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VECTOR APPROACH FOR ANALYZING SURVEY QUESTIONS

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Abstract

A vector approach is presented here to analyze survey questions. The survey questions are designed as bi-polar constructs. Participants rated the usefulness, ease of use, and look and feel of six tools on a scale from 1 to 7. The vector method treats each answer as an element in a *p*-dimensional vector, where *p* corresponds to the number of participants. The response vectors are then compared to a reference vector. The percentages of usefulness, ease of use, and look and feel are calculated using the projection of the response vectors onto the reference vector.

A clear advantage of the vector approach over statistical methods is that it does not invoke assumptions typically associated with those statistical methods. Thus the vector method can be applied to a wider variety of data sets, and the results are non-ambiguous compared to the statistical techniques. While the statistical method indicates that the participants seemed to have interpreted the three questions equally, the vector method shows clearly that the questions are not coincident and care must be taken in drawing the right conclusions.

Other results specific to the experiment described herein are that the highest rating from the participants was for the Info Workspace tool and the lowest was the EBP tool suite. Also, Common Intent depended on variables other than technology. Nevertheless, the technology should be optimized to eliminate it as a potential detrimental variable.

Introduction

Statistical results of survey questions are often reported without considering the nature of the data set. The mean and standard deviation assumes that participants' answers come from a population whose answers are normally distributed. The statistical results for one question can be compared to the results for another question. If the questions are shown not to be significantly different, then in certain circumstances the data sets can be combined, only if the same participants answered each question being compared (i.e., same sample sizes). However, normal distribution and same sample sizes are two assumptions of statistical methods that are not typically realized in large, complex experimentation.

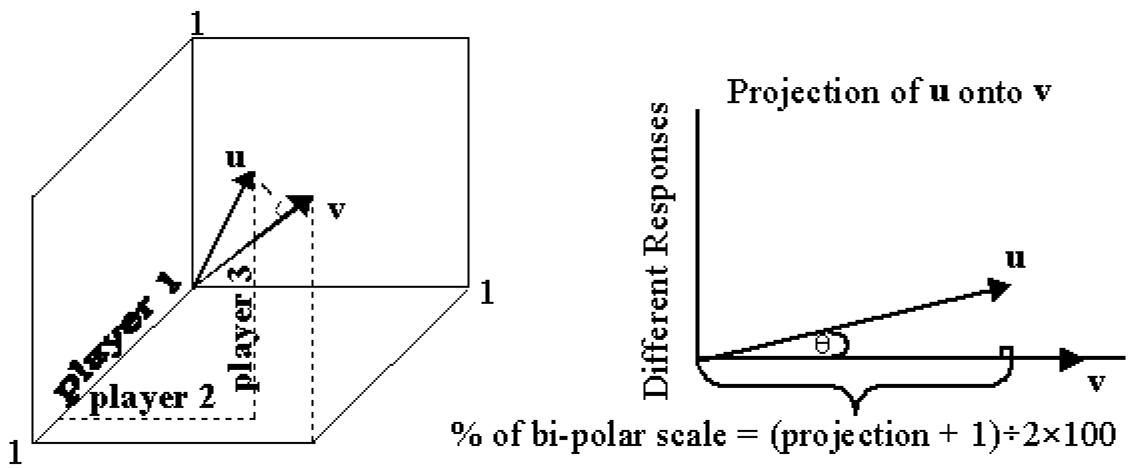
A new vector approach is considered here for data reduction and interpretation. The vector method treats the responses to each question as a multi-dimensional vector. This response vector is compared to a reference vector. The vector approach does not require any assumptions about distributions nor sample sizes, but it expresses the data in terms of a magnitude and direction relative to an ideal data set. This method is similar to the Repertory Grid's principle component analysis technique. This technique is used to elicit and analyse an individual's personal constructs (or perceptions along bi-polar scales) of an event or scenario (Kelly, 1955).

Vector Method

Assume there are p participants and q questions. Each question is bi-polar: that is, the question's response falls between two opposite values (e.g., yes and no, extremely useful and extremely useless). For the current study, each participant responds to the question by selecting an integer value between 1 and 7 inclusively. These numbers are subsequently normalized between –1 and 1.

A participant's response to a question is an element in a response vector (**u**). Thus **u** has p elements that lie on p orthogonal axes. **u** is a vector sum of answers to a single question, as illustrated in Figure 1a for player 1, player 2, and player 3, and represents a cumulative response to the question. The magnitude and direction fully define **u**.

The response vector is compared to a chosen reference vector (**v**). In this case, **v** is specified as being equivalent to all participants answering 7 (or 100% useful) for a question. After normalizing the scale from 1…7 to -1…1, this vector will have the largest possible magnitude, $\sqrt{p}$, for p participants, and all vectors (including the reference vector itself) are normalized again with respect to this magnitude. Thus **v** has a magnitude of one.



a) b)

Figure 1: Illustrating the Vector Method

Furthermore, the angle between **u** and **v** is calculated using the Euclidean inner product or the vector dot product (Anton, 1981). Figure 1b shows the angle between **u** and **v**. The projection of **u** onto **v** is related to a percentage of the bi-polar scale. Recall that the scale spans from –1 to 1. Therefore, if the projection value is 0.5, for example, then the tool is 75% useful (i.e., [0.5+1] ÷ 2×100). It is left for a mathematical proof that the projection is also related to the participants' responses mean value – assuming that a normal distribution is an appropriate model that describes their responses (Farrell, draft). In this case, the response distributions were skewed and truncated at both ends, and therefore the median and skew index (Runyon & Haber, 1984) are reported in the results section.

The y value of **u** in Figure 1b indicates that the participants had different answers. If players 1, 2, and 3 all had the same answer of 0.5, for example, **u** would lie on the same axis as **v**. Conversely, if the answers were 0.5, 0.5, and 0.4, then the **u** would not be coincident with **v**. It is left for a mathematical proof that the y value is also related to the participants' responses standard deviation, assuming again that the responses fit a normal distribution (Farrell, draft).

In summary, the vector method treats each datum as a single value along a single axis in a multiple dimensional space, computes the response vector, and compares it to a reference vector of similar dimension. The clear advantage of the vector approach is that it does not invoke any assumptions typically associated with statistical methods, and so the method is applicable to a wider variety of data sets.

Effects Based Planning

Effects Based Operations (EBO) is a transformational concept where command decisions are made based on the desired effects that the nation or coalition would want to see happen within an adverse state or organization. During the planning phase, all four instruments of national power (Diplomatic, Information, Military, Economics) are under consideration in achieving the desired effects. A key activity of EBO is Effects Based Planning (EBP), and technology supports the EBP process and distributed organization.

Effects Based Planning is a new concept being explored by various nations. EBP aims to generate a single plan that considers desired effects and potential unintended effects during the planning stage. Desired effects are generated from strategic objectives and the Operational Net Assessment (ONA). The ONA is a database that contains political, military, economic, social, information, and infrastructure (PMESII) descriptions of the adverse system. A person, place, or thing in the database is referred to as a node. The ONA contains nodes and links, where the links describe the relationships between nodes. Potential effects are also associated with the nodes and links. Needless to say, the ONA is complex.

In light of the strategic directives and Commander's Intent, the HQ staff assesses the desired effects and the actions required to modify the nodes and links in order to produce the desired effects. The actions may produce unintended or second order effects, and so the staff must reassess the effects and actions until they converge to a reasonable solution. Resources are assigned to the actions, and further iterations may occur if the resources are not available. Once the desired effects, nodes, actions, and resources (ENAR) are identified, the staff prioritizes and sequences the effects and actions, and then produces an Effects Tasking Order (ETO).

Experiment

Multinational Experiment 3 (MNE 3) examines how an ad hoc coalition would conduct an Effects Based Planning. US Joint Forces Command led the experiment and invited partner nations Australia, Canada, France, Germany, and United Kingdom to participate in the experiment from their own country. They formed the Coalition Task Force Headquarters (CTFHQ), which is based on a structure with Boards, Centers, and Cells (BCC). NATO conducted the same experiment at the same time over the same secure computer network, except that the NATO planning staff was co-located in a single facility. They formed the NATO Response Force Headquarters (NRFHQ).

One of the objectives for the Multinational Experiment 3 (MNE 3) was to identify technology requirements to support coalition/NRF Effects Based Planning. The proposition is that technology will augment the human ability to conduct EBP through a suite of tools. Thus, the critical operational issue (COI) for the technology objective is, "What functional requirements are necessary to conduct EBP within a coalition/NRF environment?" Various surveys were designed to answer this question during MNE 3. The following is a sample of the questions asked to the experiment participants.

Was the tool used? YES/NO
If YES

- Rate the usefulness of the tool (1...7)
- The tool was easy to use (1…7)
- Rate the look and feel of the tool (organization/layout, colors, fonts, etc) (1…7)

This nested survey question was asked for six tools:

1. Common Information Environment (CIE) Portal
2. Document Manager
3. Info Work Space (IWS), which is a distributed collaboration tool
4. Operational Net Assessment (ONA) database
5. Effects Based Planning tools
6. WebCOP, which is a Common Operating Picture

Participants were asked to fill out the above-mentioned questions for each tool they used.

The Joint Battle Center's data collection and analysis tool, called JDCAT, was developed in the United States and used to design and distribute these nested questions to the players. However, not everyone used all the tools. It cannot be pre-determined how many nested questions the participants would answer. Thus, the sample size (or *p*) for each tool will be different.

Results

The mean and standard deviation were calculated for the 3 questions listed above and for the 6 tools indicated (18 questions in total). The vector methodology was also used to analyze the same data set in order to highlight the differences with the two methods.

Figure 2 is a histogram for the usefulness of the IWS tool question. This histogram is typical of most questions. Table 1 contains the statistical data for all 18 questions. The normalized mean, standard deviation, median, and skew index for the usefulness of IWS question is 0.63, 0.35, 0.67, and -1.4 respectively.

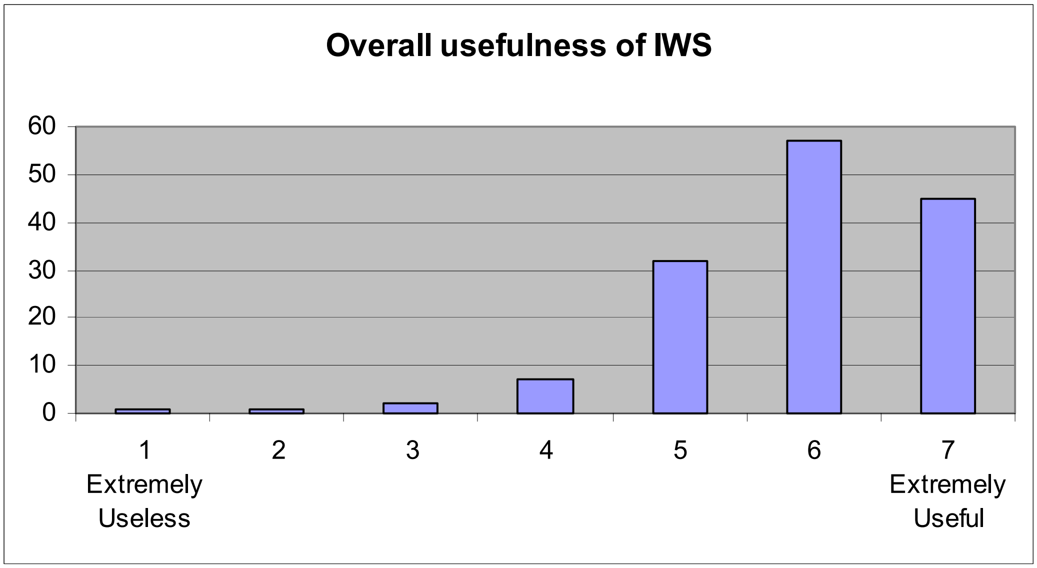


Figure 2: Mean and Standard Deviation for IWS

Tool	Sample size	Usefulness				Ease of Use				Look and Feel			
		mean	s.d.	med.	skew	mean	s.d.	med.	skew	mean	s.d.	med.	skew
CIE Portal	145	.28	.43	.33	-.35	.22	.47	.33	-.67	.10	.43	.33	-.40
Document Manager	55	.38	.38	.33	.10	.33	.42	.33	-.20	.32	.40	.33	.07
IWS	145	.63	.35	.67	-1.4	.58	.30	.67	-.50	.55	.31	.67	-.50
ONA Database	114	.30	.45	.33	-.15	.19	.47	.33	-.25	.23	.42	.33	-.30
EBP tools	62	-.09	.52	0	.18	-.44	.52	-.67	.84	-.22	.49	-.33	.17
WebCOP	28	.06	.59	0	-.12	.07	.59	0	-.18	.13	.52	0	-.16

Table 1: Statistical Values for Usefulness, Ease of Use, and Look and Feel of Tools

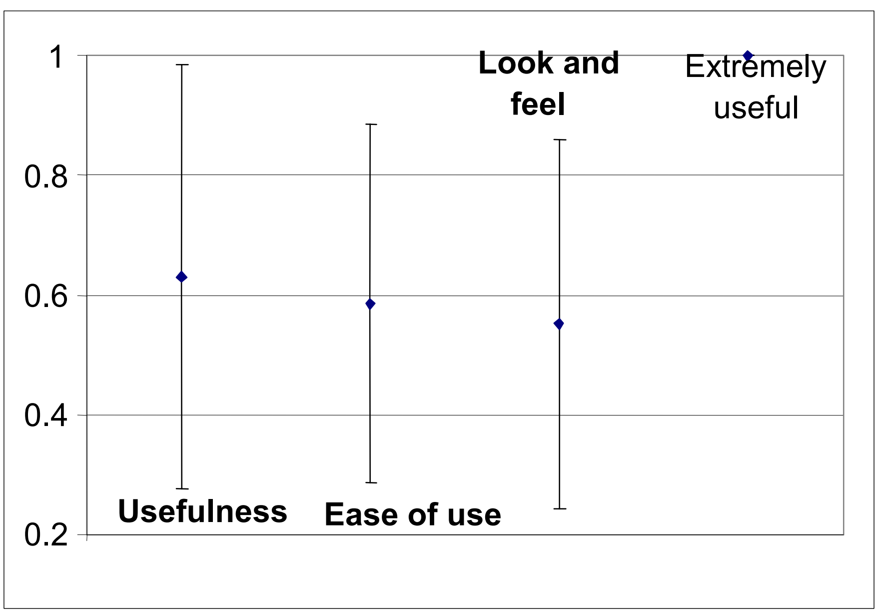


Figure 3: Mean and Standard Deviation for IWS

Figure 3 illustrates that the questions themselves are not significantly different (i.e., standard deviations overlap). Participants seemed to interpret the usefulness, ease of use, and look and feel questions in the same manner. Also for the usefulness of the IWS tool question (mean = .62 and s.d. = .35), the normal cumulative distribution up to and including one is .85. That is, 15% of the participants gave an answer greater than 100% useful, which, of course, did not happen. This is the primary difficulty for reporting mean and standard deviation with data sets that do not come from normal distributions.

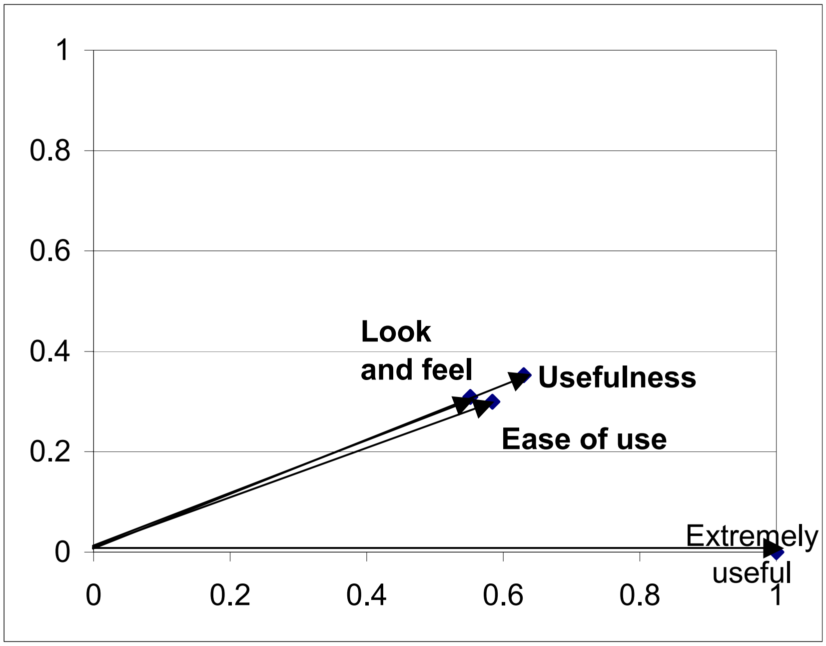


Figure 4: Vector Methodology Applied to the Responses to the IWS Questions

The vector approach was applied to all 18 questions. Figure 4 shows an example of the three response vectors for the IWS questions, along with the reference vector that lies along the x-axis. At a glance one may be tempted to draw the same conclusions as the statistical method about the similarity of the three questions since all three vectors have similar angles with respect to **v** (29.2º for usefulness, 27.1º for ease of use, and 29.3º for look and feel). However, in a multi-dimensional space, it is possible have similar angles relative to a reference vector, but the vectors actually point in different directions.

In order to resolve this issue, the relative angles are calculated between the three vectors: 21.2º between ease of use and look and feel, 29.3º and 27.8º between usefulness and the other two vectors, respectively. Figure 5 is a 3-dimensional conceptualization of what this might look like. The three vectors have similar angles relative to the reference vector, but also have different angles relative to themselves. The thinner the triangular prism, the more similar the response vectors become. In this case, a similarity threshold would need to be 29.3º in order to say that the questions are the same.

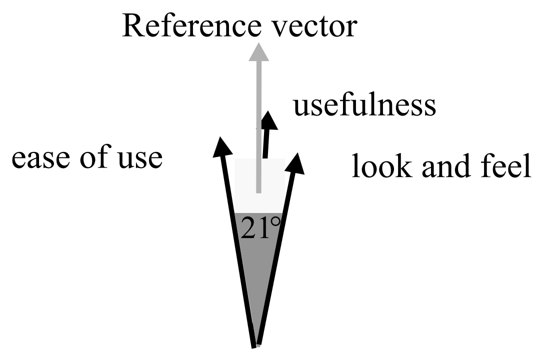


Figure 5: Conceptualization of Three Vectors having Similar Angles Relative to the Reference Vector, but Pointing in Different Directions

Also, the projection of **u** onto **v** is not ambiguous but it is a single, crisp number. This number will always fall within the limits of the bi-polar scale, unlike normal distributions where their tails extend to infinity beyond the bi-polar scale. The projection is used to calculate the percentage of the bi-polar scale. Table 2 lists these percentages for all six tools and the three questions. The highest rating from the participants was IWS and the lowest was the EBP tools.

Tool	Usefulness (%)	Ease of Use (%)	Look and Feel (%)
CIE Portal	63.8	60.9	55.2
Document Manager	69.1	66.4	66.1
IWS	81.5	79.2	77.6
ONA Database	64.9	59.6	61.7
EBP tools	45.2	28.0	39.2
WebCOP	53.0	53.6	56.5

Table 2: Percentage of Usefulness, Ease of Use, and Look and Feel

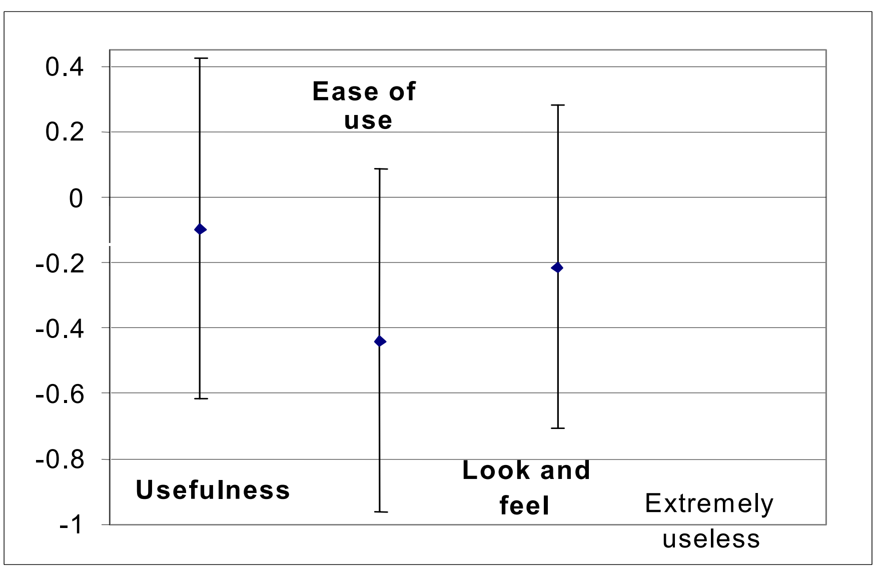


Figure 6: Mean and Standard Deviation for the EBP Tools

Figures 6 and 7 show the results for the EBP tools. The statistical results may be interpreted from 70% useful to extremely difficult to use because of the spread of the data. In contrast the vector approach shows crisply 45% useful, 28% ease of use, and 39% look and feel. It is clear that participants rated this tool poorly.

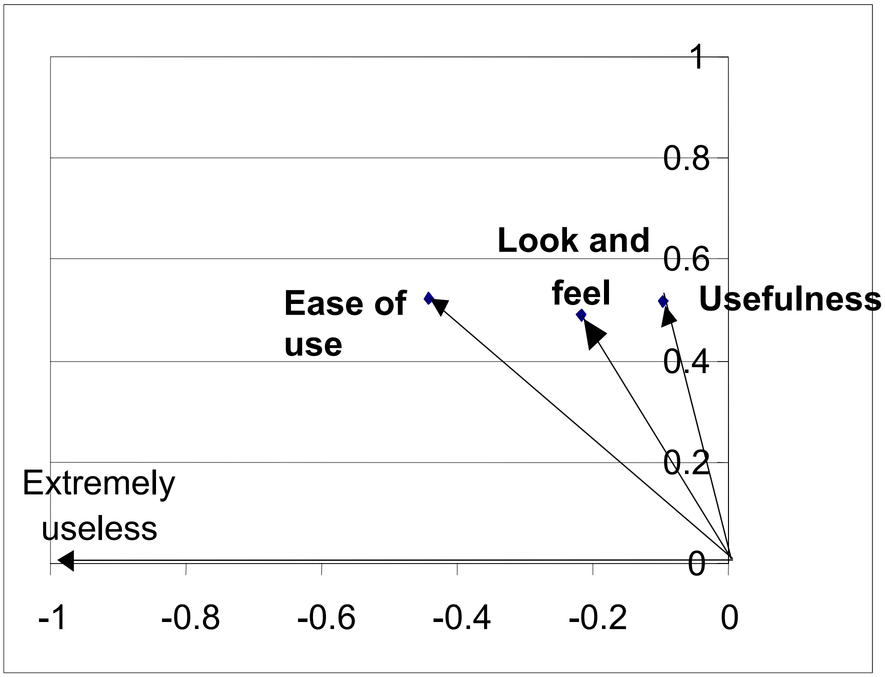


Figure 7: Vector Methodology Applied to the EBP Tools Data

Consider the three tools: CIE Portal, Document Manager and IWS. If we assume that the questions are not significantly different then the data can be combined to produce a single statistic, only if the same participants used all three tools and answered all three questions (53 participants in this case). Figure 8 shows the statistical result from 477 data points.

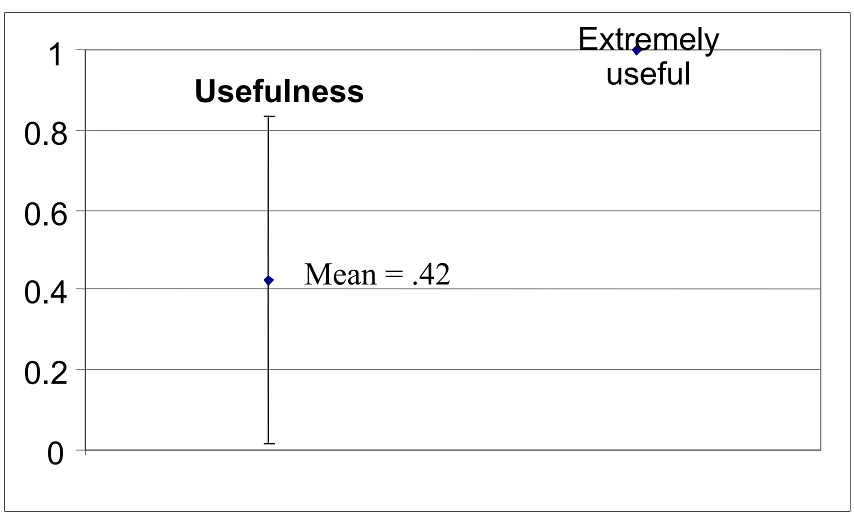


Figure 8: Statistical Results for 3 Tools and 3 Questions, and the Same Participants

The vector method allows us to consider all participants who answered some or all of the three tools and three questions. This is possible because each individual answer corresponds to a value on a single axis that forms a multi-dimensional vector. In this case there are 963 dimensions (or data points). The percent usefulness is calculated to be 65.2%, in contrast to 71.2% usefulness calculated from the mean of Figure 8. One could argue that the vector method result is more reliable since it has twice as many data points.

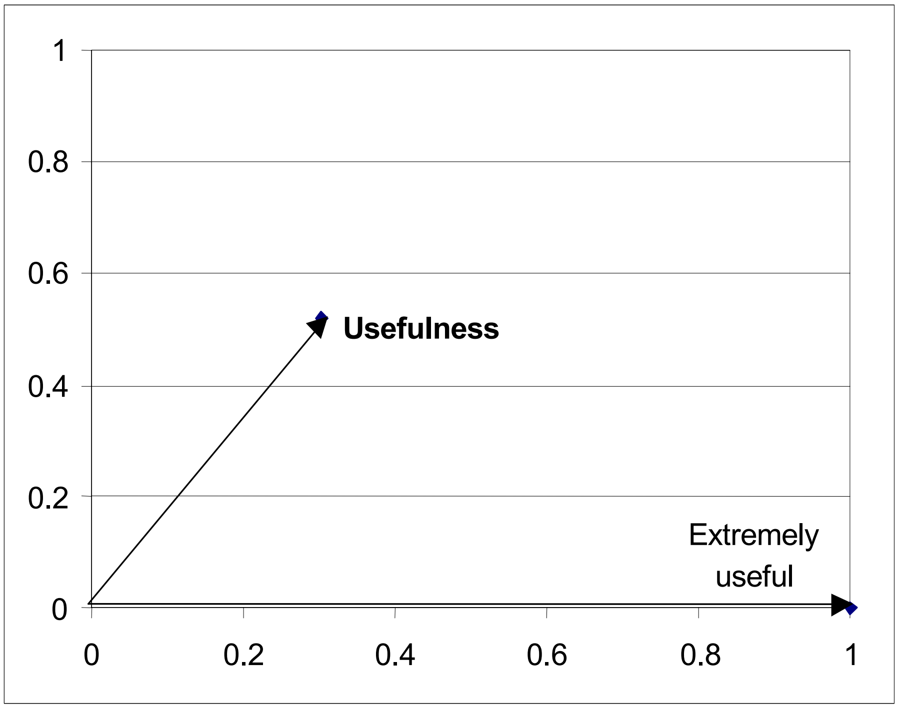


Figure 9: Vector Results for 3 Tools and 3 Questions, and All Participants

Technology and Common Intent

One reason for combining results is to compare the overall technology usefulness to other aspects of the experiment such as Common Intent (CI). In the context of EBP, a team of planners generate a plan that encapsulates the Commander's intention to achieve various strategic objectives and desired effects. The hypothesis is that high CI will lead to an effective plan while low or no CI will lead to an ineffective plan. During this event, CI was measured between medium and low using the vector method (Farrell, 2004).

A conceptual relationship between CI and technology is proposed: CI = CI(technology, *other variables*), where the *other variables* may include the EBP process, organization, workload, sleep deprivation, and so on. The relationship can be explored by plotting CI and technology usefulness along effectiveness axes as shown in Figure 10. The black circle indicates that the combination of CIE Portal, Document Manager and IWS technologies was between medium and high effectiveness (i.e., 65.2% useful) and CI was between medium and low. In this quadrant, CI must be dependent on variables other than technology. We know from the other results of the experiment that the EBP process and organization greatly influenced CI, more than the technology.

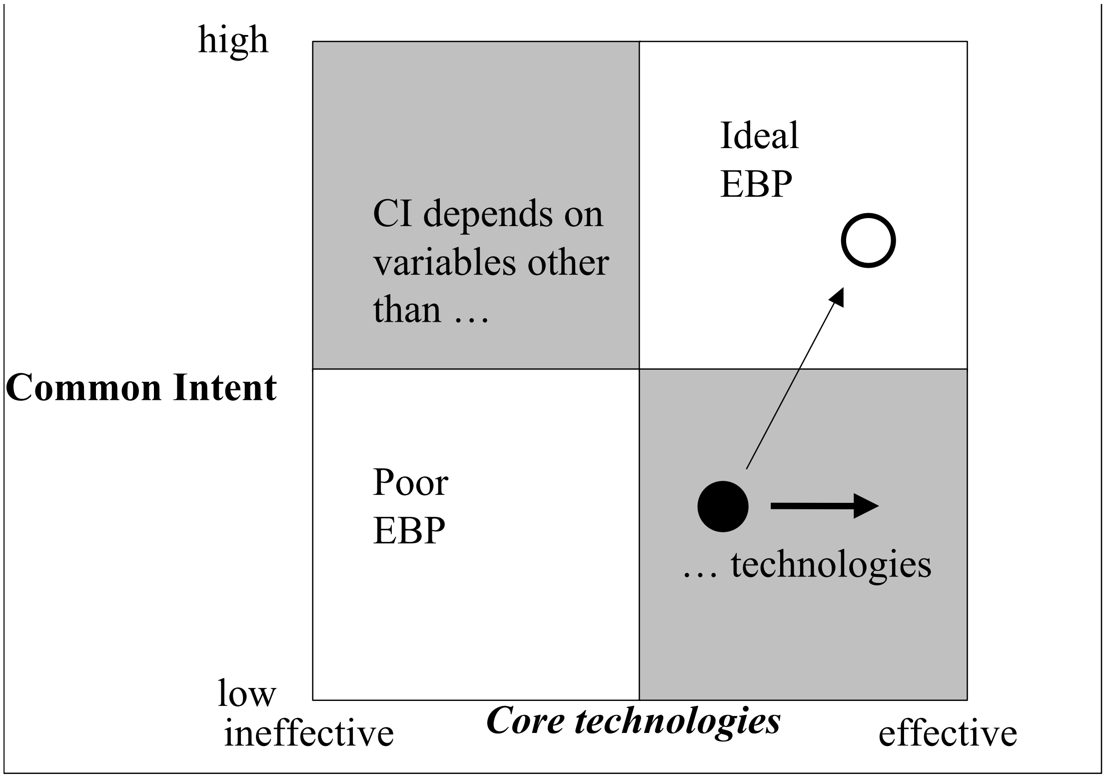


Figure 10: Common Intent versus the Core Technologies

In order to have a clearer picture of the relationship between CI and technology, a similar experiment needs to be conducted with an improved suite of tools. The thin arrow leading to the open circle is the desired outcome. However, the thick arrow shows our prediction of what may happen: that is, improving the technology will have little or no effect on Common Intent, and improving the process and organization will have a larger effect on CI. Nevertheless, the technology should be optimized to eliminate it as a potential detrimental variable.

Conclusions

A vector approach was used to reduce and interpret data from MNE3, a large and complex experiment. This method was compared and contrasted with typical statistical methods. A clear advantage of the vector approach is that it does not invoke assumptions typically associated with those statistical methods. Thus the vector method can be applied to a wider variety of data sets. As well, the results produced are non-ambiguous compared to the traditional techniques.

The statistical method indicates that the participants seemed to have the same interpretation of the three questions on usefulness. However, the vector method indicates that these three questions are not coincident, and a similarity threshold is required to determine whether the questions are indeed the same.

Other results specific to EBP and MNE 3 are that the highest rating from the participants was IWS and the lowest was the EBP tools. Common Intent was determined to depend on variables other than technology. Nevertheless, the technology should be optimized to eliminate it as a potential detrimental variable.

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