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A MULTI-ATTRIBUTE VALUE MODEL FOR THE STUDY OF THE ESTABLISHMENT OF ISR FUSION CENTER CAPABILITY

By

Kevin Ng

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OTTAWA, ONTARIO **JULY 2003**

ABSTRACT

This research note is conducted to support the definition phase of the Joint Information and Intelligence Fusion Capability (JIIFC) project. The aim is to investigate the value of co-location of personnel in improving the intelligence and information fusion process.

Based on the author's earlier research on "a multi-attribute value model or worth assessment procedure (*IEEE Trans. on SMC*, Dec. 1980)", analysis has been performed to demonstrate the value of co-location. The attributes being considered in the model include the military value; the accessibility and timeliness of the intelligence product; and the cost of the intelligence and information fusion process. Different sets of data are used to explore the alternatives. Initial results support the intuitive concept regarding the co-location of personnel required to improve the effectiveness and efficiency of the intelligence fusion process.

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A MULTI-ATTRIBUTE VALUE MODEL FOR THE STUDY OF THE ESTABLISHMENT OF ISR FUSION CENTER CAPABILITY

BACKGROUND

1. At the beginning of the 21st century, Canada faces an unpredictable and fragmented world; one in which conflict, repression and upheaval co-exist alongside peacetime, democracy and relative prosperity. To adapt the Canadian Forces (CF) and the Department of National Defence to its new challenges in the future, Strategy 2020 envisions the CF of the future as a combat capable force that employs leading edge technologies and is interoperable, task-tailored, and both rapidly and globally deployable. Fundamental to meeting this vision is the requirement for decision-makers at all levels to have access to Information & Intelligence (I^2) that is current, relevant and sustainable on a 24/7 basis. To enhance the quality of CF I^2 process, Defence Plan 2002 has directed the DCDS under Change Initiative 1-1058 to "*Establish an operating-prototype Fusion Centre connected to the IOC Common Operating Picture in NDCC*"[1] [1]. A useful source on the background of I^2 can be found in Capt (N) Knight [2].

2. One of the keys to achieving this vision is envisaged to be on the establishment of an ISR Fusion Centre capability. The existing separate stove-piped , strategic-level, single source sensor and information exploitation centers (at the very least, SIGINT, Imagery and Geomatics) would be co-located in a single facility. This Centre would also be the focal point for the timely and systematic exploitation of open source material, which, at present, is barely handled anywhere within the community. The establishment of the ISR Fusion Centre would also create the synergy that arises from having a team of skilled and knowledgeable people working closely together on tackling different aspects of the same problem [3].

3. It is expected that the Fusion Centre in Ottawa would be linked with existing operational fusion centers on the two coasts and in NORAD that provide operational situational awareness concerning maritime and aerospace activity currently.

4. In view of the importance of the ISR fusion centre, JSORT was requested by DJFC to provide assistance and examine the scientific rationale for establishing the

[1] Page 2 Reference 1

centre. The first meeting between JSORT and the sponsors was convened in late December 2002 to discuss the issue. Subsequent meetings were held to define the problem and to collect the necessary data for analysis. The data sets were obtained from the senior members of DJFC. The first set of meaningful results was forwarded to the sponsors in late January. In order to demonstrate proof of concept of the modelling approach, two further sets of data were later acquired from the sponsors. The summary of these findings was forwarded to the sponsors towards late February. This research note documents the summary results sent to the sponsors on these two occasions. They will be referred to as January and February Data Sets respectively.

5. The decision analysis approach taken adopted follows the procedure and steps provided in a previously published paper [4]. It exploits a multi-attribute value model, also known as the worth assessment procedure, to guide decision makers on the choice of options for the establishment of the ISR fusion centre capability.

6. The theory of multi-attribute utility theory [5,6] has been around for some time and remains very popular among researchers. It has been applied very successfully to real world challenges in government, industry and military. The objective of this study is to use decision analysis tools to examine the merits of three options for the establishment of the fusion centre capability, namely, full co-location, partial co-location and no co-location. Each of the alternatives/options can be characterized as a number of attributes. A joint utility or score function is calculated for each option using the data input and agreed governing set rules. The preferential ranking is decided by ordering the options using highest joint utility functions. Much of the research effort in multi-attribute theory has focused on devising ways of decomposing or breaking up the multi-attribute joint utility function into one involving only simple and manageable functions. The notable ones are the linear, multilinear forms etc. Some of the well-known hypothesis and rules for such decomposition are documented in [5,6]. When there is no uncertainty in the outcomes and the problem is only one of reconciling conflicting objectives, the use of value functions is appropriate [4]. Because of the tight project deadline on our study, it was decided (after consultation with the sponsors) that initially it would be assumed that no uncertainty on the outcomes exists. Hence a multi-attribute value model would be appropriate for the fusion centre establishment study. Nonetheless, it should be noted that the multi-attribute value model or the worth assessment procedure can also be modified to handle uncertainty by incorporating adjustment factors on the value functions. (See Ng [4] for further details.)

7. The crux of the challenge in applying multi-attribute utility theory to real world problems is how well one can successfully decompose the joint utility function into a function of individual single-attribute utility functions. In general, the necessary and sufficient conditions governing the type of separability, such as linear or multilinear, are very theoretically involved. The proofs require detail knowledge on the concepts of preferential and utility independence. In brief, given that the study of the establishment of fusion centre capability is described only by incommensurable attributes and assuming that any one of the three separate options would be acceptable if it were the only alternative, it is reasonable to assume that the marginal rate of substitution between attributes is constant. In other words, the attributes are "worth" independent in the sense that one is willing to trade partial satisfaction of one attribute for reduced satisfaction of another attribute without regard for the level of satisfaction already attained by either. Under this assumption, the joint value function for the establishment of fusion centre capability can be decomposed into a linear function of individual single-attribute value functions. Finally, even if the trade-off notions between attributes are more complicated, the typical engineering approach is to linearize the trade-off function about some nominal point, and this linear form will serve as an approximation for small changes or trade-offs. Further details on the multi-attribute value model or the worth assessment procedure can be found in the original paper by Ng [4].

PROBLEM ANALYSIS

8. A multi-attribute value model has been developed to study the establishment of the Canadian ISR fusion centre capability. The model was developed to select from among three alternatives – full co-location, partial co-location and no co-location. It is also assumed that any one of the options would be acceptable if it were the only possible alternative. (This assumption is in general adequate for the validity of the linear form for the joint value function, Ng [4].)

9. The model consists of the following stages: attribute selection, attribute rating and option evaluation.

Attribute Selection

10. Attribute selection involves the identification of key (distinguishing) attributes relating to establishment of a fusion centre capability. With assistance from the sponsors, the following criteria are included for evaluation: *cost, military value, timeliness* and *information accessibility* of the ISR product. *Cost* can be further broken down into *Capital* and *Operating & Maintenance (O&M) cost.* The benefits stemming from cognitive and social networks are difficult to quantify but, because of the team of skilled and knowledgeable people working closely together on different aspects of the same

problem, intuition suggests it is reasonable to expect the *military value* of the ISR product will be much higher for the full co-location option than that of the no co-location option where there exists little or no synergy among the skilled specialists. Similar reasoning holds for the worth score of the *military value* for the partial co-location option versus the no co-location alternative. *Information accessibility* and *timeliness* of the ISR product are two of the key elements listed in the proposed operational rules for the fusion centre capability and therefore its importance in the evaluation process should not be underestimated.

Attribute Rating

11. Attribute rating is a process whereby a quantitative assessment is made of the relative importance of each of the attributes selected. This step also includes the assignment of the single attribute value function. The sponsors are then asked to rate the relative importance of the attributes. Following Ng's approach [4], Saaty's theory of analytical hierarchies [7] was employed in the determination of the weighting factors. The process involves the pairwise evaluation of the relative importance of the attributes. For each pair of attributes, a number is given which relates the pairwise evaluation to a point on an ordinal scale. This ordinal number, which reflects the intensity of the difference between the two attributes, is recorded in a matrix. The information represented in a matrix is then abstracted by computing the eigenvector associated with the maximum eigenvalue of the matrix. The relative magnitudes of the values of the elements of the eigenvector will best represent the intensities of the judgments as they have been recorded. The purpose of this process is mainly to provide a more systematic approach in the assignment of weighting factors.

12. The sponsors are next requested to provide the value function or worth score, ranging between [0,1], for each of the attribute. In the evaluation of the fusion centre exercise, the worth score is a subjective value input by the sponsors, however, the worth score can also be determined via mathematical computation/formula or detailed computer simulation (as done in Ng [4]).

13. Data were collected in January on the pairwise comparisons between the attributes as well as the value functions, hereby will be referred to as January Data Set. The pairwise comparisons data are as follows:

Military value is definitely of absolute importance over *cost*, and the intensity is *9*.

Military value is of intermediate value between equal and weak importance when compared to *timeliness*, and the intensity is *2*.

Military value is of demonstrated importance over *accessibility*, and the intensity is *5*.

Timeliness is of weak importance over *cost*, and the intensity is *4*.

Timeliness is of equal importance over *accessibility*, and the intensity is 1.

Accessibility is of weak importance over *cost*, and the intensity is *4*.

The attribute worth score ('benefit' assessment) for the 3 options are listed in Table I.

TABLE I

WORTH SCORE FOR THE 3 OPTIONS

Attributes	**No co-location**	**Partial co-location**	**Full co-location**
Cost	0.5	0.6	0.7
Timeliness	0.3	0.6	0.8
Accessibility	0.5	0.7	0.8
Military Value	0.3	0.6	0.8

Even though the worth score or value function of *cost* (Table 1) for the establishment of fusion centre capability is progressively increasing from no to full co-location, its actual cost-functional value behaves in an opposite or concave manner. That is, a low worth score implies an actual high cost functional value; likewise, a high worth score implies a relatively low cost functional value. The trend lines of the attribute functional values are displayed in Fig. 1. Since the data are subjective input values provided by the sponsors, the intersection points of the curves bear no physical meaning or interpretation.

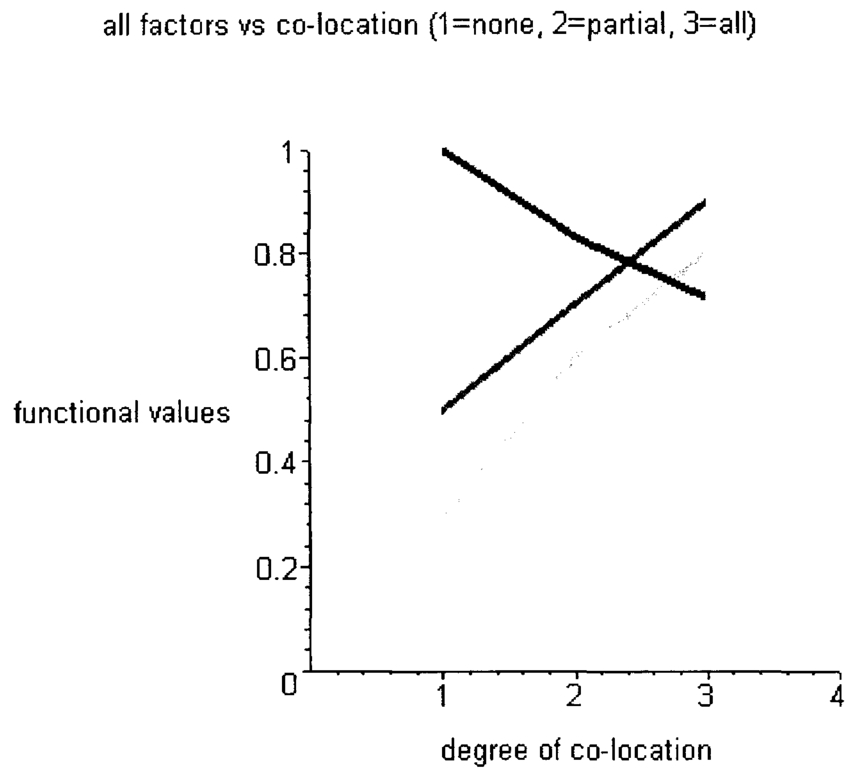

Figure 1: Trend lines of attributes versus degree of co-location (Yellow: Timeliness & Military value; Green: Accessibility; Red: Cost)

Since the worth scores of attributes *Timeliness* and *Military value* are identical, the trend line of both are represented by the bottom curve in Fig. 1. *Accessibility* trend line is the middle curve and the trend line for *cost* is the top upper curve with the distinct monotonically decreasing behaviour. Applying Saaty's theory of analytical hierarchical process, the weighting factors are readily determined and found to be {*0.0526, 0.2179, 0.1764, 0.5531*}. The consistency check of the decision maker's comparisons are also verified. This is to ensure the pairwise comparisons between attributes are done consistently, see Ng [4].

Option Evaluation

14. Finally, the options can be easily evaluated according to the linear multi-attribute value function. (All calculations and graphs are done interactively using symbolic computations package 'Maple 8'.) The results are plotted in Figure 2.

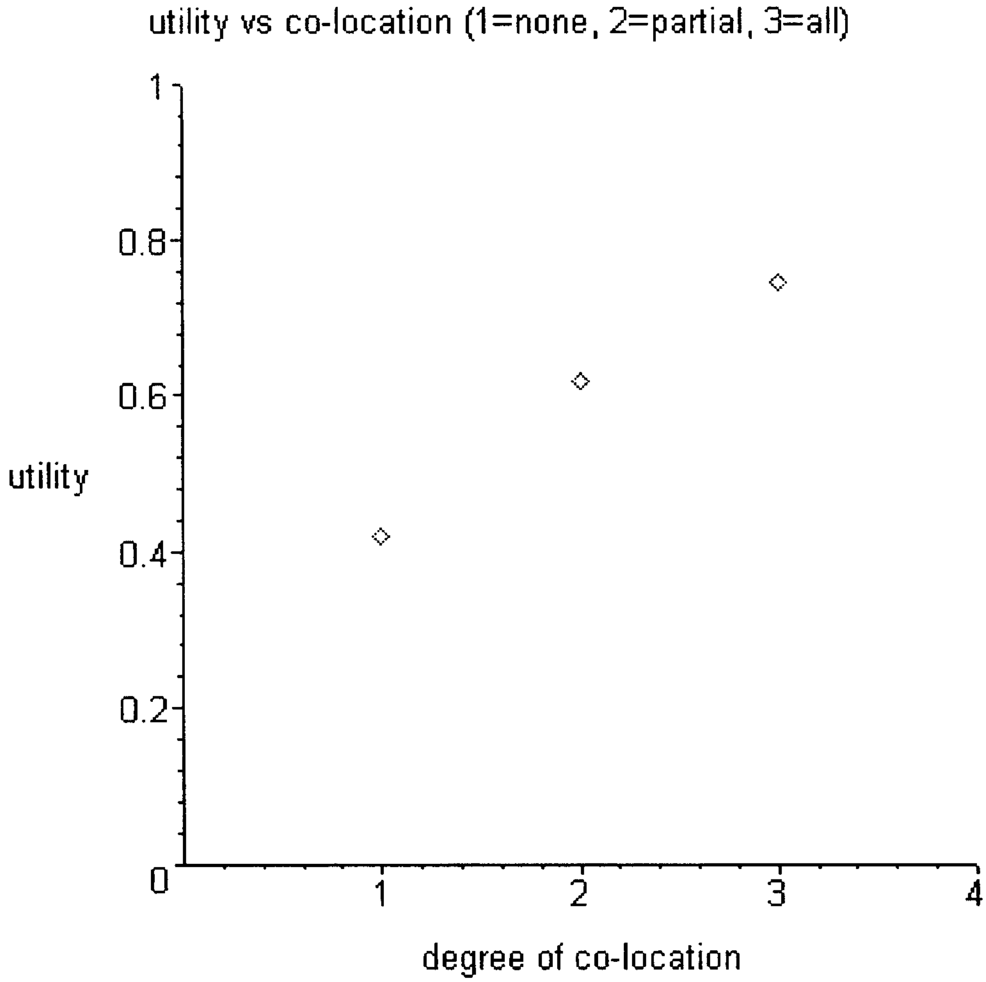

Figure 2: Joint worth score or value for the 3 options

According to the multi-attribute value theory, the full co-location option is the preferred alternative. The aggregrate value obtained for the no co-location option has the least score.

15. In brief, we have developed a model for the establishment of the ISR fusion centre capability. We work with a model of a problem rather than directly with the problem itself. The next important step is to validate the model. Model validation involves substantiating that the model, within its domain of applicability, behaves with satisfactory accuracy consistent with the objectives of the study [8]. However, the tight project deadline precludes undertaking any formal model validation. In order to shed further insight into the modeling process, two new sets of data are acquired from the sponsors in February, hereby referred to as February Data Set. The February Data Set differs from the January Data Set in that it contains different pairwise comparison

between attributes. Additionally, the value function for the *cost* attribute is further divided into 2 categories – '*Capital*' and '*Operating & Maintenance (O & M)*'. The February Data Set is as follows:

Scenario 1: Pairwise comparison between attributes

Military Value to *Cost*: *6*

Military Value to *Timeliness*: *2*

Military Value to *Accessibility*: *3*

Timeliness to *Cost*: *2*

Timeliness to *Accessibility*: *1*

Accessibility to *Cost*: *3*

Scenario 2: Pairwise comparison between attributes

Military Value to *Cost*: *3*

Military Value to *Timeliness*: *1*

Military Value to *Accessibility*: *3*

Timeliness to *Cost*: *3*

Timeliness to *Accessibility*: *1*

Accessibility to *Cost*: *2*

The value-functions determined for the alternatives of no co-location, partial or full co-locations are shown in Table II.

TABLE II

WORTH SCORE OR VALUE-FUNCTIONS FOR VARIOUS DEGREES OF CO-LOCATION

Attributes	**No**	**Partial**	**Full**
Cost (Capital)	0.8	0.5	0.3
Timeliness	0.3	0.5	0.7
Accessibility	0.5	0.6	0.7
Military Value	0.3	0.5	0.7
Cost (O&M)	0.5	0.5	0.7
Timeliness	0.3	0.5	0.7
Accessibility	0.5	0.6	0.7
Military Value	0.3	0.5	0.7

Thus there are 4 different cases, namely

Case 1 - Scenario 1 with *capital cost*

Case 2 - Scenario 1 with *O & M cost*

Case 3 - Scenario 2 with *capital cost*

Case 4 - Scenario 2 with *O & M cost*

The following observations are derived from the February Data Set. First, the worth scores or value functions for *military value*, *timeliness* and *accessibility* for all 4 cases are identical. The distinguishing factor is in difference in worth scores for *Capital* and *O&M cost*. The full co-location option for '*Capital cost* ' has the lowest worth score among the alternatives. This might be attributable to the fact that new buildings would have to be acquired in order to co-locate the skilled personnel in the same vicinity; whereas, the current existing buildings are adequate for the no co-location option. On the other hand, the *cost* worth score for full co-location option in '*O&M cost*' is the highest by virtue of the new facilities installed, since maintenance cost can then be kept to a minimum. Finally, the worth scores for the partial co-location option for *Capital* and *O&M cost* are identical, therefore the joint value functions for this option for cases 1 and 2 are given by the same value (since they have the same attribute comparison matrix). Similarly, the worth scores for the partial co-location option for cases 3 and 4 are equal. The aggregrate utility or value functions for the 4 cases are displayed in Figure 3.

16. It is noticed that the aggregate worth scores or value functions within each option are very close to each other for all the 4 cases; in some cases, the point score (nearly) coincides with each other and thus becomes indistinguishable on the graph in Fig. 3. For example, for the partial co-location option, even though scenario1 and scenario 2 contains distinct and different sets of attribute comparison data, the joint value functions (given by *0.5206* and *0.5207* respectively) are so close in value such that they appear as only one point in Fig. 3. In summary,

The worth score or value-functions of no co-location for the 4 cases range between *0.358* to *0.395*

The worth score or value-functions of partial co-location for the 4 cases coincide to give only one value *0.521*

The worth score or value-functions of full co-location for the 4 cases range between *0.657* to *0.700*

Nonetheless result clearly identifies the full co-location option as the preferred alternative for all the 4 cases derived from the February Data Set.

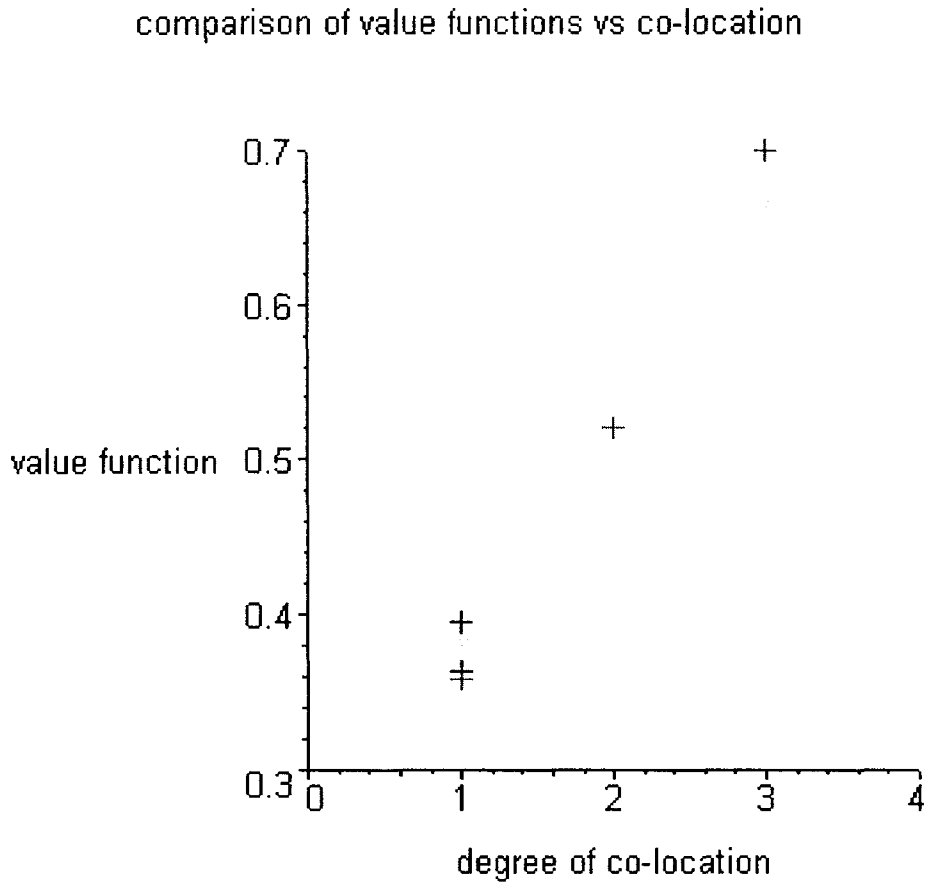

Figure 3: Joint worth scores or values for cases 1, 2, 3, 4 (The colour of the crosses have no specific meanings, the significance of the scored values can be found in the text)

CONCLUSION

17. We have demonstrated that the multi-attribute value model can generate useful insights to assist military decision makers on the establishment of ISR fusion centre capability. However, it should be emphasized that the proposed decision model is just a way of structuring the problem. It gives no magical formulas for correct decisions. In fact, the model forces the decision-maker to rely more strongly than ever on his own judgments but does give him a framework in which to work.

18. Furthermore, it should not be construed that the results of the February Data Set provides a model validation process for our worth assessment procedure. At best, the fairly consistent results produced by the 2 Data Sets simply increase our confidence towards the use of the model. Finally because assumptions of the model are made explicit and causes and effects are related, our approach can prove to be a useful tool for military decision makers.

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