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INFORMATION TRANSFER IN DISPLAY- CONTROL SYSTEMS

A Manual for the Use and Application
of the Display Evaluative Index

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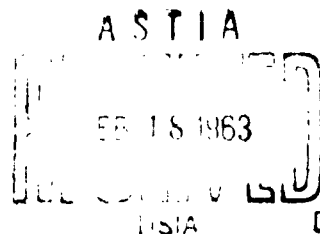
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Fort Monmouth, New Jersey

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Applied Psychological Services
Wayne, Pennsylvania



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A Manual for the Use and Application of the Display Evaluative Index

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for the

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PURPOSE

The over-all goal of the present program, conducted by Applied Psychological Services, is to develop a technique for evaluating the information transfer characteristics of the displays in a display→human operator→control system.

The basis of the study is the present state of the art of Signal Corps' systems.

The total program is composed of eight phases. These include:

- Phase 1 Survey and development of a technique for evaluating display→human operator→control systems and mathematical expression of the logic
- Phase 2 Development of exponents for the mathematical expression of the logic
- Phase 3 First verification of technique against outside criterion data
- Phase 4 Application of the technique to additional representative Signal Corps' equipments and systems
- Phase 5 Determination of the uniqueness of the factors included in the mathematical expression and appropriate modification of the technique
- Phase 6 Study of additional factors which might enhance the validity, reliability, and utility of the technique
- Phase 7 Preparation of a user's guide for the technique
- Phase 8 Study of novel human information handling rates and other human factors engineering problems associated with Signal Corps' equipment and systems under research and development for the purpose of enhancing the utility of the displays and improving system effectiveness.

The present report represents the results of Phase 7.

ABSTRACT

A manual containing step-by-step instructions for applying the Display Evaluative Index (DEI) technique, a technique for measuring the ability of a display→human operator→control system to transfer information and for the operator to act on this information, is presented. In addition to these instructions, the manual contains computational examples, definitions, a glossary, and suggested work forms.

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I. INTRODUCTION

With the advent of more complex Signal Corps' systems and the increased time span between system concept development and actual hardware production, the need has arisen for methods and techniques for comparatively evaluating various design concepts before prototype systems and subsystems are actually produced. While subjective standards and appraisals possess merit in the absence of more objective and reliable measurement and evaluative techniques, the provision of quantitative system effectiveness measurement techniques which can be applied early in the design stage might do much to eliminate costly design errors and expensive retrofits.

Accordingly, Applied Psychological Services under contract with Engineering Science Department, U. S. Army Electronics Research and Development Laboratory, has been engaged in a research program for evaluating the ability of the displays in a system to transfer information to the operator in the system and for the operator to act on the information received. Specifically, it is the purpose of this technique to allow comparative answers to questions such as:

- [1] Can it be expected that the operator will receive, interpret, and act on the information presented by design A in a superior manner than to design B?
- [2] If we change a display, what will be the relative effect on the equipment's ability to transfer information to the operator and on the operator's effectiveness?

This technique is referred to henceforth as the display evaluative technique. The index number which emerges from application of the technique is the display evaluative index or DEI.

Purpose of This Manual

This manual describes the method for applying the DEI technique.

Purpose and Scope of the DEI Technique

The purpose of the DEI technique is to provide a quantitative measure of the effectiveness of a particular equipment design from the information transfer (display→operator decision→control action) points of view. The basis of the equipment evaluation is one or more tasks performed by an equipment-operator combination. A task is essentially defined as a unit of activity rather than by the detailed operations which the operator performs. Different design variations may require the operator to perform different operations in order to perform the same task. For each application of the technique, the details of the operations must be known for each design variation. The same set of variations may give different rankings over different tasks.

The index is limited to one operator equipments or to situations in which there is no interaction between operators. It is further assumed that the indicators and controls on the equipment meet minimal human factors design standards as set forth in various human factors engineering design guides. Thus, it is assumed that panel arrangements are reasonable, indicators are of approved types and sizes, force and torque requirements

are met, directional expectancies are satisfied, etc. The DEI does not rate the electronic or mechanical reliability of the equipment. It does rate the information transfer effectiveness.

Although the DEI was designed to possess a range of values between 0 and 1 (1 being a perfect system), any individual DEI value possesses little interpretive significance. Comparison of any individual DEI value with the DEI values of alternative designs for the same system allows a choice of the best system from the points of view considered.

II. USE AND APPLICATION OF THE DEI TECHNIQUE

The first step of the analysis involves construction of a transfer chart for the particular operator-equipment task being considered.

Transfer Chart Symbols

The transfer chart portrays the display and control elements, as well as the information transfer, of the equipment-operator combination being analyzed. The symbols used in the transfer chart are shown in Table 1.

To construct a transfer chart:

1. On the left side of a large paper, draw a symbol (Table 1) to represent each indicator on the equipment. Label the symbols successively I_1 , I_2 , etc., and with the actual legends appearing on the equipment, or by its function. The symbols are drawn under each other.
2. On the right side of the chart, draw a symbol to represent each control on the equipment. Label the symbols successively C_1 , C_2 , etc., and with their actual legends on the equipment or by their function.

Your transfer chart will now appear like that shown in Figure 1.

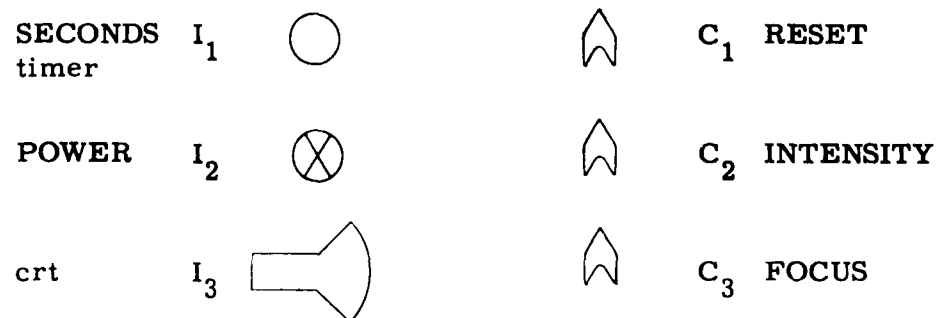
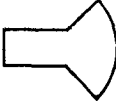


Figure 1 Preliminary step in transfer chart construction

Table 1

Suggested Symbols for Transfer Chart

Indicator				
Control				
Mixer				
Gate				
Computation, delay, memory, etc.				

I label for display element

C label for control element

(Dn) label for element composed of a number, n, of separate ON-OFF indicators or controls

Links

3. Link the indicators and their related controls. To accomplish this draw a solid line (called an information link) from an indicator to a control if the control is actuated at any one time on the basis of information obtained solely and directly from its related indicator. If this operation is repeated, no additional (duplicate) link is drawn. If, at another time, the same control is actuated on the basis of a display on another indicator, draw a separate line linking these. On the other hand, if a control action depends on the reading of several indicators, use one of the following schemes:

- (a) If the control can be actuated on the basis of information from any one of several indicators, use a mixer, , to connect the indicators to the control. Figure 2 shows this representation.

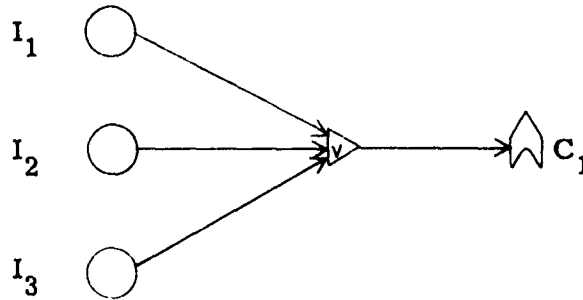


Figure 2 Mixer representation

- (b) If the control action requires information from more than one indicator, use a gate, , to connect the indicators to the control.

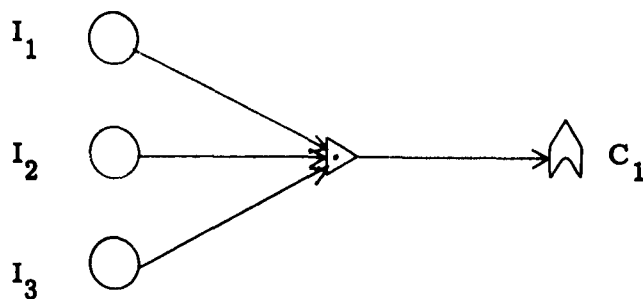


Figure 3 Gate representation

- (c) If the information from one or more indicators must be converted or otherwise mentally processed by the operator before he operates the control or controls, the link is broken and a box, , is inserted. Write the name or formula of the process involved in the box. Each line segment is considered an information link.

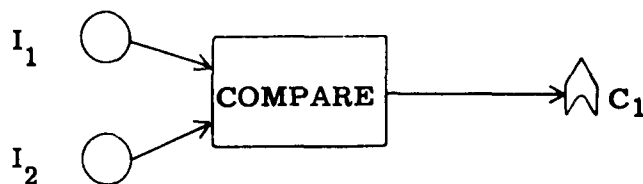


Figure 4 Mental information processing representation

The direction of information flow is indicated by arrows.

4. It is possible that one control's setting may be used as the basis for adjusting another control. This situation is illustrated in Figure 5, where the setting of C_1 determines the setting of C_2 .

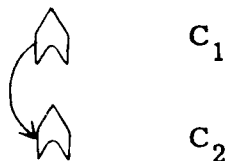


Figure 5 Control-control link

5. If an indicator (e.g., cathode ray tube) or control is to be marked according to its own display (e.g., target position), draw an information link from the indicator or control back to itself

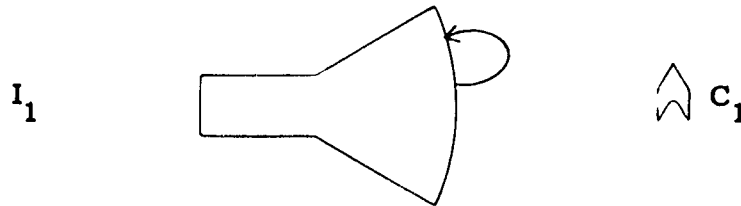


Figure 6 Display-display link

6. Draw a solid line, called instruction link, to a control, a $\square$, or a $\triangleright$ if action is to be taken on the basis of fixed instructions (without recourse to an indicator). An instruction link is not an information link and starts in the space between indicators and controls, e.g., links 1 and 2 in Figure 7.

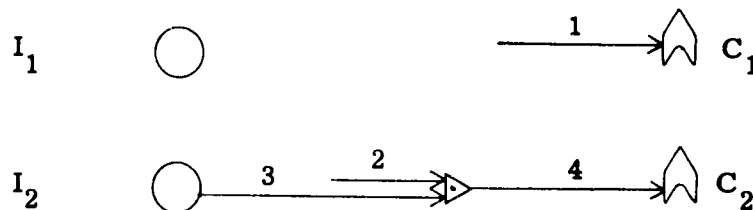


Figure 7 Instruction link

Links from a $\square$ or $\triangleright$ are information links.

7. If, after drawing all links, one or more "unused" indicators are apparent and these indicators merely reflect the status, condition, or position of a control or of several controls, then draw a dashed line, called a corroborative link, from the control or controls to the indicator.

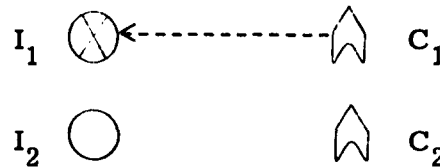


Figure 8 Corroborative link

8. Number each link, starting with the information links and ending with the corroborative links.
9. Label each box successively: i. e. , B_1 , B_2 , etc.
10. If an indicator or control is composed of two or more components such as lights or pushbuttons, all of which relate to a common function, note this by writing the symbol (Dn) near the symbol of the indicator or control. Here, n is the number of parts (either all lights, or all pushbuttons, etc.). For 5 parts, the symbol would be (D5), as shown in Figure 9.

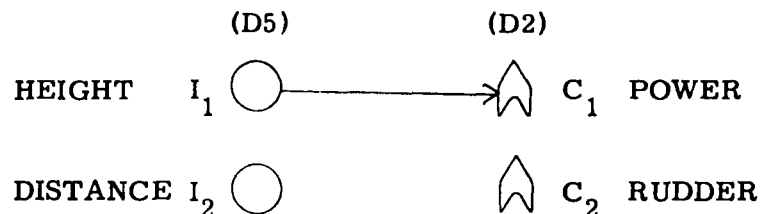


Figure 9 Multiple unit representation

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Display Digits

13. In the column headed Display Digits, list the number of digits of information available at the beginning of each information link. There are several possible cases:

- (a) For a link from an indicator or a control, the number of digits, i , if not apparent from the element, may be calculated by using the formula:

$$i = \log_{10} s$$

For a meter or dial, s is the larger of the following: (1) the total number of different possible readings the operator can make (or is instructed to discern), or (2) the actual number of markings on the dial. For a counter type indicator and for a combination of lights, s is the actual number of states which may occur.

Example 1 A counter type indicator has three drums and all settings from 000 to 999 may occur. It can be seen at once that there are 3 digits. Since 1000 possible states or indicators are involved, using the formula gives the same result:

$$i = \log_{10} 1000 = 3 \text{ digits}$$

Example 2 A counter never can indicate 200 of its possible 1000 settings. Therefore:

$$i = \log_{10} 800 = 2.90 \text{ digits}$$

Example 3 A meter with a range of 0 to 50 has scale markings every five units and is read to the nearest 5 units. There are thus 11 possible states or readings (including 0). The number of digits must now be calculated:

$$i = \log_{10} 11 = 1.04 \text{ digits}$$

Example 4 A meter with a range of 0 to 50 has scale markings every five units and is read to the nearest unit. There are thus 51 possible readings:

$$i = \log_{10} 51 = 1.71 \text{ digits}$$

Example 5 A meter has a range of 0 to 50, scale markings every five units, and action is to be taken on the basis of only three regions on the meter: 0 to 15, 15 to 30, and 30 to 50. Here s is 11, the larger of the two possibilities:

$$i = \log_{10} 11 = 1.04 \text{ digits}$$

Example 6 An indicator consists of three lights. These lights are used in combination to provide eight different signals. s is 8:

$$i = \log_{10} 8 = .91 \text{ digits}$$

- (b) The number of digits for a link coming from a mixer, $\triangleright$, is equal to largest value of i to the mixer.
- (c) The number of digits for a link coming from a gate, $\triangleright$, equals the sum of the input information to the gate, where an inhibiting or enabling link is assigned zero information.

- (d) The output information from a COMPARE box has either $\log_{10}3$ or $\log_{10}2$ digits depending on whether the comparison is of type $<$, $=$, $>$, or $\neq$.
- (e) A link from a DELAY box has the same information as the link to the box.
- (f) A link from a COMPUTATION box has information:

$$i = \log_{10} v$$

where v is the number of different possible values of the result of the computation

- (g) The information from a TABLE REFERENCE box is:

$$i = \log_{10} v$$

where v is the number of different values in the body of tables, i. e., of the dependent variable.

Action Digits

14. Under Action Digits, for each link list the number of digits of information required at the end (arrow) of each information link. Use the same formula as for display digits:

$$i = \log_{10} s$$

In this case s is the actual number of positions possible for the control or the actual number of index marks associated with a control, whichever is greater. Uncalibrated or continuous knobs (no reference marks or detents) are considered to have three states associated with them: no

motion, turn clockwise, and turn counterclockwise. Therefore, for these controls:

$$i = \log_{10} 3 = .477 \text{ digits}$$

Information Match

15. Calculate the absolute match in digits between each link and its related control. Absolute match in digits applies only to controls associated with information links or transfers, and not to instruction or corroborative links. It is the absolute difference between the number of digits associated with a link and the number of digits in the receiving element, i. e., the smaller number subtracted from the larger number.

An exception occurs with a COMPARE box. Such a box has two input links. A match exists if the number of digits for the two links are equal. Place the value of the absolute difference in the row of the link with the higher value.

A COMPUTATION box produces no mismatch with the input link.

Example Consider the transfer chart and table for a hypothetical task and system as shown in the foldout at the back of this manual. Labels for the indicators and controls have been omitted from the figure. The task consists of the six information transfers listed below in terms of links and boxes:

1, B₁, 2
3, 4, B₂, 5
6, 8, 7
9
10, 11, 12
13, B₃, 14, 15 (assuming C₄ and C₅
are both set almost
simultaneously)

Assume that the first three columns of the transfer chart (Table A1, on foldout) have already been filled in. Subsequent results in column 4 are shown underlined. The match calculation corresponding to each link number will now be explained, using hypothetical data.

Link 1 I_1 has 100 divisions ($i = 2$), of which only 50 are read out or distinguished ($i = 1.7$) and used in computation (one at a time). Therefore, the mismatch, M_1 , is $2 - 1.7 = .3$ and $|M_1| = .3$.

Link 2 Due to the nature of the computation, 50 different input values give only 20 different results ($i = 1.3$). C_2 , a continuous dial, has 100 divisions ($i = 2$): $|M_2| = 2 - 1.3 = .7$.

Link 4 Information from I_1 ($i = 2$) and from I_2 ($i = 3$) is compared. Their difference is a mismatch and is written opposite the link with highest i value: $|M_4| = 3 - 2 = 1$.

Link 5 The comparison is two way ($=, \neq$) which gives $i = .3$. C_2 has 5 positions ($i = .7$): $|M_5| = .7 - .3 = .4$.

Link 7 Information from I_2 ($i = 3$) and C_3 ($i = .9$) is combined to operate C_2 : $i_6 + i_8 = 3 + .9 = 3.9$. C_2 has .7 digits: $|M_7| = 3.9 - .7 = 3.2$.

Link 9 Link 9 is a direct link: $|M_9| = 1.48 - .9 = .58$.

Link 12 C_4 is operated on the basis of information from either I_3 or I_4 . The maximum of 1.48 or 2.3 is taken as the information for link 12. The mismatch for link 12 is then $2.3 - 2 = .30$.

Link 13 I_5 has 50 different possible readings ($i = 1.7$), while the table has 1000 input values listed ($i = 3$): $|M_{13}| = 3 - 1.7 = 1.3$.

Link 14 There are 500 different output values from the table ($i = 2.7$). C_4 has 2 digits: $|M_{14}| = 2.7 - 2 = .7$.

Link 15 C_5 has 200 states ($i = 2.3$): $|M_{15}| = 2.7 - 2.3 = .4$. The preceding example was designed to illustrate a variety of mismatch situations and is not typical of actual systems.

Link Weights

In addition to the match calculation, weights are assigned to each link and to the boxes.

16. Link weights are obtained by consulting the "Display Digits" or "Action Digits" columns, the transfer chart, and Table 2.

Table 2

Link Weights

Type of Link	Digits (i)	Weight (w)
Corroborative	less than .5	0.5
Corroborative	.5 or more	1.0
To ▽ or from any ▽		0.0
Instruction or information	less than .5	1.0
Instruction or information	.5 or more	2.0
From box		1.0

A box is given a "link" weight of 4. The weight of an instruction link is based on the information for the control, while the weight of an information link is based on the information from the indicator. Using the transfer chart, column 2 of the transfer table, and filling in the weights gives the results in column 5 of the foldout transfer table (Table A1).

Time Limits

17. If a time limit has been set or is inherent in part of a task (subtask) then the Time t column must be completed only for the final links going to an indicator or control and for boxes which are involved in the time limited subtasks.

For an information link to an indicator or control, calculate Time t (in seconds) employing the formula:

$$t = .5i + .15$$

where i is the number of Display Digits associated with the link.

For a transfer involving a box, add the operation time for the box to the link times.

The transfer table is now complete and will be used later to derive some of the data for the DEI.

DEI Computation

Further steps in the computation are now delineated continuing with the previous numbering.

18. Sum all the numbers in column 5 of the transfer table. This gives Σw . Add 1 to this and place this number on line 1 of the worksheet labeled $1 + \Sigma w$. A sample worksheet is included in the appendix of this manual.
19. Count those indicators and controls on the transfer chart which are connected to either an information or instruction link (solid line). This gives the number of "used" elements $(n + m)_u$. For example, in Figure 7, there are 3 used elements. Place this number on line 2, labeled $(n + m)_u$, on the worksheet.
20. Count all indicators and controls on the transfer chart. This gives $(n + m)_t$. Place this number on line 3 labeled $(n + m)_t$.
21. Count the instruction and information links (solid lines) on the transfer chart. This gives N which is recorded on line 4 of the worksheet.

22. Find the total number of parts, Q , on the transfer chart. To do this, add all the (D) subscript numbers, counting indicators and controls without this label as (D1). See step 10. Record Q on line 5 of the worksheet.
23. Count the elements on the transfer chart other than indicators and controls, i. e., the mixers ($\triangleright$), gates ($\triangleright$), and boxes. This gives n_0 . Record on line 6 of the worksheet.
24. If any indicator or control consists of pushbuttons or ON-OFF lamps or devices and if the number of states, indications, etc., is 12 or more ($i = 1.08$ or more) then the factor R is applicable to this indicator or control. R is the smaller of $\frac{r}{q}$, $\frac{q}{r}$. The value of q is the number of parts--the same number as is used to calculate Q . The calculation of the r is illustrated in the following examples:

Example 1 A function is controlled by 247 pushbuttons ($q = 247$). The presence of each, except the leftmost digit of the number 247 contributes 10 to r . Thus, the units and the tens position each contribute 10, or a total of 20. The specific digit in these positions is not relevant. The leftmost digit is important. It contributes one more than its value. In this example, it contributes $2 + 1 = 3$. r is the total of these contributions or $20 + 3 = 23$. R is the smaller of $\frac{23}{247}$, $\frac{247}{23}$; $R = \frac{23}{247}$. However, if the leftmost digit is from 2 to 9, and all digits to its right are zero, it contributes itself. If the leftmost digit is 1 and all digits to its right are zero, it contributes nothing. For $s = 100$, $r = 20$; for $s = 300$, $r = 23$.

Example 2 An indicator consists of 4 lights which are used in combination to give 15 different signals ($i = 1, 18$). There is one position on the right which contributes 10 to r . The leftmost digit is 1; its contribution is $1 + 1 = 2$. Accordingly, $r = 10 + 2 = 12$ and

$$\frac{r}{q} = \frac{12}{4}; \quad \frac{q}{r} = \frac{4}{12}; \quad R = \frac{4}{12} = \frac{1}{3}$$

Multiply all R factors together. This gives $\bar{R}$. If one R factor exists, then $\bar{R} = R$. If no R factors exist, then $\bar{R} = 1$. Record this $\bar{R}$ value on line 10 of the worksheet.

25. If several time critical subtasks exist, treat each subtask as follows.

Consider the first time critical subtask. Sum the t values (column 6 of the transfer table) which are associated with subtask 1. Be sure to include the time used in operations represented by boxes. This gives T_1 .

Add the i values associated with each of the t values. This gives I_1 .

Calculate the value of $I_1 \left(\frac{T_1}{T'_1} \right)^3$ where T'_1 is the allotted time for task 1.

To do this, calculate $\frac{T_1}{T'_1}$ and either look up $\left(\frac{T_1}{T'_1} \right)^3$ or calculate $\left(\frac{T_1}{T'_1} \right) \left(\frac{T_1}{T'_1} \right) \left(\frac{T_1}{T'_1} \right)$.

Then multiply this cube by I_1 .

If the allotted time T'_1 is less than the required time T_1 , calculate

$$I_1 \left(\frac{T_1}{T'_1} - 1 \right).$$

Make these computations for all time critical subtasks and sum the

$I \left(\frac{T}{T'} \right)^3$ values. This gives $\Sigma I \left(\frac{T}{T'} \right)^3$. Record on line 12 of the record

sheet. Also sum the $I \left(\frac{T}{T'} - 1 \right)$ values. This gives $\Sigma I \left(\frac{T}{T'} - 1 \right)$. Record

on line 14 of the record sheet.

Example For the system shown on the foldout, assume that subtask 1 consists of operating C_3 and C_4 based on the information transfers 9, 10, 11, 12. The time, T_1 , allotted for performance is 2.5 seconds. A second subtask consists of only one information transfer (6, 8, 7) and has an allotted time, T'_2 of 2.0 seconds.

Consider the first subtask (transfers 9, 10, 11, and 12). The value of t for link 9 is:

$$t = .5i + .15 = .5(1.48) + .15 = .74 + .15 = .89 \text{ seconds.}$$

For link 12,

$$t_{12} = .5(2.3) + .15 = 1.15 + .15 = 1.30 \text{ seconds}$$

The total time, T_1 , for task 1 is:

$$.89 + 1.30 = 2.19 \text{ seconds}$$

For subtask 1, the allotted time, T'_1 , was 2.5 seconds. The required time for subtask 1 does not exceed the allotted time; accordingly, only $I_1(T_1/T'_1)^3$ is calculated. The information associated with transfer 10, 11, 12 is that for link 12, viz., 2.3 digits. For link 9, $i_9 = 1.48$.

The total information for subtask 1 is $I_1 = 2.30 + 1.48 = 3.78$ digits. Therefore:

$$I_1 \left(\frac{T_1}{T'_1} \right)^3 = 3.78 \left(\frac{2.19}{2.5} \right)^3 = 3.78 (.796)^3 = 3.78 (.504) = 1.91$$

The calculation for subtask 2 (transfers 6, 8, 7) is as follows:

The value of t for link 7 is obtained by computing t for 3.9 digits:

$$t = .5(3.9) + .15 = 1.95 + .15 = 2.10 \text{ seconds}$$

The total time, T_2 , is 2.10 seconds. This exceeds the allotted time of 2 seconds so that both $I_2 \left(\frac{T_2}{T'_2} \right)^3$ and $I_2 \left(\frac{T_2}{T'_2} - 1 \right)$ must be computed. Therefore:

$$I_2 \left(\frac{T_2}{T_1} \right)^3 = 3.9 \left(\frac{2.10}{2} \right)^3 = 3.9(1.05)^3 = 3.9(1.16) = 4.52$$

$$\text{and } I_2 \left(\frac{T_2}{T_1} - 1 \right) = 3.9(1.05 - 1) = 3.9(.05) = .195$$

Now the totals for both subtasks are calculated:

$$\Sigma I \left(\frac{T}{T_1} \right)^3 = 1.91 + 4.52 = 6.43$$

$$\text{and } \Sigma I \left(\frac{T}{T_1} - 1 \right) = .195$$

26. Sum the values in column 4 of the Transfer Table. This gives the sum of the absolute mismatches, $\Sigma |M|$. Record this sum on line 15 of the worksheet.
27. On the transfer table, check those links associated with critical transfers. A critical transfer is one which, if not accomplished properly, causes the whole task to fail. Count the number of checks. This gives N_c . Record on line 16 of the worksheet. All variables have now been calculated and recorded; all that remains is the calculation of the DEI value.

Final Calculation

Further calculations are carried out on the basis of the data already on the worksheet.

28. Total the values on lines 5 and 6 of the worksheet. This gives $(Q + n_0)$.
29. Calculate the product of lines 4, 3, and 7; write the product on line 8.
30. Look up or calculate the square root of line 8 and write result on line 9.
31. Calculate the fourth root of $\bar{R}$ (line 10). One method is to take the square root of the square root of $\bar{R}$, i. e. ,

$$\sqrt[4]{\bar{R}} = \sqrt{\sqrt{\bar{R}}}$$

32. Calculate $\frac{1}{16}$ of line 12; write the result on line 13.
33. Write $\frac{1}{10}$ of line 16 on line 17.
34. Total lines 13, 14, 15, and 17 and write the result on line 18.
35. Calculate $\frac{1}{4}$ of line 18 and write the result on line 19.
36. Look up the exponential function value of the negative of line 19.

Example Suppose $\frac{1}{4}$ sum = .42

Then a table of exponential functions gives

$$e^{-.4r} = .657$$

37. Calculate the final DEI (without cost factor) by multiplying the values of lines 2, 11, and 20 and dividing this by the product of lines 1 and 9.

Uniformity of Application

If at all possible, analyses of variations of the same design should be uniform or consistent. It is better to make the same assumptions or judgements in all evaluations than to make random assumptions or independent judgements. Therefore, one analysis should be used as the basis for incremental changes in the number of elements, links, mismatch, etc., for all other variations.

The 0 to 1 Scale

In certain cases it may be desirable to convert the obtained DEI values to a scale which ranges from 0 to 1, where the equipment variation with the lowest DEI value is given a rating of 0 and the variation with the highest DEI a rating of 1.

Each variation will have a rating calculated as follows:

- (1) Compute $I - I_L$ where I_L is the lowest DEI value, and I is any variation.
- (2) Divide $I - I_L$ by $I_G - I_L$ where I_G is the greatest DEI value.

This procedure gives the relative 0 to 1 value for variation i .

As an example, suppose the results shown below are the DEI values for five different equipment variations.

	DEI(I)	$I - I_L$	$\frac{I - I_L}{I_G - I_L}$
Variation			
0	.0132	.0022	.10
1	.0251	.0141	.65
2	.0110	0	0
3	.0328	.0218	1
4	.0187	.0077	.35

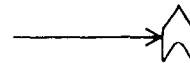
The results may then be plotted directly on a 10 cm. scale as shown below:



Hints for the Construction of Transfer Charts

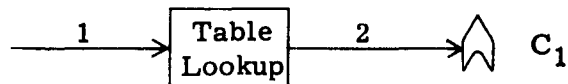
The following examples are intended to be helpful in constructing the transfer chart and table. The operation is stated first. This is followed by the section of the transfer chart corresponding to it. An explanation and comments are then given.

Example 1 Procedural instructions require a control to be set to a fixed predetermined position.



An instruction link is employed. The weight of this link is determined by the number of states of the control. Assume the control to be a POWER ON-OFF switch (two states): $\log_{10} 2 = .30$ which is less than .5; $w = 1$. No mismatch is attributed to an instruction link.

Example 2 Set C_1 according to a fixed tabularized input.



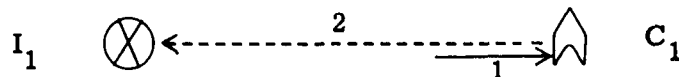
Link 1 is an instruction link and as such can contain no mismatch. Link 2 is an information link. The match depends on the difference between the number of different table entries and the number of states of the control.

Example 3 According to fixed instructions, operate a self-indicating pushbutton.



This is an instruction link and as such possesses no mismatch.

Example 4 According to fixed instructions, throw switch C_1 to ON. When in the ON position, indicator I_1 lights.



Link 1 is an instruction link.

Link 2 is a corroborative link.

$w_1 = 1$, $w_2 = \frac{1}{2}$. Since C_1 and I_1 both possess two states, no mismatch can exist.

Example 5 A verbal command is given to set a switch to one out of a number (N) of possible positions.



If $n > 3$, $w_1 = 2$
 If $n \leq 3$, $w_1 = 1$

Example 6 Set I_1 to a predetermined value by means of C_1 .



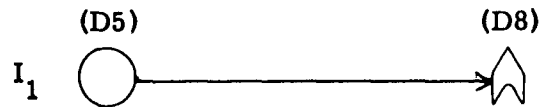
The present setting of I_1 is compared with the desired or nominal value. Link 2 is an instruction link. No mismatch can occur for links 1 or 2; $w_1 = w_2$; w_1 depends on i_1 . If C_1 is continuous and uncalibrated, no mismatch occurs for link 3. A link from a box has a weight of 1; $w_3 = 1$.

Example 7 Mark the position or state of an indicator on the indicator. Mark the position or state of a control on the control.



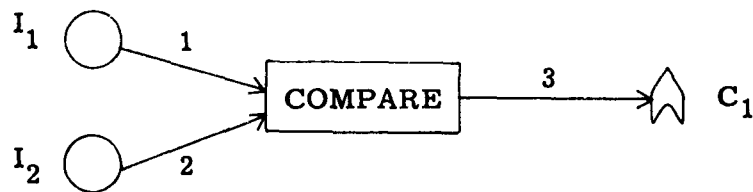
The link weight depends on the number of states of the indicator or control, respectively.

Example 8 C_1 is to be set according to I_1 . I_1 has 5 independent but related lights and C_1 has 8 independent but related pushbuttons.



The (D5) indicates the 5 parts of I_1 and the (D8) the 8 parts of the C_1 . The Q value is $5 + 8 = 13$.

Example 9 Set I_1 to the reading of I_2 by means of C_1 .



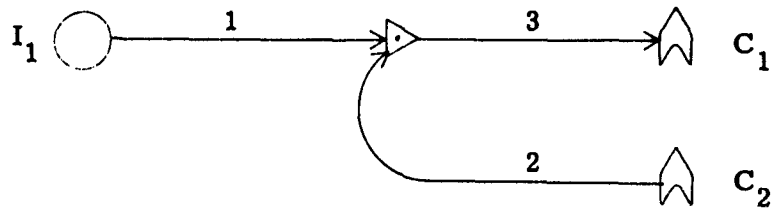
Assume I_1 to possess 20 states, I_2 to possess 50 states, and C_1 to be continuous. There is an information mismatch: $\log_{10} 50 - \log_{10} 20 = 1.7 - 1.3 = .4$ digits. This is attributed to the link from the indicator having the greatest information--link 2. The output from the compare box has 3 states in this case (greater than, equal to, and less than). Since C_1 may be moved in either direction or left unchanged, there is then no mismatch for link 3. Weights are assigned to links 1 and 2 according to the number of digits associated with I_1 and I_2 ; w_1 and w_2 have values of 2. The link (3) from the box has a fixed weight of 1.

Example 10 Extremize (maximize or minimize) an indicator reading by means of a control knob.



The operation of extremizing is not of such complexity as to warrant the use of a box. Any divisions on the indicator and control are ignored (only 3 states are assumed to exist), so that normally no mismatch exists.

Example 11 Set control C_1 according to information on a general purpose meter, I_1 , whose function has been selected by selector switch C_2 .



Link 2 is an enabling link (a special type of information link which allows information transfer to take place). Any mismatch would be between the information associated with I_1 and C_1 . The weights of links 1 and 2 depend on the number of states of I_1 and C_2 ; the weight of the link from the gate (w_3) is 0.

Cost Factor

The DEI value already calculated is multiplied by the cost factor when the cost of the equipment is to be taken into consideration.

Divide the actual cost, $\$_i$, by $\$_r$, the reasonable cost, and subtract the quotient from 1. This gives:

$$1 - \frac{\$_i}{\$_r}$$

The result may be positive or negative. Look up the value of the exponential function for this value of $1 - \frac{\$_i}{\$_r}$. This gives:

$$\exp\left(1 - \frac{\$_i}{\$_r}\right)$$

Divide the operating cost per year, $\$_0$, by the reasonable cost, $\$_r$, and add 1 to the quotient. This gives:

$$1 + \frac{\$_0}{\$_r}$$

Divide this into the previously calculated exponential function value:

$$E = \frac{\exp\left(1 - \frac{\$_i}{\$_r}\right)}{1 + \frac{\$_0}{\$_r}}$$

Raise E to the appropriate power f. In the absence of any predetermined value, it is suggested that $f = \frac{1}{3}$ be used. This is equivalent to taking the cube root of E.

Example Assume the reasonable cost ($\$r$) of an equipment to be \$10,000, the actual cost ($\$i$) to be \$11,000, and the operating cost per year ($\$0$) to be \$1,000.

$$\frac{\$i}{\$r} = \frac{11,000}{10,000} = 1.1$$

$$1 - \frac{\$i}{\$r} = 1 - 1.1 = -.1$$

$$\exp(-.1) = .905$$

$$\frac{\$0}{\$r} = \frac{1,000}{10,000} = .1$$

$$1 + \frac{\$0}{\$r} = 1 + .1 = 1.1$$

$$E = \frac{\exp(1 - \frac{\$i}{\$r})}{1 + \frac{\$0}{\$r}} = \frac{.905}{1.1} = .823$$

The cost factor is $\sqrt[3]{E}$ if f is taken to be $\frac{1}{3}$.

$$\sqrt[3]{.823} = .937$$

If the DEI value previously calculated is .00230, then the resulting value is $.00230 \times .937 = .00215$.

Symbols Used

DEI	display evaluative index
E	base for expense factor
E^f	expense factor
$\exp(x) = e^x$	exponential function of x
i	information in digits associated with an indicator or control, also information associated with one transfer
I	total information transfer for one subtask
I'	DEI value
m	number of controls
M	match in digits for an information transfer
n	number of indicators
n_0	number of elements other than indicators or controls on transfer chart
N	total number of information and instruction links
N_c	number of critical links
$(n + m)_t$	total number of elements (used and unused)
$(n + m)_u$	number of "used elements"
q	actual number of ON-OFF parts of an indicator or control
Q	total number of indicator and control parts
r	required (ideal) number of parts for a multiple part element
R	utilization efficiency factor for one element
$\overline{R}$	product of all utilization efficiency factors

s	number of states associated with an element
$\$ _i$	actual initial cost of equipment
$\$ _0$	operating cost of equipment/year
$\$ _r$	reasonable cost of equipment
Σ	summation sign
t	time in seconds actually required to make an information transfer
T	total actual time required for one subtask
T'	allotted time for one subtask
w	weight of a link

GLOSSARY

Box	a symbol () which is inserted in a link when considerable data processing by the operator is involved in an information transfer; the box is used to indicate functions such as computations, comparisons, code conversion, delay (retention in memory) and information distribution.
Control	an element which is responsive to some physical action by the operator and which affects the state of the system. A control may consist of a number of related dependent parts. A control is considered as one unit on the transfer chart and in calculating $(n + m)_u$ and $(n + m)_t$. If a control consists of separate ON-OFF type parts, each part is counted separately for the Q calculation. The control symbol on the transfer chart is then also labeled with a (Dn) symbol where n is the number of parts.
Corroborative link	a dashed line drawn from a control to an unused indicator when that indicator reflects the setting of the control, <u>and</u> that control is operated in the course of performing the task.
Critical transfer	an information transfer which: (1) must be performed, (2) if performed improperly is not correctable or repeatable, and (3) if performed improperly will cause failure of the whole task.
Digit	a unit of information equivalent to that of a ten state device. The amount of information in digits is given by the formula

$$i = \log_{10} n$$

where n is the number of states of an element. One digit is equivalent to 3.32 bits.

Enabling link	an information link to a gate () which allows the transfer of information by other links (through the same gate) to a control.
Gate	a symbol () used on the transfer chart when information from two or more sources is required in order to actuate a control.

Indicator	an element capable of assuming a variety of states which are distinguishable by the operator. An indicator may consist of a number of related, dependent parts. An indicator is considered as one unit on the transfer chart and in calculating $(n + m)_u$ and $(n + m)_t$. If an indicator consists of separate ON-OFF type parts, each part is counted separately for the Q calculation. The indicator symbol on the transfer chart is then labeled with a (Dn) symbol where n is the number of parts.
Information	a measure of the number of different possible states of an indicator or a control, given by the formula $i = \log_{10} n$ where n is the number of different states. The unit of information is the digit.
Information link	a line drawn on a transfer chart from an element used as an indicator or from any  or  symbol when a transfer of information is involved.
Information transfer	information transfer occurs when the operator perceives and distinguishes one out of two or more possible states of a display element and takes some action based on this display. On the transfer chart it is represented by all the links and connecting symbols leading to the element acted on.
Inhibiting link	an information link to a gate () which prevents the transfer of information by other links (through the same gate) to a control.
Instruction link	a line drawn on a transfer chart to a control when that control is set to a fixed, predetermined position according to operating instructions. Only one instruction link may be drawn to any one control.
Match (mismatch)M	the difference in the amount of information associated with two different elements, e. g., an indicator and the control with which it is linked.
Mixer	a symbol () used on the transfer chart when any one or more than one source of information may be used as the basis for a control action.

Reasonable cost (\$ _r)	cost as estimated by the customer or as is known from experience with similar equipment.
Subtask	a set of operations, usually a fractional part of the task. A subtask may in some cases correspond to one link or it may be the whole task.
Task	the utilization of an equipment to accomplish a specified operational end result or results.
Unused element	an element (indicator or control) which is not connected to an instruction nor to an information link.
Used element	an element (indicator or control) which is connected to an instruction or information link.

APPENDIX A

Appendix A presents the following:

1. Sample worksheet for the DEI calculation
2. Transfer chart (Figure A1) referred to in previous section of this report
3. Transfer table (Table A1) referred to in previous section of this report

DEI WORKSHEET

Date _____

_____ Name of Analyst

_____ Equipment

_____ DEI Value

-
1. $(1 + \Sigma w)$ =
 2. $(n + m)_u$ =
 3. $(n + m)_t$ =
 4. N =
 5. Q =
 6. n_0 =
 7. $(Q + n_0)$ = (5.) + (6.) =
 8. $N(n + m)_t(Q + n_0)$ = (4.)(3.)(7.) =
 9. $\sqrt{N(n + m)_t(Q + n_0)}$ = $\sqrt{(8.)}$ =
 10. R =
 11. $\sqrt[4]{R}$ =
 12. $\Sigma I \left(\frac{T}{T'}\right)^3$ =
 13. $\frac{1}{16} \Sigma I \left(\frac{T}{T'}\right)^3$ =
 14. $\Sigma I \left(\frac{T}{T'} - 1\right)$ =
 15. $\Sigma |M|$ =
 16. N_c =
 17. $\frac{1}{10} N_c$ =
 18. Sum = (12.)+(14.)+(15.)+(17.) =

$$19. \quad \frac{1}{4} \text{ Sum} = \dots\dots\dots$$

$$20. \quad \exp(-\frac{1}{4} \text{ Sum}) = \boxed{}$$

$$\text{DEI} = \frac{(2.)(11.)(20.)}{(1.)(9.)} = \underline{\hspace{2cm}} = \boxed{}$$

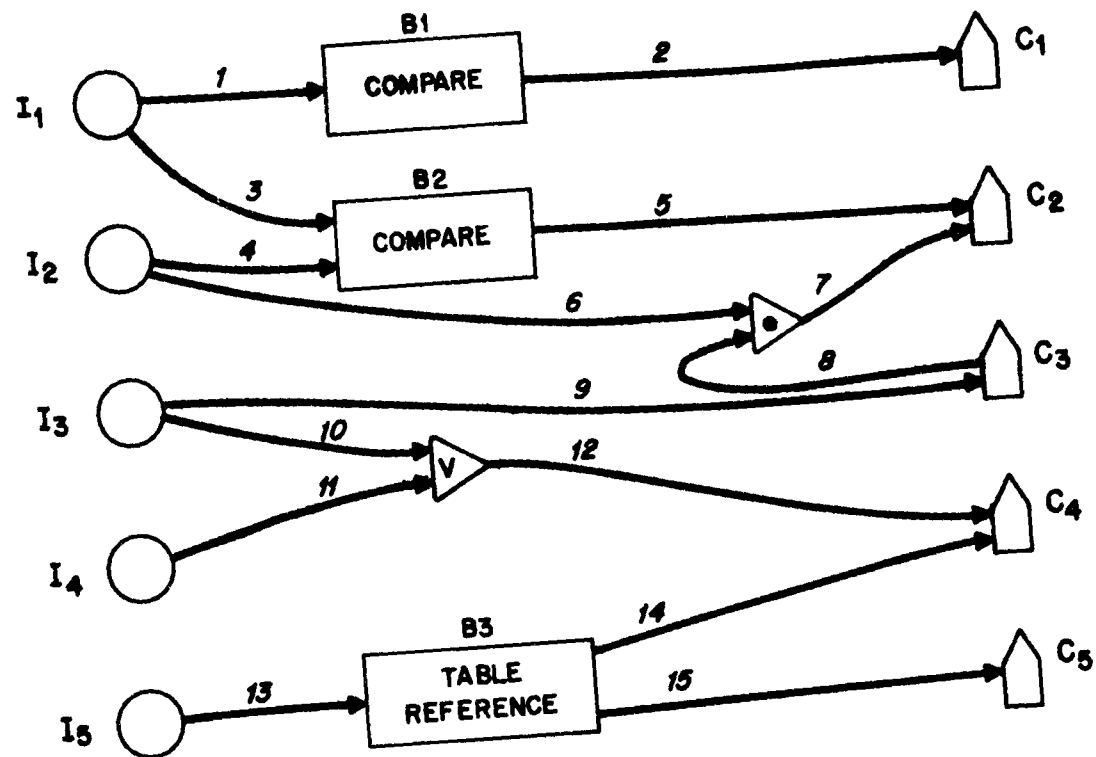


Figure A₁ Transfer chart.

Link No.	Display Digits l	Action Digits	Absolute Mismatch Digits	Link Weight	Time t
1	2.0	1.7	<u>.30</u>	2	2.10
2	1.3	2	<u>.70</u>	1	
3	2.0	—	—	2	
4	3.0	—	<u>1.00</u>	2	
5	0.3	0.7	<u>.40</u>	1	
6	3.0	—	—	2	0.89
7	3.9	0.7	<u>3.20</u>	0	
8	0.9	—	—	2	
9	1.48	0.9	0.58	2	1.30
10	1.48	—	—	0	
11	2.3	—	—	0	
12	2.3	2	<u>0.30</u>	0	
13	1.7	3	1.30	2	
14	2.7	2	<u>0.70</u>	1	
15	2.7	2.3	<u>0.40</u>	1	
B1				4	
B2				4	
B3				4	

Table A₁ Transfer table.

AD	Accession No. APPLIED PSYCHOLOGICAL SERVICES Wayne, Pa.	Unclassified
INFORMATION TRANSFER IN DISPLAY-CONTROL SYSTEMS VI. A MANUAL FOR THE USE AND APPLICATION OF THE DISPLAY EVALUATIVE TECHNIQUE A. I. Siegel, W. Miehl, and P. Federman Sixth Quarterly Progress Report 16 September 1962 - 15 December 1962 DA 36-039 SC-87230, Project No. 3A95-20-001 Unclassified Report A manual for applying the Display Evaluative Index (DEI) technique, a technique for measuring the ability of a display→human operator→ control system to transfer information and for the operator to act on this information, is presented. The manual contains step-by-step instructions, computational examples, definitions, and sample work forms.		1. Man-machine Systems Design-Human Functions Analysis 2. Signal Corps Contract DA 36-039 SC-87230

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INFORMATION TRANSFER IN DISPLAY-CONTROL SYSTEMS VI. A MANUAL FOR THE USE AND APPLICATION OF THE DISPLAY EVALUATIVE TECHNIQUE A. I. Siegel, W. Miehl, and P. Federman Sixth Quarterly Progress Report 16 September 1962 - 15 December 1962 DA 36-039 SC-87230, Project No. 3A95-20-001 Unclassified Report A manual for applying the Display Evaluative Index (DEI) technique, a technique for measuring the ability of a display→human operator→ control system to transfer information and for the operator to act on this information, is presented. The manual contains step-by-step instructions, computational examples, definitions, and sample work forms.		1. Man-machine Systems Design-Human Functions Analysis 2. Signal Corps Contract DA 36-039 SC-87230

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		1. Man-machine Systems Design-Human Functions Analysis 2. Signal Corps Contract DA 36-039 SC-87230

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