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Strategy for Optimum Acquisition of Information

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This note is a brief tutorial on a strategy for optimizing the acquisition of information. It is a procedure well known to decision theorists but hardly understood or applied by those making decisions about spending dollars, time and other forms of capital on the acquisition of information. In the writer's judgment it has wide applicability to NGATS with respect to aircraft and ATM equipage, design of decision support tools, operator training, and system architecture. By "acquisition of information" the author means either doing research presumably to discover a state S (the value of some property of an object or event) or designing/deploying some physical instrumentation to measure S. In the latter case, for example, the question may be what instrumentation to put on board an aircraft to provide operating performance and safety of greater worth by knowing S, or whether to add that instrumentation at all, given the cost of the instrumentation itself.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION

Inches	0			1			2			3		4		5
Centimeters	0	1	2	3	4	5	6	7	8	9	10	11	12	13

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Strategy for Optimum Acquisition of Information

This note is a brief tutorial on a strategy for optimizing the acquisition of information. It is a procedure well known to decision theorists (Howard, 1966) but hardly understood or applied by those making decisions about spending dollars, time and other forms of capital on the acquisition of information. In the writer's judgment it has wide applicability to the Next Generation Air Transportation System (NGATS) with respect to aircraft and ATM equipage, design of decision support tools, operator training, and system architecture.

By "acquisition of information" the author means either doing research (presumably to discover a state S, the value of some property of an object or event) or designing/deploying some physical instrumentation to measure S. In the latter case, for example, the question may be what instrumentation to put on board an aircraft to provide operating performance and safety of greater worth by knowing S, or whether to add that instrumentation at all, given the cost of the instrumentation itself.

As an indication of how this procedure relates to NGATS, the first research/policy item mentioned in the NGATS Concept of Operations document V-0.2 (2006, p. 2-3) states: "A major requirement for achieving the NGATS concept is transforming the aircraft e*quipage paradigm* (cost, time, level of integration in the flight deck, etc.) to reduce both the cost of adding advanced capabilities in the aircraft and to reduce the time it takes to upgrade aircraft as capabilities evolve."

The basic idea is first explained, and is followed by an example of its application.

The Basic Idea

The whole point of knowing S is to be able to take an action A that yields a better result than the action one would take not knowing S.

Let us define a set of possible states S_i, a set of possible actions A_j, the worth $W(S_iA_j)$ for taking action A_j when S_i is true, the prior probability $P(S_i)$ of each state, and the cost C of the instrument or other means to discover S_i.

If one knows the specific state S_i, then one can select that action A_j which, in combination with that S_i, maximizes W. Averaged over all the ways S_i can occur,

$$W_{max}(\text{knowledge}) = \Sigma_i P(S_i) \text{ max over } A_j \text{ of } \left[W(S_iA_j)\right]$$

If, however, one is ignorant of the state S_i but knows only the probability $P(S_i)$, then the best action to take is that which maximizes the expected worth.

$$W_{max}(\text{ignorance}) = \text{max over } A_j \text{ of } \left[\Sigma_i P(S_i)\, W(S_iA_j)\right]$$

In the former case A_j is selected to yield the best result for each specific S_i while in the latter case one is limited to a one-time selection that is best on average for the whole distribution of S_i, Therefore W_{max}(knowledge) will be significantly greater than W_{max}(ignorance). The two equations differ in the sense that W_{max}(knowledge) is an average for many actions each of which is best for whatever state is disclosed to be true, whereas W_{max} (ignorance) is the outcome for the single action which is best on average for the whole probability distribution of states, i.e. the action with the greatest expected value of possible actions. This difference is commonly called the “information value” and is to be distinguished from Shannon information, the latter being a measure of the rarity or unexpectedness of an event (Sheridan, 1995).

However any information acquisition has a cost C of performing the investigation or investing in the measuring equipment. So the net gain for acquiring the information S_i is

$$W_{(net)} = \sum_i P(S_i) \text{ max over } A_j \text{ of } \left[W(S_iA_j)\right] - \text{max over } A_j \text{ of } \left[\sum_i P(S_i)\, W(S_iA_j)\right] - C$$

If $W_{(net)}$ is positive one should go ahead with acquiring the instrumentation or performing the research, otherwise one should not.

Applying the Idea to Reality

Performing this analysis goes well beyond just asking what better information will the instrumentation (or research) provide, especially in critical situations. It weighs in the probability of those critical situations occurring, and makes the comparison with how well one could get along without the specific information in those critical situations, how well the “nominal” action would be suited to the critical situation in the absence of the better information. It forces the evaluator to consider the set of possible states, to estimate both the probability of each and the relative worth of taking different actions under each of those conditions, and integrating this information in a logical way.

In practice there can be a very large number of states, while typically fewer alternative actions are available. Categorizing combinations of alternative states and simultaneous actions even into a small table (e.g., Table 1) may be useful in that the analyst/designer/ program manager is forced to estimate the relative worth W which can be cast in either positive terms (e.g., accuracy of performance), or negative terms, (e.g., some units associated with cost or risk).

In the example below we consider a system whose alternative possible states are normal or at several levels of failure, and potential actions that may be more or less appropriate. If the control agent (human or computer) has perfect knowledge of the state AND the knowledge and capability to make the most appropriate response, we assume that action will be taken. Since that is the reference ideal the value of W in those cells is 0, while all the others are in error and have negative W values to represent relative costs of the inappropriate actions. Thus, normal operating action (ignoring a worst-case failure) nets the greatest cost, and the cost of such action is reduced as the failure is less severe. The cell values are, of course, arbitrary, but one can conjure up scenarios for which the W values shown might be reasonable. Two other hypothetical actions are listed; these correspond to likely error actions that are inappropriate to any of the failure conditions.

Whether to Buy and Install Some Instrumentation: An Example
(Values for Different Actions Aj When State Si Is True)

STATE Si	Probability $P(S_i)$	Normal operating action	Max failure action	Moderate failure action	Minor failure action	Other action A	Other action B
Normal	0.93	0	-40	-20	-10	-10	-5
Worst failure	0.01	-200	0	-50	-40	-30	-20
Moderate failure	0.02	-100	-20	0	-20	-20	-10
Minor failure	0.04	-50	-40	-30	0	-10	-5

Computing W_{net}, we see that the first term is zero since the best action when each S is known is zero, and the expectation over the distribution is then zero. The second term requires that for each action we find the sum of the products of each of the four W values in that column and the corresponding probability.

Thus, we have for

Normal operating action: 0.93*0 + 0.01*(-200) + 0.02*(-100) + 0.04*(-50) = -6
Max failure action: 0.93*(-40) + 0.01*0 + 0.02*(-20) + 0.04*(-40) = -39.2
Moderate failure action: 0.93*(-20) + 0.01*(-50) + 0.02*0 + 0.04*(-30) = -20.3
Minor failure action: 0.93*(-10) + 0.01*(-40) + 0.02*(-20) + 0.04*0 = -10.1
Other action A: 0.93*(-10) + 0.01*(-30) + 0.02*(-20) + 0.04*(-10) = -10.4
Other action B: 0.93*(-5) + 0.01*(-20) + 0.02*(-10) + 0.04*(-5) = -5.25

The maximum (the best single action in this example of a situation of ignorance) is “Other action B” where W_{max} (ignorance) = -5.25, with “Normal operating action” a very close second at W = -6. In other words, in the absence of any knowledge about what is going on these are the best actions to take. Note that “Other action B” has a relatively benign cost for all states (a small cost during normal operation, but avoidance of very high cost in failure states), while “Normal operating action” has zero cost for the high probability “normal” state, and the high costs for the other states are offset by the very low probabilities of those states.

Selecting -5.25 we find that the net value of perfect knowledge $W_{(net)}$ is 0- (-5.25) –C = 5.25 – C. So if (5.25 – C) >0, or equivalently if 5.25>C, it is worthwhile to buy and install the instrumentation, otherwise it is not.

Extensions of Information Value Idea

The information value idea has been applied to situations where knowledge is partial. For example when an operator first gets information about the true state of some situation, that information may be perfect (a probability distribution which is a vertical line) assuming the information itself is correct, but with increasing time in a dynamic environment, the information may become less perfect, asymptoting to knowledge that is no better than a stationary probability distribution. Given a model of this growth of uncertainty over time and of the cost of accessing the information (e.g., operators must time-share their attention) one can calculate how often the supervisor of some automation process should attend to it (Sheridan, 1970).

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