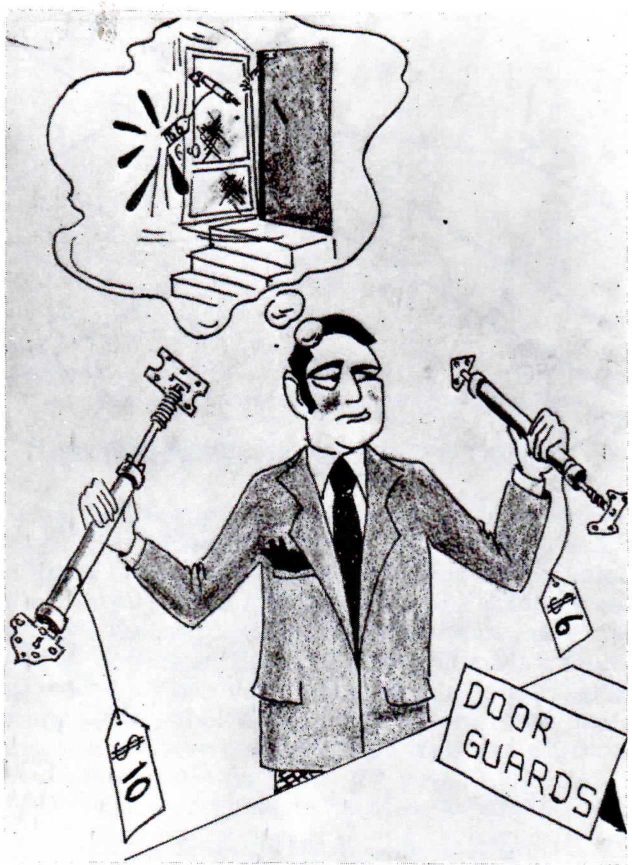
BETTER SOLUTIONS WITH DECISION TREES PART II

Number 288

In the last Systemation Letter (No. 287), decision trees were used to help the systems analyst recommend better solutions. The example used was a simple case, and due to space limitations, not all of the details were provided.

This Letter presents and discusses certain of those details, such as:

1. When to use decision trees.
2. Other ways to use decision trees.
3. Guidelines for constructing decision trees.
4. Guidelines for assigning costs.
5. Guidelines for estimating chances of future events.
6. Why decision trees work.

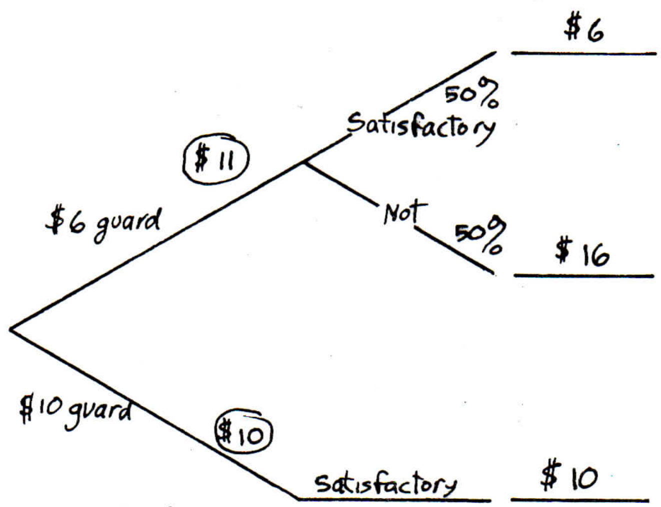


WHEN TO USE DECISION TREES

Decision trees should be used whenever possible. By getting into the habit of using decision trees for decision making, even if only mentally, you will find that setting up more complex problems will become easier. Think about the number of times you have had to decide on a simple purchase (for your home, car, etc.) and you have had to weigh the cost of various items in terms of durability, fit, life, etc.

For instance, you need a screen door guard. You've found two, one costing $6, but you're not sure it's strong enough. Another costs $10, but you're sure it will work. You guess that there's a 50-50 chance of the first one working. Since you cannot test it without installing it and therefore making it unreturnable, you must make your decision prior to purchase.

A decision tree makes the decision simple:



You choose the $10 guard.

You can also use the decision tree technique to determine what percentage chance of working would make it economical to buy the $6 guard.

Trial and error show that a 60% chance of the $6 guard working would make the costs the same ($10). Above a 60% chance would make the $6 guard the better choice.

Although this example seems trivial, making

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choices using decision trees even in such simple problems instead of guessing can save you time and money and also reduce headaches.

OTHER WAYS TO USE DECISION TREES

A powerful use for decision trees is in situations in which non-monetary costs must be included in the problem solution. Non-monetary costs are those which cannot be expressed in dollars. These can include . . . customer relations . . . integrity . . . stock holder confidence . . . etc.

For instance, the practice problem in Systemation Letter 287 ignored community and Environmental Protection Agency (EPA) costs.

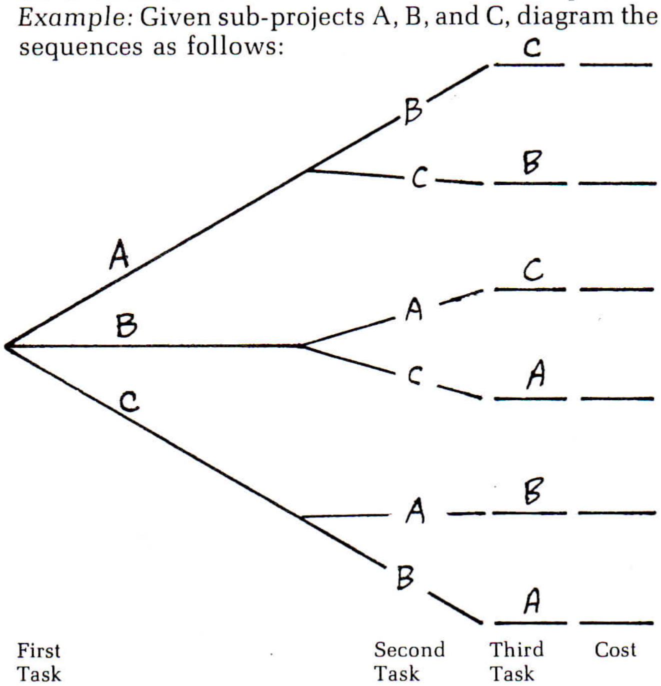
The solution showed that XYZ Refining Company should wait and install a guaranteed pollution control device rather than install a chancy one. This meant that XYZ would continue polluting the air for an extra year and pay fines to the EPA.

As our solution stated, the expected cost savings of $31,000 should be weighed against the possible poor relationship it would cause with the community and the EPA. This, of course, is a management as well as a political decision. But, the decision couldn't have been made if the expected costs hadn't been computed first.

So, decision trees can be used to establish a realistic, expected cost for each alternative and then the non-monetary costs can be analyzed and directly compared with each alternative's monetary costs.

There is *another situation* where you can effectively use decision trees. This occurs when you are called on to evaluate any combination of possibilities that may occur. For instance, you may have to carry out a project, but you don't know the sequence a set of independent tasks will or should take. In addition, rising prices can affect costs of different tasks depending on when they are completed.

You can diagram the various combinations of tasks on a decision tree and evaluate each sequence. *Example:* Given sub-projects A, B, and C, diagram the sequences as follows:



Each sequence can be evaluated.

With this diagram and a few minutes at the calculator or time-share terminal, you are able to determine:

1. How much each path will cost
2. Which path is least or most expensive
3. What project should be started first or second.

You may not have a say in the first choice, but you can choose the second one more wisely. You may find your decision helpful in convincing someone to get started earlier or possibly to wait!

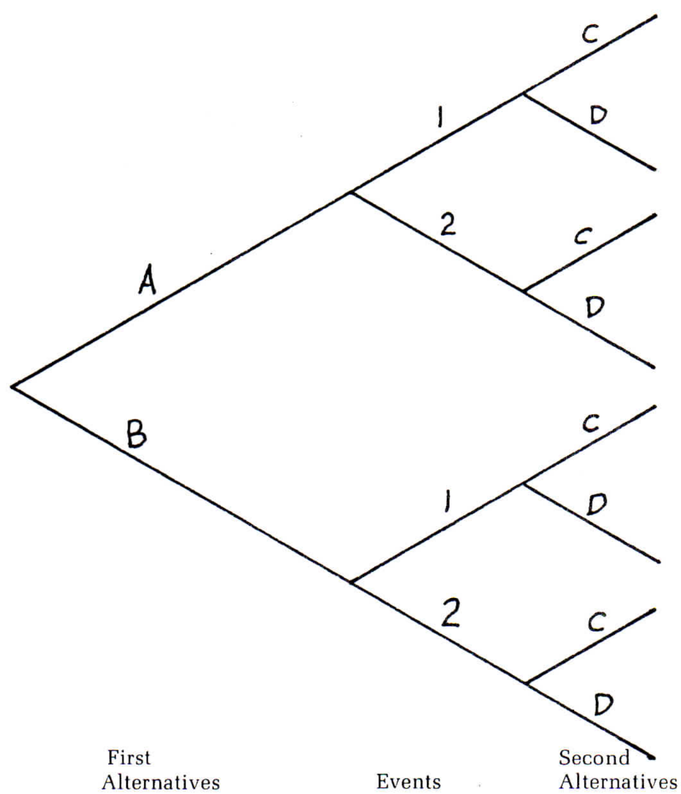
RULES FOR CONSTRUCTING DECISION TREES

There are three basic rules of decision tree construction. These are:

1. Completeness
2. Ordering (sequencing)
3. Non-ambiguity

Rule 1: The tree must be complete. Every possible choice and each relevant future event must be shown on the tree. This rule is easy with a good definition of the problem and identification of alternatives and future events.

Rule 2: The decision tree must be ordered properly. It is ordered by time in a left to right direction. This means that the *sequence* of alternatives and events on the diagram *must be shown as it will occur in time.* If a choice can be made between A and B *now*, and *after* event 1 or 2 has occurred, a choice can be made between alternatives C and D, diagram this way:



The decision tree should be ordered properly.

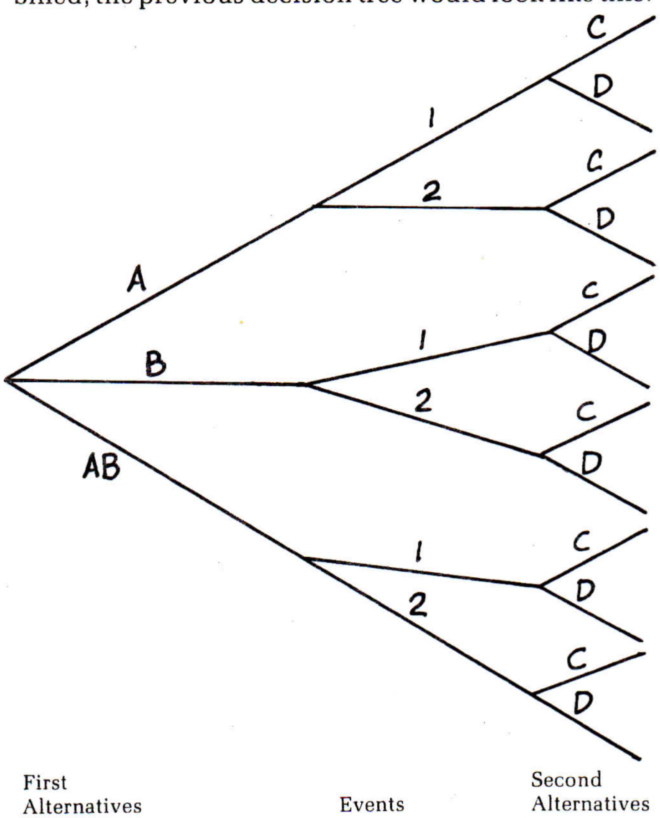
Other important ordering principles are as follows:

- The date of an event is *not* important, it is the date that you learn of the event that is important.

- An alternative that can be revoked later at no cost is actually not an alternative. If it can be revoked later at a cost, it is actually two choices — one now and one later.
- Alternatives may be diagrammed out of order if no events occur between them. Events may also be diagrammed out of order if no alternatives fall in between them.

Rule 3: The third basic rule is that of non-ambiguity. If two or more of the alternatives may be combined and chosen, they should be. The combination is then considered another alternative. By making such combinations and diagramming all of them on the decision tree, the tree is considered non-ambiguous.

For instance, if alternatives A and B can be combined, the previous decision tree would look like this.



The decision tree should show all combinations.

GUIDELINES FOR ASSIGNING COSTS

The important rule in assigning costs is to be consistent. This means that all the units of cost should be the same. (The dollar is the most frequently used cost unit.) As you write the costs on the decision tree, don't use thousands of dollars in one place, and millions of dollars in another. Also, the costs should relate to the same date. Inflation and interest give money a time value. If you are doing long range planning, you will want to base future costs and gains on today's dollar, not the dollar ten years from now.

A choice is often made between buying now to improve your operations, or saving the money. If the results of your purchase will not be known for several years, you should show how your savings could grow in the same period of time.

Not only should the costs be consistent among themselves, they must be consistent with the other factors in the analysis. For instance, if the chance estimates of a future event are based on a day, the costs must also be based on a day. This situation occured in the sample problem in Systemation Letter 287 on decision trees. The chances of a breakdown for belt A were 4% and 96% for *each day*. Therefore, the lifetime cost of the belt had to be reduced to a *daily* cost. This gives a realistic view of the cost differences once the analysis is performed. However, it is only necessary to use daily costs if the chances are based on daily events. Use monthly, annual, or lifetime costs as the problem dictates.

Also, be careful not to mix daily costs for one period with daily costs for a longer or shorter period. The daily costs must be based on the same period of time. If daily costs can be summed to give total costs, do so and avoid the mismatch. You can also convert daily costs for five years to daily costs for one year by multiplying by 5.

GUIDELINES FOR ESTIMATING CHANCES OF FUTURE EVENTS

A basic rule is that the sum of chances of all the possible future events *for an alternative* is 100/. For instance, one alternative (A) may have the possibility of events 1, 2, and 3 occurring if it is chosen. However, another alternative (B) may only have events 1 and 2. The sum of the chances for 1, 2, and 3 in A's case must equal 100% and the sum for 1 and 2 in B's case must also equal 100%. Looking back to page 1, you see that the choice of the $6 guard gave a satisfactory or a not satisfactory event at 50% each. This sums to 100%. Because the $10 guard had a single event, that event had to be 100%.

The idea of estimating chances of future events seems difficult at first. However, a couple of techniques help considerably. If you have past records of the performance of the alternatives you are trying to choose between, you are one step ahead. To get the chance of a breakdown on a piece of equipment, count up the number of total operating days. Also count the number of days it is not operating. (You may even want to know for how long — save this, too.) Dividing the number of breakdown days by the total will give you a percentage or chance of a breakdown on any day in the future. If you are concerned only about the chances in a month, count the number of months and divide this into the number of months that had at least one breakdown.

However, insure that this is a good indicator. Pick the time period in which there is some chance of a breakdown occurring. An hour may be too small; a week or month may be too long. Select a period where 0, 1, 2, or 3 occurrences of an event may happen. Any more will create a very complicated tree.

If you have no past records, you can use a second technique. First, try to find an expert on the problem for which you're seeking a decision. Even if you can't, proceed on. One of you can then follow this procedure:

(1) Is the chance of an event above or below 50%? If above 50%, go to 3, if below 50%, go to 2. If neither, estimate 50%.
(2) Is it less than 25%?

(a) Yes. Estimate somewhere from 5% to 20%.
(b) No. Estimate somewhere from 30% to 45%.
(c) Neither. Estimate 25%.

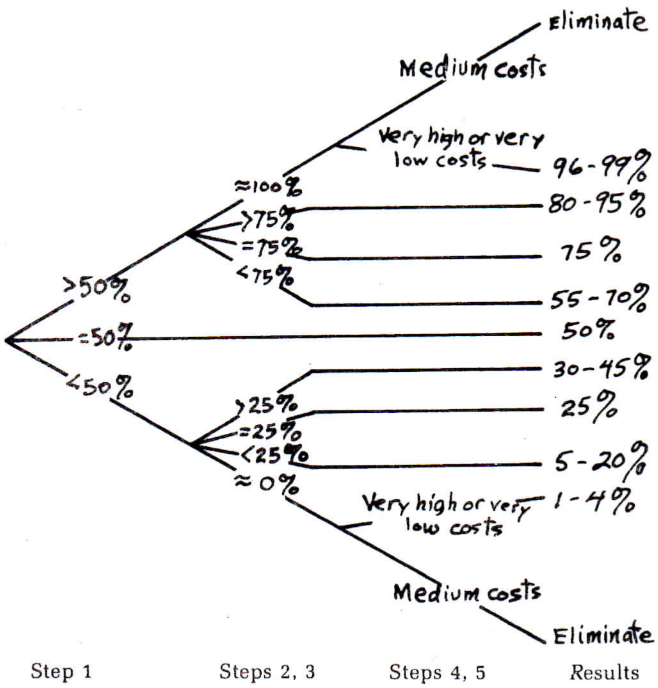
(3) Is it greater than 75%?
   (a) Yes. Estimate somewhere from 80% to 95%.
   (b) No. Estimate somewhere from 55% to 70%.
   (c) Neither. Estimate 75%.

(4) If your estimate is very close to 0%, consider eliminating the event unless it has a very high or very low cost associated with it.

(5) If your estimate is very close to 100%, consider eliminating the others, unless 4 holds true.

(6) Do the same for all events in a group; then raise or lower them proportionately to make the sum equal to 100%. This can be quickly done by dividing each by the sum of them all. For example, your estimates for events 1, 2, and 3 are 25%, 40% and 15%. The sum is 80%. Dividing, you get 31%, 50% and 19% (which sum to 100%).

The chance estimating procedure can be summarized using a tree:

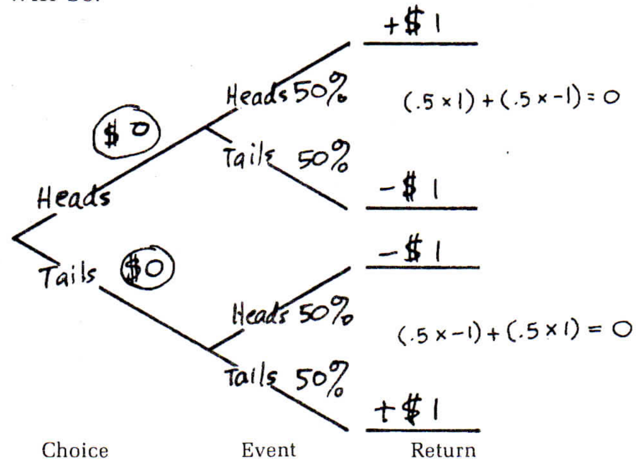


WHY DECISION TREES WORK

You may be asking the question, Why should I recommend a solution based on costs that won't actually occur? For instance, the $6 guard on page 1 shows a cost of $11. But you see that it will either cost $6 or $16, not $11. This $11 cost is not meant to be the cost for this single problem. The idea is to determine what the costs will be to you for several similar problems.

Let's take a look at a simple problem — the flip of a coin. A coin has a 50% chance of coming up heads and the same for tails, though each flip only produces a head or a tail. If the flip is repeated several times, about half of the results will be heads and half tails. If you bet $1 on heads for 100 flips, you would win about 50 times and lose about 50 times. This would give you a net return of nothing.

If you were trying to decide between heads or tails, a decision tree would show you what the situation will be:



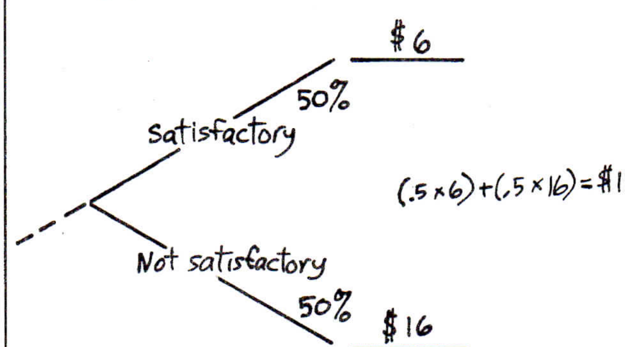
In the long run, neither heads nor tails is better.

This shows that if the problem were repeated several times heads or tails have the same return even though heads could win $1 or lose $1 on each flip.

Decision trees are used to improve your ability to choose the best solution. They are not going to give you a perfect record. By practicing the steps outlined in this letter and Systemation Letter 287, you will make better decisions more often.

When using decision trees, put as much information on the tree as possible--alternative names, partial costs, analysis calculations, etc. This way you can usually concentrate everything concerning the problem solution on one page!

For instance, the calculations for the screen door guard can be done on the decision tree:



Now the tree shows *everything* about the problem.

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SYSTEMATION LETTER

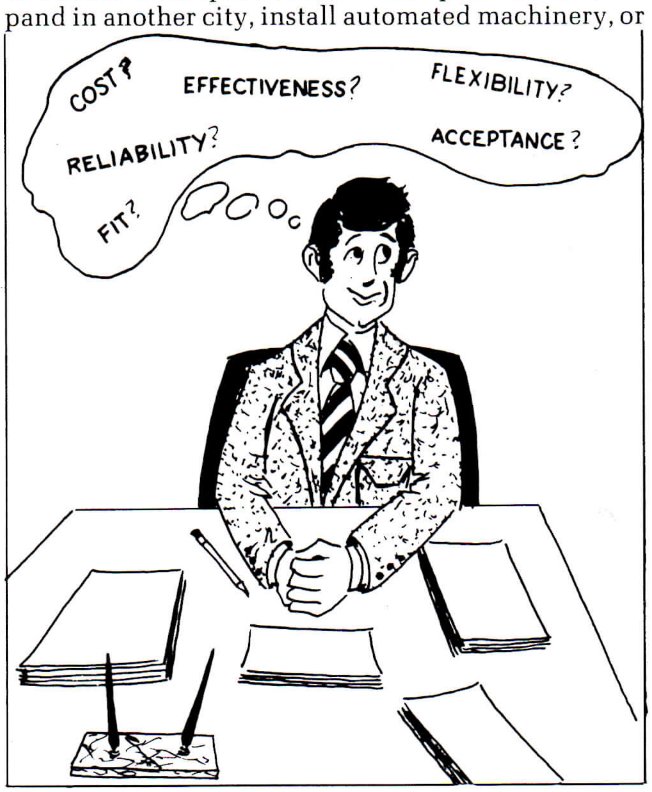
ON THE ART OF BETTER MANAGEMENT THROUGH SYSTEMS

Number 295

A SYSTEMS APPROACH TO SOLVING COMPLEX PROBLEMS (Part I)

How many times have you been asked to analyze a complex problem and found that there are so many different factors to be considered, you don't know how you can consider them all? In making a feasibility study, for instance, you find that there are several goals that need to be satisfied. These goals may be both qualitative *and* quantitative. In addition, the goals are somewhat interrelated — the satisfaction of one goal depends on another goal's satisfaction. Most of the time, we simply consider the costs involved and make our recommendations on that basis, and perhaps throwing in some of the other considerations to sell our conclusions.

When we think about how often similar situations come up, the simple "cost-plus" approach often leaves us less than confident with our results. Studies to choose a computer, start a new product line, expand in another city, install automated machinery, or hire a new person all involve many, interrelated goals. If there were some way to analyze the alternatives considering all the goals, we would provide much better results and be more confident in our conclusions.



Several goals need to be satisfied.

A method called Goal Fabric Analysis* allows us to consider all pertinent goals and provide an ordered list of alternatives as our results. By breaking down goals into sub-goals, we can analyze our alternatives using well defined criteria, thereby justifying our conclusions.

Intangible goals such as customer satisfaction, sales potential, aesthetics, effectiveness . . . can be used equally well as costs, economic life, and other quantifiable goals.

This Letter will explain how to:

- Outline your goals
- Build a goal fabric
- Use the goal fabric to analyze your alternatives.

GOALS LIST

The first step is to list *all* the goals that you are trying to reach. This will require some thinking on what the problem is and what it takes to solve it. The list will easily become complicated with interrelated goals. To illustrate, let us look at a situation that we may have some knowledge of — selecting a systems analyst. The goals list could look something like this:

1. Lots of drive
2. Writes well
3. Has at least 5 years experience
4. Fits into the organization
5. Accepts reasonable salary
6. Has an analytical mind
7. Has lots of initiative
8. Is creative
9. Has a compatible personality.

- •
- •

* Goal Fabric Analysis was first presented in "Abstract Representation of Goals," a paper by Professor M. L. Manheim of MIT and F.L. Hall, then with Peat, Marwick, Livingston, and Co., Boston, now with McMaster University, Hamilton, Ontario.

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As you can see, the list may be both long and interrelated — goal 7 (initiative) is part of goal 1 (drive); goal 9 (personality) is part of goal 4 (fit).

GOALS OUTLINE

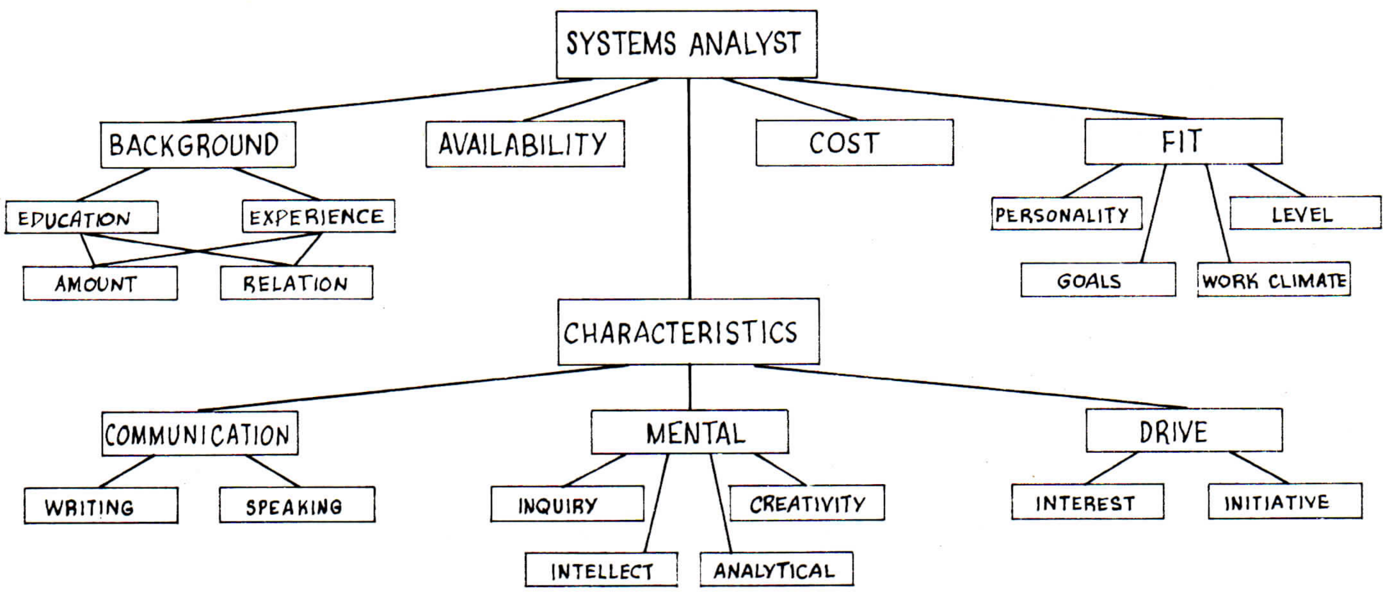
In order to make some sense out of the list, you organize the list into an outline. The outline shows the goals broken down into their sub-goals, and the sub-goals further broken down, if appropriate. Using our example, part of the outline would look like this:

1. Characteristics
   - A. Communication
     1. Writing
     2. Speaking
   - B. Drive
     1. Interest
     2. Initiative
   - C. . . .
2. Background
   - A. Experience
     1. Amount
     2. Relation
   - B. . . .

Converting the list to outline form will help you round out your list by filling in any logical holes a list can easily leave out. The outline also makes it easier to perform the next step — building the goal fabric.

GOAL FABRIC

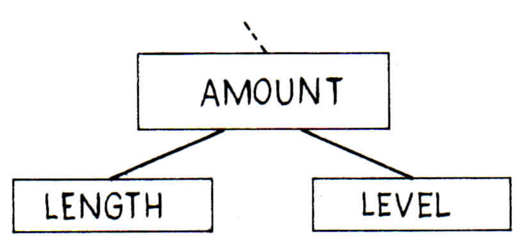
In order to best present and perform a goal fabric analysis, construct a goal fabric. This is simply a diagram of the goals outline you just completed. It usually fits on one piece of paper and is used throughout the analysis. The goal fabric for our systems analyst selection is as shown below:



Note that the sub-goals **amount** and **relation** are connected to both EDUCATION and EXPERIENCE. This was only to save space. These sub-goals could be repeated under EDUCATION and EXPERIENCE or left as diagrammed. Either method works equally well. Note also that the goal CHARACTERISTICS and its sub-goals are placed below the others on the diagram. This placement is also used to save space and not intended to mean that CHARACTERISTICS are below BACKGROUND, AVAILABILITY, COST, or FIT.

The goal fabric should be examined carefully to see that it is as complete as possible. For instance, under COMMUNICATION you could add communication **with others,** since writing and speaking are only part of the communication picture. You add the sub-goal **with others** under the goal COMMUNICATION. This item is also added to the goals outline as the third entry under Communication (1.A.).

Also, sub-goals should be amplified if they seem ambiguous. For instance, the **amount** of EDUCATION or EXPERIENCE can be expanded to indicate the *length* and the *level* of either. The goal fabric is modified again:



The main objective of both the goals outline and its goal fabric is to break the goals down into meaningful sub-goals. The lowest order sub-goals or the criteria are those which can be evaluated from a comparative standpoint. For instance, background is an ambiguous word whereas the *level* of a person's EDUCATION or EXPERIENCE has a more definite meaning and can be used to compare candidates for your systems analyst position.

ALTERNATIVES EVALUATION

Once you are satisfied with the goal fabric, you are ready to evaluate the alternatives that you have available to you. In this case, it is the candidates which meet the minimum requirements. The alternatives should be investigated and evaluated with respect to the criteria (lowest order sub-goals) on the goal fabric. This can be done directly on the goals outline. One column for each alternative is drawn on the outline and notes on each criterion entered:

Systems Analyst

(Alternatives Evaluation)

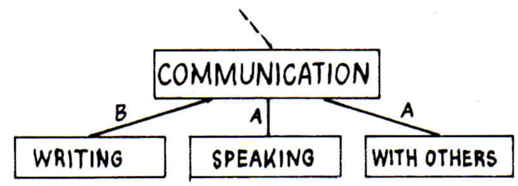
	Alternative A	B	C	D
1. Characteristics				
A. Communication				
1. Writing	[illegible]	[illegible]	[illegible]	[illegible]
2. Speaking	[illegible]	[illegible]	[illegible]	[illegible]
3. With Others	[illegible]	[illegible]	[illegible]	[illegible]
B.				
C.				
D.				
2. Background				
A. Experience				
1. Amount				
a. Length				
b. Level				
B.				
C.				
D.				

The notes under each alternative are not intended to be numbers or some other strict scale. They are only intended to remind you of how you evaluated each candidate. Notes like "good," "fair," "bad," "marginal," etc. are sufficient in most cases. Of course, salary figure estimates and number of years experience are excellent, if available. This data is collected from the candidate's resume, application, interviews, and references or you may have to summarize several inputs from other people in your firm.

ALTERNATIVES COMPARISON

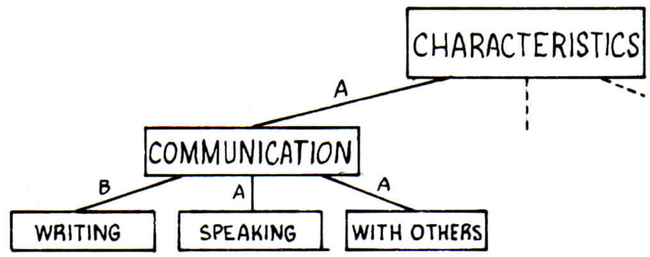
The next step is to compare the alternatives in pairs using the evaluation data. Using your goals outline and goal fabric, check each criterion. You determine which candidate looks better for each criterion and make a note of this on a copy of the goal fabric. For instance, candidate A may have better speaking ability than candidate B. So when comparing these two, an "A" is placed on the line to **speaking** under COMMUNICATION.

The results of the comparison of A and B for the other criteria under COMMUNICATION are also placed on the goal fabric:

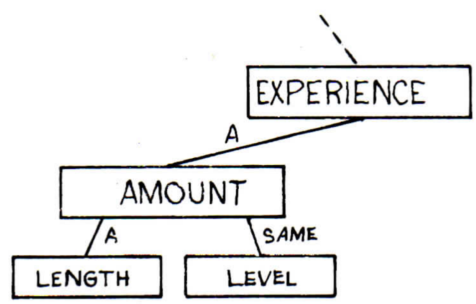


You continue this process, placing the results for each criterion for the pair A and B on the goal fabric.

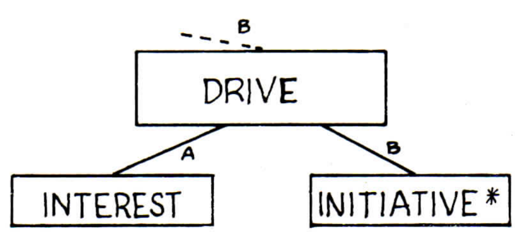
Now you use this information to determine which alternative dominates under each sub-goal. For instance, since A is better than B in two out of the three criteria for COMMUNICATION, A dominates. This dominance is passed on to the COMMUNICATION sub-goal and recorded on the line from CHARACTERISTICS:



This system is continued for all criteria. In cases where the criteria evaluated is the same for each alternative, you would use the other criteria to determine dominance. For example, if A and B both have the same *level* of experience, the *length* of experience would determine the dominance under **amount:**

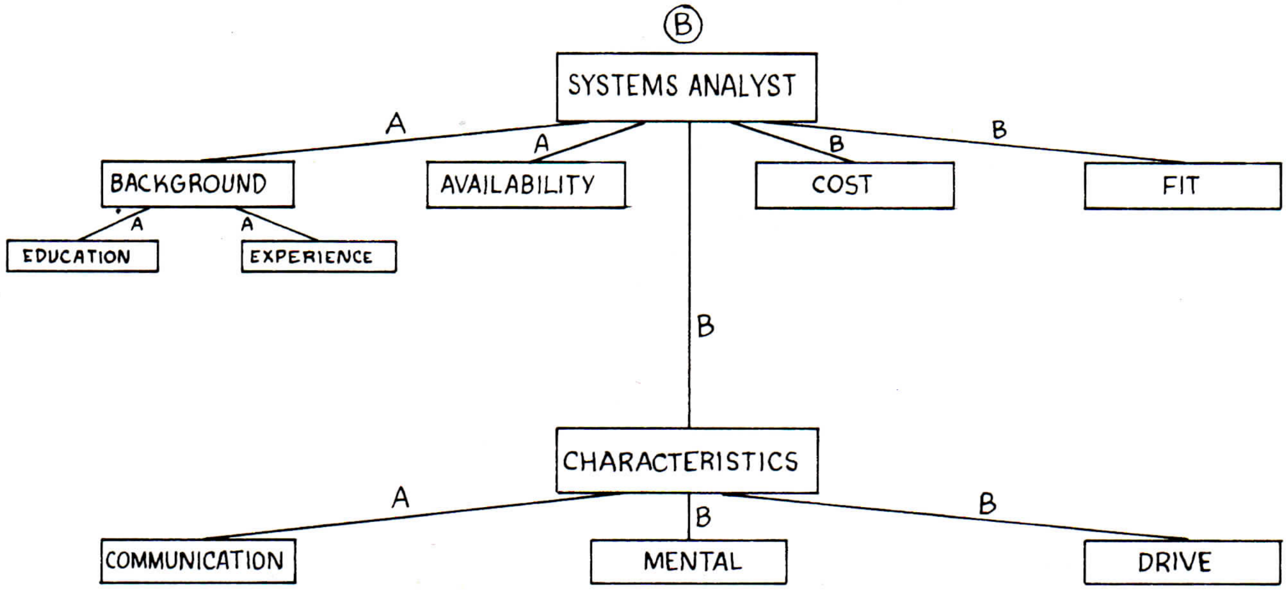


Another problem occurs when a sub-goal has only two criteria with one alternative better on one and the other alternative better on the other. You have to weigh the relative importance of one criterion over the other. For instance, candidate A may have more **interest** and B had more **initiative** (under DRIVE), and you may consider interest less important than initiative. Therefore, B dominates for DRIVE:



This weighing should be recorded on the fabric or outline to keep analysis consistent (note the asterisk on **initiative**).

Now that you have determined the dominance for each sub-goal, you can transfer this dominance up to the next sub-goal. This process continues until you determine the overall dominance. Follow this transfer of dominance on the example goal fabric (criteria not shown):



The Goal Fabric used to compare alternatives A and B.

ALTERNATIVES RANKING

Once you have determined the dominance of a pair of candidates, you can compare the dominant candidate to the next candidate. Or you can determine the dominance for all combinations of pairs. The "all combinations" method is fine for 3 or 4 candidates, but is not recommended for more than 4.

Using the "all combinations" method in our example, start out with 4 alternatives, A, B, C, and D ranked in that order (ABCD for short). Once you show that B is dominant over A, the order becomes BACD. Now A is compared to C. Given that A is dominant over C, the order remains the same — BACD.

Successive comparisons of the remaining combinations of pairs will lead to the final order — DBAC. The pairings, dominance, and results are as follows:

Pair	Dominance	Ranking
AB	B	BACD
AC	A	BACD
AD	D	BDAC
BC	B	BDAC
BD	D	DBAC
CD	D	DBAC

It actually wasn't necessary to compare B to C or C to D since the dominance was determined in earlier comparisons.

Goal Fabric Analysis method is straightforward and easy to perform. The steps are:
1. List the goals
2. Outline the goals
3. Sketch the goal fabric
4. Evaluate the alternatives
5. Compare the alternatives in pairs
6. Rank the alternatives

Goal Fabric Analysis can and should be used whenever possible. Using it provides definite advantages:
- It shows the complete rationale for the results.
- It is dynamic. The goal fabric can be modified and the analysis easily repeated using two annotated goal fabrics for each pair.
- Additional alternatives can be added and ranked without destroying the original data or ranking.
- It is flexible. It can be used by analysts, staff, or management with their own data or using data provided by the ultimate decision maker.

In a later Systemation Letter, I will give more details on how to deal with interrelated criteria, additional reduction techniques, ranking shortcuts, solutions to deadlocks, and a minicomputer selection example.

Kenton H. Johnson, Guest Author

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SYSTEMATION LETTER

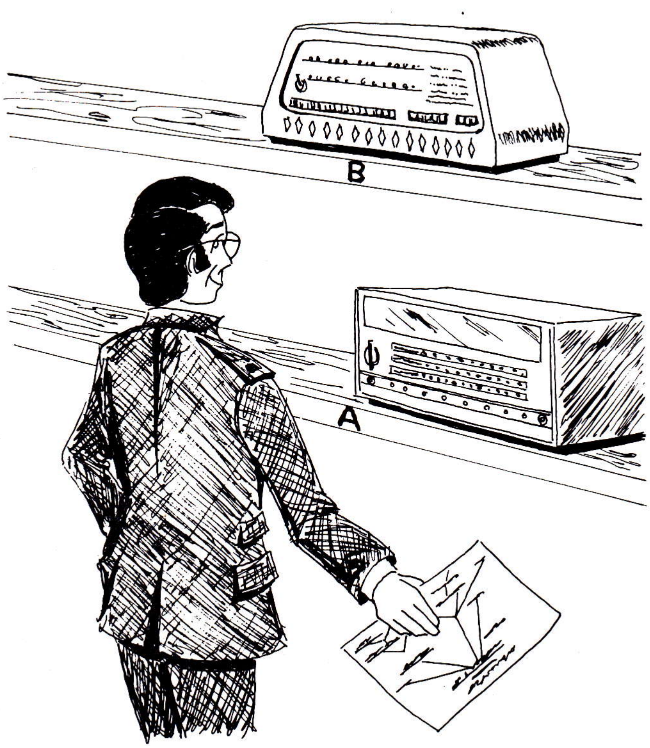
ON THE ART OF BETTER MANAGEMENT THROUGH SYSTEMS

Number 297

A SYSTEMS APPROACH TO SOLVING COMPLEX PROBLEMS (PART II)

In Systemation Letter 295, I introduced a very powerful technique for analyzing and solving complex problems. This technique, known as Goal Fabric Analysis,* proves to be flexible, dynamic, and shows a more complete rationale for the results. In this letter, I give another use of Goal Fabric Analysis — that of selecting a minicomputer. Using this example, we will examine:

- The interrelations between goals
- Several additional reduction techniques
- How to deal with deadlocks
- A very useful ranking short-cut



Choose a better mini with Goal Fabric Analysis.

*Goal Fabric Analysis was first presented in "Abstract Representation of Goals," a paper by Professor M.L. Manheim of MIT and F.L. Hall, then with Peat, Marwich, Livingston and Co., Boston, now with McMaster University, Hamilton, Ontario.

MINICOMPUTER SELECTION PROBLEM

Since minicomputers are fast becoming both feasible and desirable for many applications, I plan to show how you can select the best minicomputer for your needs, using Goal Fabric Analysis. I am going to limit the scope of the problem to computer selection. A similar analysis can be performed on other components of the system and combined with the selected computer . . . or entire systems can be analyzed.

Problem. The first step is to define what we want to do with the minicomputer.

> *I am going to be looking for a computer to do a lot of input-output work and a lesser amount of computation. My staff and I have reduced the alternatives to two models (A and B) by eliminating those that cost too much, those for which we cannot get specifications, those we have known to be of poor quality, or those which have various other problems.*

We could analyze more if they passed initial screening, but two is enough to provide a good illustration of the analysis.

Goals List. The next step is to quickly list all of the goals you can think of. You may want to try it yourself before you continue reading. I came up with a list like this:

- Fast
- Large storage capacity
- Compatible input-output structure
- Large, easy to work with instruction set
- Low maintenance
- Lowest cost for features
- Good software support

How do our lists match? Similar, or at least, equally complex?

Goals Outline. In order to come up with a better technique to analyze our goals, lets group them into an outline, filling in the gaps. We may even want to

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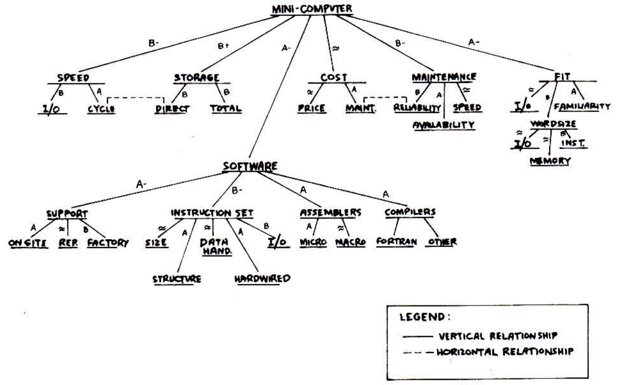
add additional goals. The list above transforms into the following outline.

MINI COMPUTER – GOALS OUTLINE

	A	B	NOTES
1. Speed			
A. Input-output (I/O) (Million words per sec)	1.25	2.0	
B. Cycle (micro seconds/inst.)	.8	.9	
2. Storage			
A. Direct	1K	32K	
B. Total (min-max)	4K - 32K	8K - 128K	
3. Cost			
A. Price	$6,500/4K	$13,000/8K	
B. Maintenance	35/hr.	40/hr.	
4. Fit			
A. I/O	Good	Good	(Scale - poor/
B. Familiarity	Fair	Poor	fair/good)
C. Word Size (bits)			
(1) I/O	16	16	
(2) Memory	16	16	
(3) Instruction	16	16, 32, 48	
5. Maintenance			
A. Reliability of the machine	Fair	Good	(Scale - poor/
B. Speed of repair	Fair	Fair	fair/good)
C. Availability	Fair	Poor	
6. Software			
A. Support			
(1) On-site	Yes	No	
(2) Representative	Yes	Yes	
(3) Factory	No	Yes	
B. Instruction Set			
(1) Size	Medium	Medium	
(2) Structure	Straightforward	Complicated	
(3) Data Handling	Good	Good	
(4) Hardwired Instructions	Standard	Optional	
(5) I/O	Complicated	Straightforward	
C. Assemblers			
(1) Micro	Standard	2 pass	
(2) Macro	Standard	Standard	
D. Compilers	FORTRAN/ BASIC	FORTRAN/ ALGOL	Prefer BASIC

Evaluations. As you can see, the outline shows the results of the next step — evaluating the alternatives for the lowest goals or criteria. Some of the evaluations shown on the outline are fairly subjective, but these are used equally well as quantitative evaluations.

Goal Fabric. The best way to use the goals outline and the evaluations is to build a goal fabric like the one below. Once the goals outline is completed, building the fabric is simply a graphical problem. I did some special arranging so that I could show special relationships, as between *cycle speed* and *direct storage.* I will discuss these relationships and other details, before we continue on with the solution.



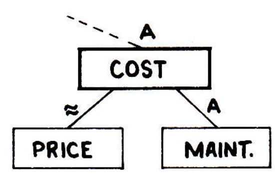
GOAL INTERRELATIONSHIPS

When you first listed your goals, you noticed two kinds of relationships . . . vertical and horizontal. The vertical relationships are those between sub-goals and their higher level goals. They help answer such questions as "How do we reach this goal?" or "What does this goal mean?" Vertical relationships are easy to understand and to work with. Horizontal relationships exist between goals or sub-goals not in the same category. These relationships show the dependence or independence of a goal. For instance, cycle time and direct storage access are related in that direct access to memory will save time and instructions so that cycle time is less important when memory is directly accessable. For this reason, a dashed line (----) was placed between *cycle speed* and *direct storage.* This relationship will be used when comparing the alternatives. The same type of relationship exists between *maintenance cost* and *reliability,* in that maintenance costs are not as important if the machine is fairly reliable and corrective maintenance is minimal. Only those horizontal relationships which affect the evaluation and comparison of an alternative are important. Casual relationships like reliability and purchase price are not important to the Goal Fabric Analysis.

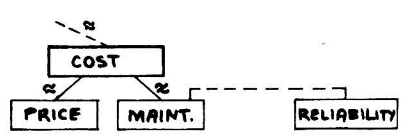
Now let's return to our minicomputer selection by discussing some goal fabric reduction techniques.

REDUCTION TECHNIQUES

Dominance. In Part I of this letter we used dominance to reduce our goal fabric. Horizontal relationships were not considered. In our minicomputer example, the sub-goal *cost* has two sub-goals — *purchase price* and *maintenance.* Using the data in the goals outline, the comparison of A and B without horizontal relationships would look like this, with A dominating (≈ means the same):



However, if the relationship between *maintenance costs* and *reliability* is considered, neither dominates:



This is because the better reliability of *MINI B* offsets the difference in maintenance costs.

Decision Maker's Choice. Sometimes, the decision maker determines dominance in a set of criteria without evaluating each criterion. For instance, COMPILERS could be broken down further than FORTRAN and *others* into efficiency, standard coding, job control language, etc. However, the decision-maker has established a preference for BASIC and will disregard the other criteria in favor of the one with BASIC.

Interval Comparison. Looking at the outline, notice that the evaluations under *maintenance* show *reliability* with B dominating (good over fair), *speed* equal, and *availability* with A dominating (fair over poor). In order to determine dominance for *maintenance,* some trade-offs are necessary. In this case, the dominance of B is over a different range than the dominance of A. By comparing these different ranges or intervals, dominance can be determined. I considered the "fair-poor" interval for *availability* less of a difference than the "fair-good" interval for *reliability.* Because of this, B dominates.

Breakpoint. Breakpoints are used when deadlocks occur between monetary and non-monetary goals. The breakpoint is the monetary value at which the alternatives are equal. The difference between the breakpoint and the actual value of the alternatives is compared to the non-monetary goals. If the non-monetary goals are worth more, choose the alternative which dominates on non-monetary goals; if not, choose the other alternative. Breakpoints are discussed further under *deadlocks.*

MINI SELECTION SOLUTION

Using the additional techniques from above, I made the comparison between A and B using the goal fabric. The results for everything but the final choice are shown on the original goal fabric. The minuses and pluses after the dominance notes indicate that the dominance was close (-), fairly definite ( ), or absolute (+). This helps in making the final dominance decision.

I determined the choice to be minicomputer B. In making the choice, I looked at the top sub-goals: *speed, storage, cost, maintenance, fit,* and *software.* I considered all but *COST* to be equally important. Since neither mini dominated *cost,* I chose the one which dominated the majority of the sub-goals — *MINI B.*

DEADLOCKS

In some decisions, deadlocks occur in which the decision maker or his staff cannot easily determine the dominance among a sub-set of goals. Usually, the deadlock is between economic and non-economic sub-goals. For instance, the upper stages of a goal fabric analysis might look like this:

You can see that the choice is now between safety and economics. There are three ways to handle this kind of deadlock.

1. Add or breakdown existing sub-goals into more, non-economic sub-goals to show dominance more clearly. The minicomputer selection goal fabric avoided this deadlock by showing COST as one of several sub-goals. Also, only economically similar alternatives were analyzed.
2. Another method is to use the breakpoint reduction technique. This shows the decision-maker exactly what the non-economic sub-goals must be worth to be a deadlock — less will give dominance to the candidate dominating economics and vise versa.
3. If the methods prove insufficient, review the analysis and make adjustments.

If nothing can break the deadlock, then consider the choices equivalent. For other than economic/non-economic deadlocks, methods (1) and (3) can still be used to break the tie. It is unusual, however, that two choices can be considered equivalent — the decision-maker can usually apply past experience to break a tie before it becomes much of a problem.

RANKING SHORTCUT

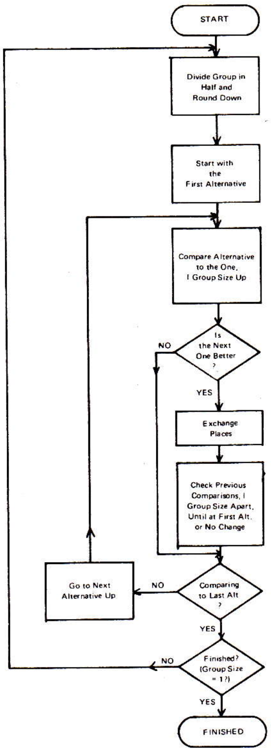
The minicomputer example analyzed only two candidates in which the ranking was trivial. However, many Goal Fabric Analyses involve several candidates. As seen from Part I of this letter, analyzing even four candidates can be somewhat tedious. Comparing each candidate to all the rest can become nearly impossible for six or more candidates. A computer analysis may be of help, but most goals do not lend themselves to numerical evaluations. Using the "winner versus the next candidate" approach can give the best, but does not produce a perfectly ranked list.

There is a technique, however, which can be used fairly easily to reduce the number of comparisons to the absolute minimum and provide an accurately ranked list of candidates. I call this the Divide and Compare Technique.* Basically, it involves successively dividing the list in halves and comparing the members of one part to the others. The results are very encouraging:

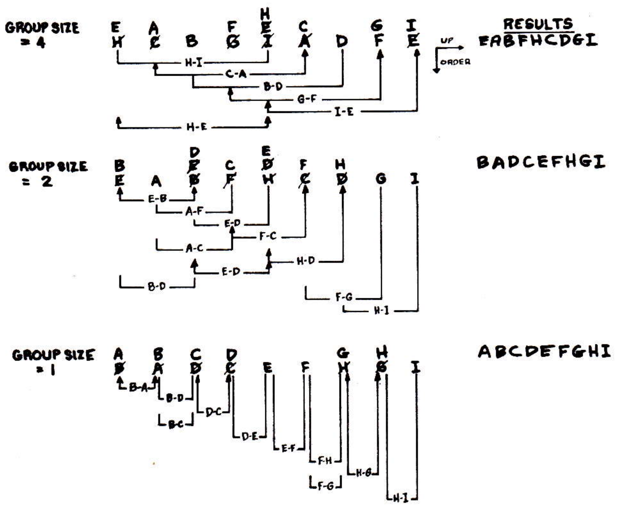
	Normal Number of Comparisons	
Number of Candidates	Comparing Each to All	Divide and Compare
2	1	1
3	2	2
4	6	5
5	24	9
6	120	11
7	720	13
8	5,040	22
9	40,320	26

* Similar to a binary sort

In order to easily perform and explain the Divide and Compare Technique, use the following flowchart:



Example. Ordering nine candidates H C B G I A D F E in which their final order will be alphabetical.



LEGEND:
└X-Y┘ COMPARISON OF X AND Y
↑X-Y↑ EXCHANGE X AND Y

The process will become clear as we walk through the flowchart and the example.

Begin by dividing the nine candidates in half and round down — 9÷2=4½→4. Starting with the first candidate position (H), compare it to the candidate one group size (4) up (I). Since H comes before I, there is no exchange. Move up to the next candidate (C) and compare it to the next candidate one group size up (A). Since A comes before C, exchange A and C. This process continues for B — D, G — F, and I — E, exchanging places where necessary. At the last exchange (I — E), you will notice that this affects the first comparison with the center candidate position (where E is now). You can see that another comparison and exchange is necessary (between E and H). This is not absolutely necessary, but saves many comparisons and exchanges in the following iterations. The result of the first iteration is shown in the example diagram (E A B F H C D G I).

Next, divide the group in half again and round down (if necessary) — 4÷2=2→2. Again, start with the first candidate position (E) and compare it to the next candidate 2 up (B). Since B comes before E, exchange B and E. Repeat for A — F, E — D, and F — C. Since F and C are exchanged, check previous comparisons with the lower position (A — C, no exchange). Now compare H and D. Since there is an exchange, check previous comparisons. Notice that the comparison E — D results in an exchange, so check the comparison previous to that (B — D). There is no exchange. Go on and finish F — G and H — I. The results for this interation are as shown: B A D C E F H G I.

The last interation is similar to the first and second. Follow the flowchart and the example through and you will see the final results are as shown: A B C D E F G H I. Notice that when checking previous comparisons after an exchange, you only have to back up till you make a comparison with no exchange.

STEPS IN GOAL FABRIC ANALYSIS

1. List the goals
2. Outline the goals
   - Fill in gaps
   - Identify interrelationships
3. Sketch the goal fabric
   - Show interrelationships
   - Add more sub-goals and/or criteria as necessary
4. Evaluate the alternatives
   - Using only screened candidates
   - With respect to criteria (lowest sub-goals)
5. Compare the alternatives in pairs using:
   - Dominance
   - Decision-maker choice
   - Interval comparison
   - Breakpoints
6. Rank the alternatives
   - Use "each against all" for less than 5
   - Use "divide/compare" for 5 or more

Goal Fabric Analysis can and should be used for any decision involving more than just "cost-plus" goals which is handled quite well with something like decision trees.* I have detailed the steps and ways to handle difficulties. It is now up to you to put Goal Fabric Analysis to good use in solving your complex problems.

* See Systemation Letters 287-288.

Kenton H. Johnson, Guest Author

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