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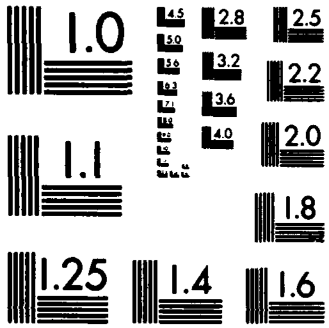

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COMPUTER AIDED TECHNIQUES FOR CREW
STATION DESIGN
Work-space Organizer-WORG
Workstation Layout Generator-WOLAG
by
Babur Mustafa Pulat
ONR Contract Number N00014-81-C-0320

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Report N00014-81-C-02 June 1983

COMPUTER AIDED TECHNIQUES FOR CREW STATION DESIGN

Work-space Organizer-WORG

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TECHNICAL REPORT

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Prepared for:

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study reports the development of two more modules in the Multi-Man-Machine Work Area Design and Evaluation System - MAWADES. The Work-space Organizer-WORG, and the Workstation Layout Generator-WOLAG.

WORG is an interactive computerized model, which prepares the layout of several workstations within a work-space. The relative locations of the workstations are determined after link analysis (visual,-

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voice and electronic communication) between stations.

WOLAG is also a computerized interactive model, designed to prepare panel layouts at each station for sit-stand duty. Displays and controls are laid out sequentially on a panel based on system functions and operator tasks. The physical dimensions of the panel, along with panel sections and angles between sections, are determined after consideration of workspace geometry (anthropometric variables), the visual space(visual field, eye-head movements, etc.), and locational priority zones.

Both modules collect evaluative measures on the designs generated. This data may be analyzed by a decision maker to choose the best design.

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INTRODUCTION

A previous report (Pulat, 1982) communicated the development of a computer aided workstation assessor for crew operations - WOSTAS. This study reports the development of two more computer aided models: WORG and WOLAG.

The aforementioned models are component parts of a multi-man-machine work area design and evaluation system (MAWADES) being developed under a Navy contract research program. MAWADES is a computerized general purpose model. It aims at preparing and evaluating alternate layouts of a command, control, and communications center where a crew is performing the above functions working with instrument panels at sit-stand duty.

Briefly, WOSTAS generates alternate scheduling schemes of mission tasks to workstations. WORG then takes over, and prepares an ergonomically sound layout of these workstations within a workspace. Finally, WOLAG designs the instrument panel for each workstation.

WORK-SPACE ORGANIZER - WORG

WORG has been developed for the purpose of arranging workstations within a work-space. The arrangement scheme follows link values computed for between stations. These will be referred to in more detail later.

WORG is an interactive module written in FORTRAN IV programming language. It consists of a main program and four subprograms. Since the program has been structured around an interactive philosophy, the effects of input changes on the layout generated can be observed in minimal time.

Inputs:

The input data for the model are as follows:

1) General: This item includes the total number of workstations and the total number of tasks to be carried out across the stations.

2) Workstation Information: Included here are station numbers and the operator count at each station.

3) Task Information: For each task, the following items need to be specified:

   a) Task number
   b) Area requirement of associated display or control, if any
   c) Criticality rating
   d) Predecessor count, and task numbers of preceeding tasks
   e) Successor count, and task numbers of successors
   f) Workstation assignment
   g) Sequential link (frequency-of-use per unit time) between this task and each successor
   h) Task type

Tables 1 and 2 give the codes for criticality ratings and task types respectively.

Table 1. Criticality Ratings

Task Requirements	Criticality Codes
Primary or Warning Displays	7
Primary or Emergency Controls	6
Voice Communications	5
Secondary Displays	4
Secondary Controls	3
Auxiliary Displays	2
Foot Controls and others	1

Table 2. Task Types

Task Type	Type Code
Panel - Operator	1
Panel - Panel	2
Common Panel - Operator	3
Operator - Panel	4
Operator - Operator	5

As implied in the Task Information category of the input data, th mission of the crew is represented as a network of tasks. On this network, the successors of any task are the ones which follow in the logical sequence of accomplishment. Only after completing the predecessors, succeeding tasks may be attempted.

WORG assumes that the workstation assignment of the tasks in the mission has already been done, and the operator count at each station has been determined. In the MAWADES model, WOSTAS performs these operations (Pulat, 1982).

Model Structure:

Figure 1 gives the flowchart of WORG. The model has been structu such that the user does not have to input data each time WORG needs t be run. Naturally, for a new case study, data files need to be re-

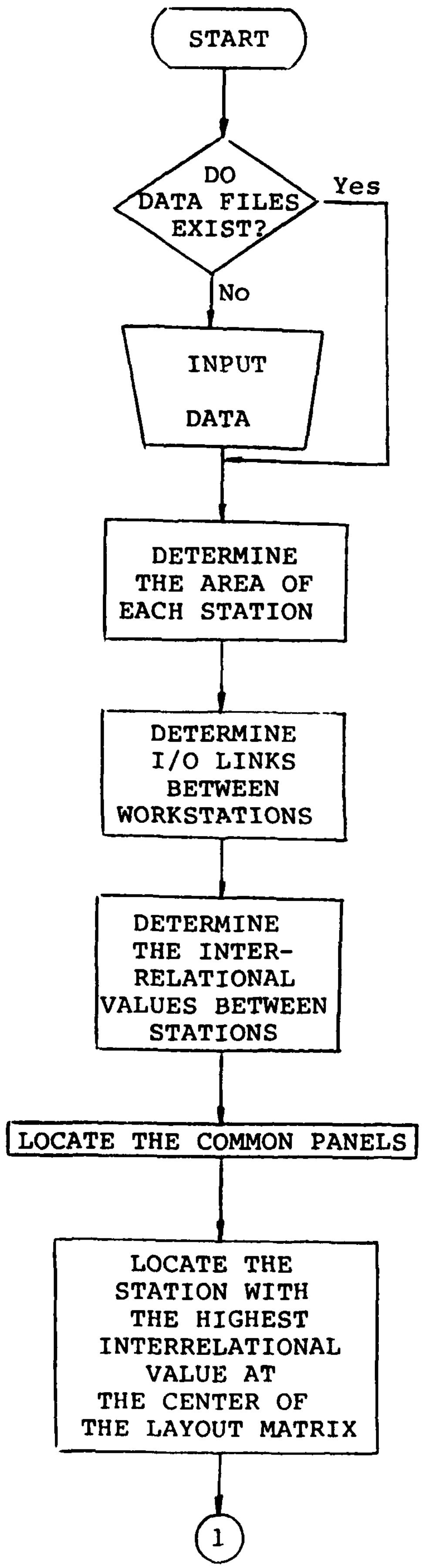
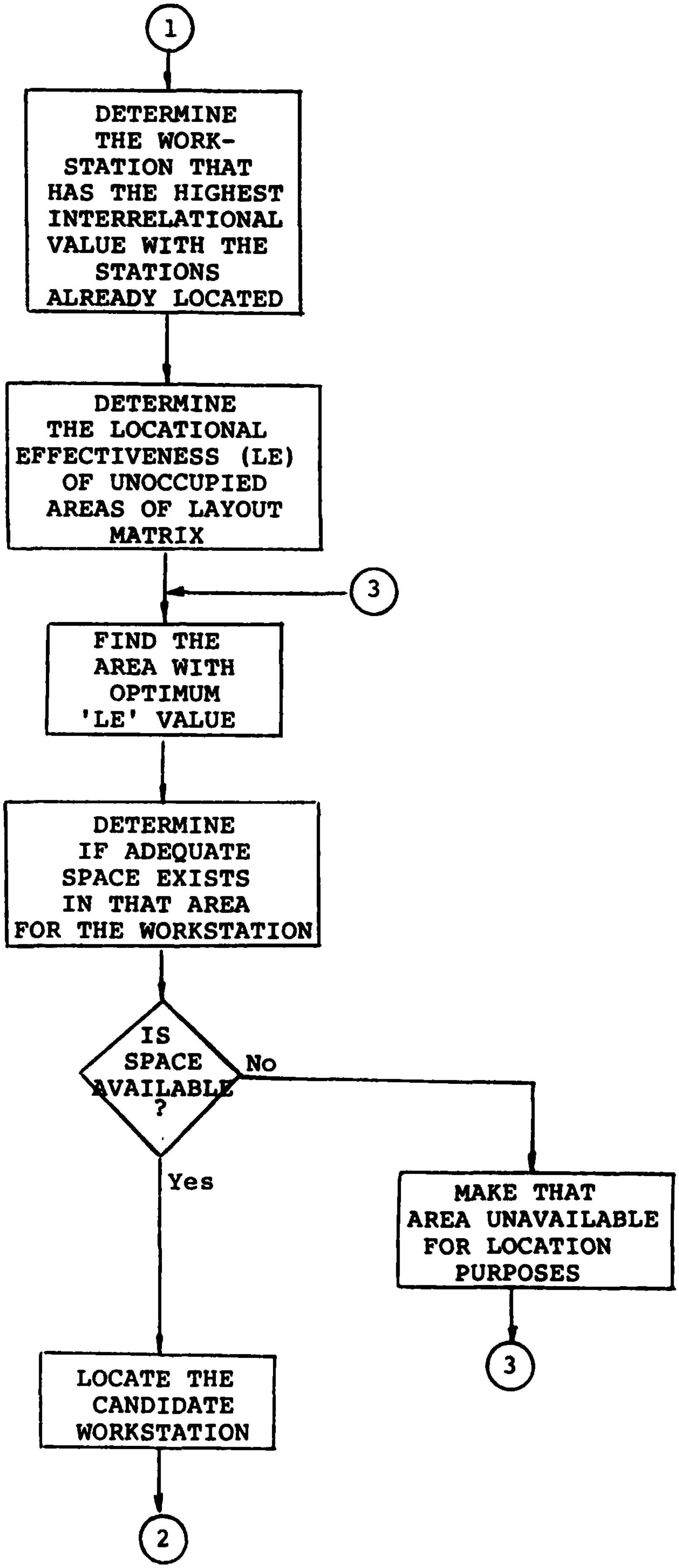


FIGURE 1 Flowchart of WORG



FUGURE 1 (continued)

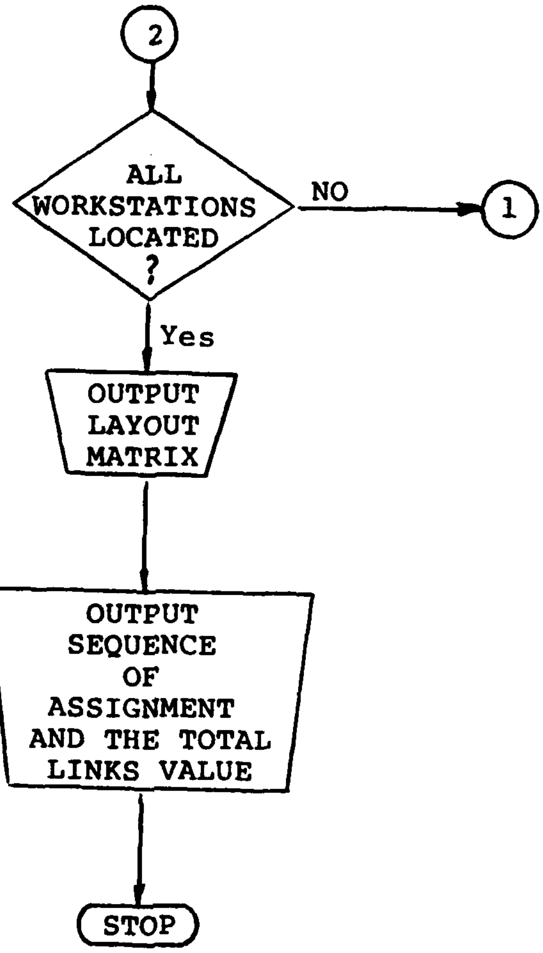


FIGURE 1 (continued)

structed. Whichever the case is, after the data has been accessed, WORG calculates the area requirement of each workstation. This includes the panel space (displays, controls, clearances, and additiona space for future use), operator area(s), access and egress space, and aisle space around all four sides of the workstation (Van Cott and Kinkade, 1972; Woodson, 1981, and Diffrient et al. 1983).

Link values are then computed between stations. This is a two stage process. In the first stage, link task set is identified. The following criteria are used to detect the task couples that belong to this set:

a) The tasks must have been assigned to separate stations.
b) Both tasks should have type codes of 2, 3, or 5 only.
c) One task should either be the predecessor or the successor of the other.

At the second stage, link values (interrelational values) are computed between stations according to the following formula:

$$LV_{ij} = \sum_{\ell,m \in A} (CR_\ell + CR_m) * FR_{\ell,m} \qquad i,j = 1,\ldots,M \quad j > i$$

where

LV_{ij}: Link Value between stations i and j.

CR_ℓ : Criticality Code of task ℓ

CR_m : Criticality Code of task m.

$FR_{\ell,m}$: Sequential link between tasks ℓ and m.

ℓ,m: Tasks indentified as belonging to the link task set (A).

M : Number of workstations

Link analysis is often recommended for locating or arranging the components of a system within a given environment (McCormick and Sanders, 1982; Woodson, 1981; Huchingson, 1981). Although the recommendations as to the computation of the link values center around the importance and frequency of interrelationships between the components there is no agreed upon format of the computation. The FR and CR values in the above equation represent the frequency and the importan of the links respectively. The additive and the multiplicative relationships place more emphasis on links that occur between critical components and less on those that occur between non-critical ones.

As the first step of the workstation arrangement process, common panels (maps, etc.) are located around the perimeter of a layout grid composed of half meter squares for each grid element. Then, the work station possessing the highest link value is located at the center of the grid. The area requirement of each station, as determined earli is strictly followed during the location process.

The link values file is searched to find the station which has the highest link with the one already located. Once the candidate station is obtained, for each empty grid element, a locational effectiveness value is calculated according to the following formula:

$$LE_j = \sum_i ED_{ij} * LV_{ic}$$

where

LE_j : Locational effectiveness of jth empty grid element.

ED_{ij} : Euclidean distance between the centroid of the ith already located station and the jth grid element.

LV_{ic} : Link Value between the ith located station and the candidate (c) station.

A search is performed around the element possessing minimum LE value. The candidate station is located in the area if sufficient space exists. If not, search process continues around the element in the LE rank until the station is successfully located.

The search $\rightarrow$ select $\rightarrow$ locate process continues until all stations have been located on the layout matrix.

Outputs:

The report files of WORG are as follows:

(a) The layout grid showing the exact locations of the workstations. The relative locations of the stations are given by the relative arrangement of the station numbers on the final layout.

(b) Placement sequence of the workstations on the layout matrix.

(c) Total Links Value - This is an evaluative measure for the layout obtained. If several alternative layouts are acceptable, the one which has minimum total links value will be more desirable. The measure is calculated through the following relationship:

$$TLV = \sum_{i} \sum_{j>i} ED_{ij} * LV_{ij}$$

where

TLV : Total Links Value for the layout

ED_{ij} : Euclidean distance between the centroids of the ith and jth stations.

LV_{ij} : Link value between stations i and j.

Appendix I gives the above report files for a hypothetical proble Station 18 denotes a common panel. Each entry on the layout represen an area of half-meter square (½ mt x ½ mt). Zero entries correspond unused areas of the layout grid. The distance between the common pan and other stations came about due to the fact that the problem did no involve many stations. In such a case, preserving the relative locations, other stations may be moved towards the common panel (which is around the perimeter) for compactness.

Station six possesses the maximum links to all others. Thus, other stations have been located around station six, which is the first station located (after the common panel) according to the "Sequence of Assignments" file.

The "Total Links" value for one layout does not have much significance. It is for evaluative purposes when several alternative designs are being considered. Minimum links value suggests desirability of the layout since one would like to have the stations with high operational relationships located closer (minimum distances indicated) together.

WORKSTATION LAYOUT GENERATOR - WOLAG

In the MAWADES model, WOLAG's function is to prepare the layout of the instrument panel at each workstation. The panel's physical features (including the height, length, and partitions) are embedded into the model. The units (displays and controls) are located sequentially on the panel, which is initially blank.

WOLAG is an interactive module written in FORTRAN IV programming language. The results of any design study will immediately be available for user interaction for sensitivity or trade-off analysis.

Inputs

As input, the following information is required:

1. General Data: Total number of workstations (panels), and the width of each panel.

2. Workstation Inputs:

   -Functional groups of units
   a) Number of such groups at each panel
   b) Group composition (member units)
   c) Group type (simo use, sequential use, or free units group

   -Sequence-of-use between functional groups, if any.

   -For each display or control
   a) Area requirement (cm^2)
   b) Criticality code
   c) Operational relationship with other units
   d) Clearance code.

The criticality codes are similar to the ones used in WORG. However, units used for voice communications are assumed not to be a part of the panel. Thus, the codes for WOLAG range from 1 (foot controls and others) to 6 (primary or warning displays).

Operational relationships between units are entered in letter codes as follows: A: High relationship, B: Medium, C: Low relationship. These ratings denote sequential use links between pairs of displays and/or controls.

Clearance code refers to minimum recommended separation between pairs of like units. The relevant recommendations of Chapanis and Kinkade (1972) have been adopted for use in WOLAG.

The user is asked to form functional groups of units from those:

a) Which require simultaneous use of various units (simo use group).
b) Which have sequence-of-use relationship between the members (sequential use group).
c) Which do not possess any of the above two characteristics (free units group). This group may further be partitioned into sub-groups for any other reason.

It is possible to form larger functional groups of displays and contr by specifying the sequence-of-use between the subgroups.

Model Structure

Figure 2 gives the flowchart of WOLAG. As is the case in WORG, new data files may be input for a new study, or existing files may be modified and reused for sensitivity analysis on a previously completed design study. The panel layouts are prepared in a sequential manner moving from station 1 to the last station. The basic layout process is the same across the workstations. However, due to differe unit requirements and/or functional group compositions and sequence-of-use data between the functional groups, each station may obtain a different layout of the panel. The discussion that follows gives the basic steps of the layout procedure at any workstation.

Location of functional groups of displays and/or controls starts with the one possessing highest interaction with other groups. Once all the units belonging to that particular group have been located, the sequence-of-use data between groups is checked, and exhausted if any such data has been specified involving the group already located. Next, all the remaining functional groups are evaluated with respect to operational relationships between their member units and the units belonging to the groups already located. The group with the highest interrelationship (interaction) is located, and a second check of sequence-of-use data between functional groups is performed. This sequence continues until all functional groups of displays and controls have been located on the panel.

The interaction (operational relationship) between functional groups, if no sequence-of-use data has been specified, is calculated as follows:

$$INT_{ij} = \sum_{\ell} \sum_{m>\ell} (CR_{\ell i} + CR_{mj}) * IRAT_{\ell i,mj}$$

where:

INT_{ij} : Interaction (or link) value between ith and jth functional groups.

$CR_{\ell i}$: Criticality code of ℓth unit in the ith group.

CR_{mj} : Criticality code of mth unit in the jth group.

$IRAT_{\ell i,mj}$: Sequential link rating between the above units.

The locational effectiveness (LE) calculation is slightly different from the one in WORG:

$$LE_j = \sum_i ED_{ij} * IRAT_{ic} + P_c$$

where

LE_j : Locational effectiveness of jth empty grid element

ED_{ij} : Euclidean distance between the centroid of the ith already located unit and the jth grid element.

$IRAT_{ic}$: Sequential link rating between the ith located unit and the candidate(c) unit.

P_c : Zonal Penalty associated with the criticality code of the candidate(c) unit and the locational priorit zone within which jth empty grid element lies.

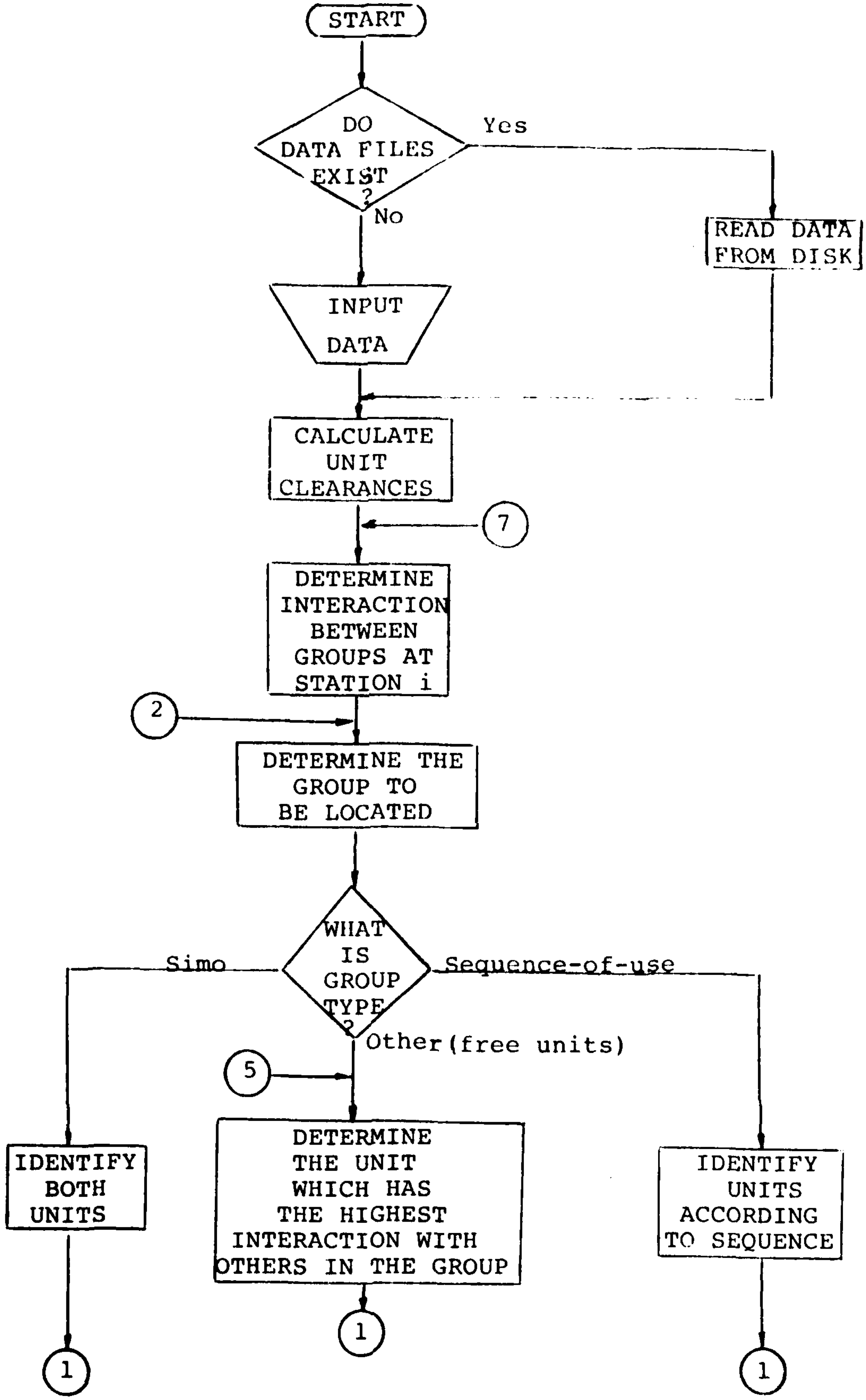


Figure 2. Flowchart of WOLAG

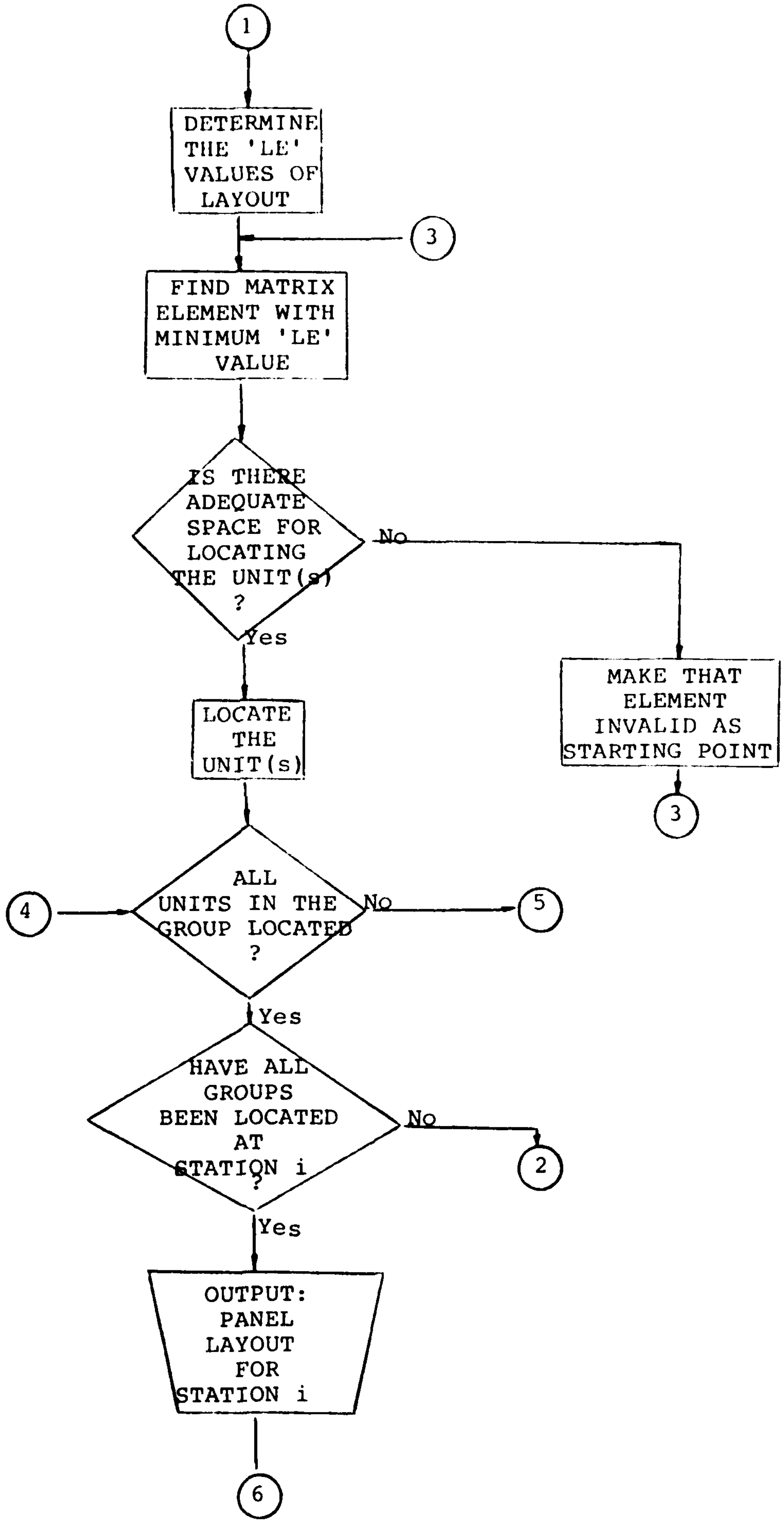


Figure 2. (continued)

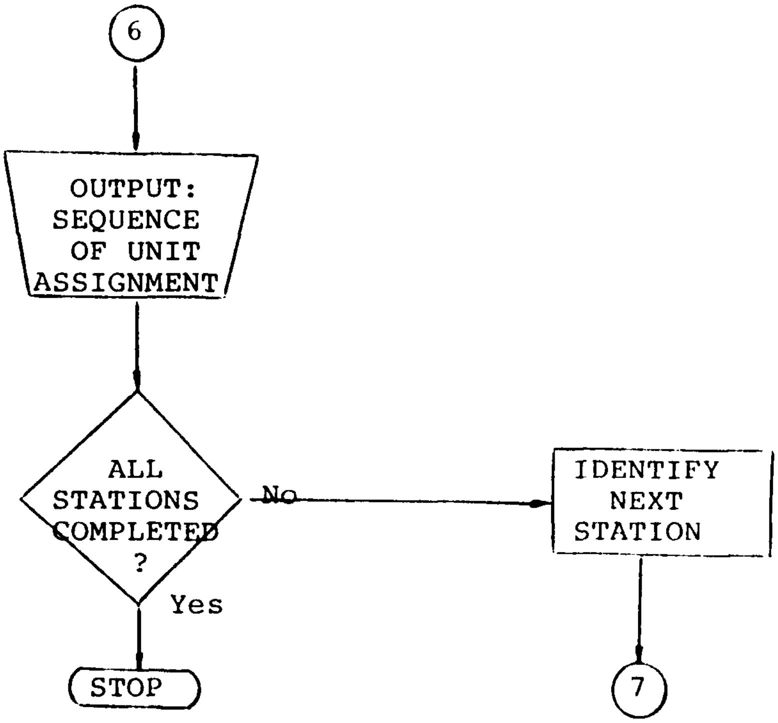


Figure 2. (continued)

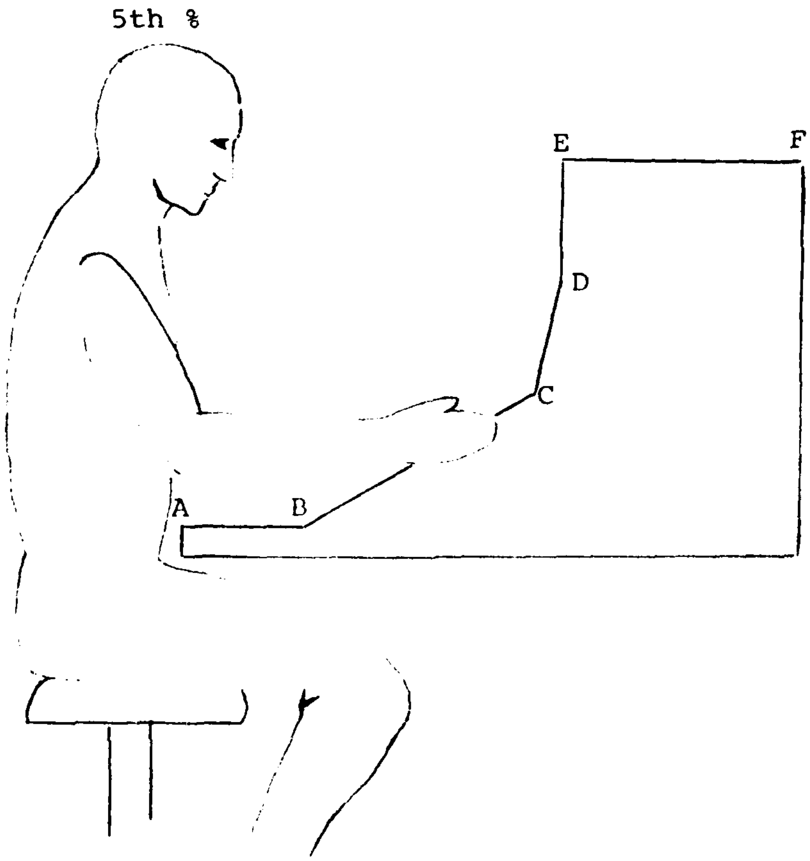
In order to ensure that the proposed layout fits to the human characteristics, several cautions have been exercised during planning the physical dimensions, shape, and partitions of the panels. Major ones are:

1. Workspace Geometry
2. Visual Space
3. Locational Priority Zones

The workspace geometry considerations arise from the need of constraining overall physical dimensions of the instrument panel so that all controls will be within reach distances, and the information presented by displays can be read accurately with minimal visual parallax. Constraints on the panel size have been imposed on all directions from the seat reference point. If two operators have been assigned to a workstation, physical dimensions on the horizontal axis double.

Anthropometric and visual characteristics of at least 90% of adult U.S. population have been considered in defining the physical panel dimensions. Critical anthropometric variables that controlled the design process are depth of reach, eye height, and shoulder heigh (Diffrient et al. 1983).

For a given panel, there are three sections on which displays and controls can be located through WOLAG: a) a vertical top section b) an inclined upper-middle section and c) an inclined lower-middle section. A horizontal front section is reserved as writing surface (see Figure 3). The lengths, and the angles between these sections have been generated through the visual space considerations on the vertical axis. Comfortable angular dimensions through eye and head



AB=15.72cm   ∡ B=150°

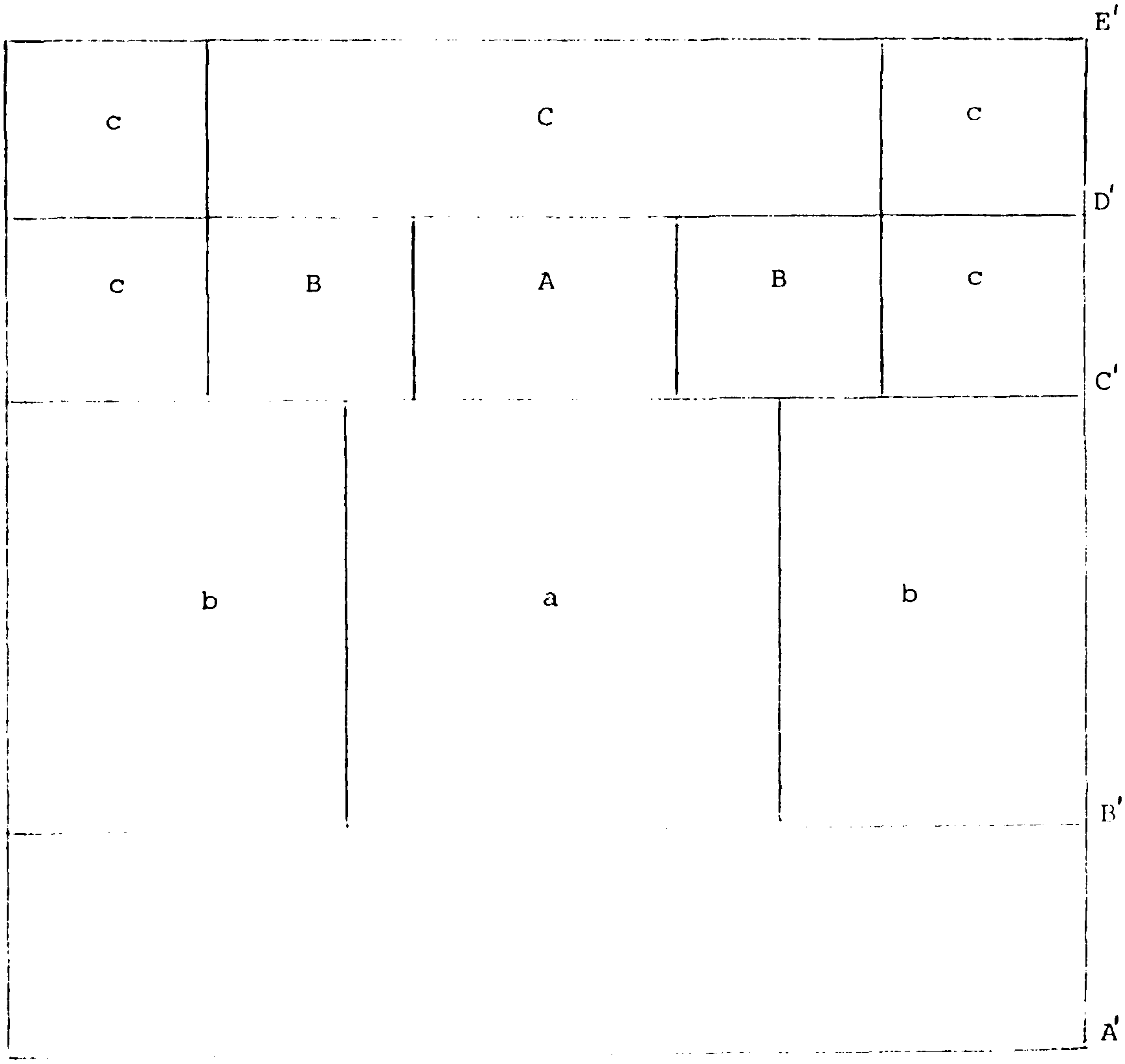
BC=32.18cm   ∡ C=135°

CD=14.10cm   ∡ D=165°

DE=14.38cm

EF=31.00cm

Figure 3. Geometric Relationships at the Workstation



	Primary Displays	Secondary Displays	Auxiliary Displays	Primary Controls	Secondary Controls	Auxiliary Controls
Area Code	A	B	C	a	b	c
Width Ratio	.2625	.2125	.6876	.4000	.3000	.1562

Figure 4. Unit Locational Priority Zones on the Panel

movements in the vertical axis (Woodson, 1981), along with recommendations on preferred placement of different types of units around the Normal Line of Sight (McCormick and Sanders, 1982) were the major inputs to generating unit locational priority zones on the panel. These are partitions of the panel which establish relative utilities of various sections for locating different display and/or control types, such as warning displays, secondary controls, auxiliary displays, etc. The above considerations, along with Lazet's (1977) recommendations on panel partitioning resulted in the priority zones given by Figure 4.

Some other ergonomic design considerations exercised during locating displays and controls on the panel are:

1. Locating primary units in central locations, and placing secondary and auxiliary units following and around the critical ones.

2. Placing less frequently used units at peripheral locations with displays in the upper portions and controls in lower portions of the panel.

3. Locating functional groups from left to right of the panel to the extent allowed by other location considerations.

4. Locating simo-controls in the same general area.

5. Locating controls with adequate clearances in between in order to minimize accidental activation.

Outputs

WOLAG outputs the following for each workstation:

a) A layout matrix of the instrument panel complete with unit assignments, and unused portions, if any.

b) Placement sequence of the units on the panel.

c) Evaluative measures on the designs generated

1. Total Links Value: Similar to the one in WORG.

2. Average Zone Deviation: Calculated as follows:

$$AZD = \sum_i ZD_i/M$$

where

AZD: Average Zone Deviation

ZD_i: Zone deviation value for ith unit. This is the euclidean distance between the centroid of the ith unit and the centroid of the closest appropriate zone.

M : Total number of units on the panel.

3. Total Zone Deviation: Numerator of the AZD equation.

If several panel designs are acceptable at any workstation, the one which minimizes the above statistics may be desirable.

Appendix II gives sample outputs of WOLAG for two workstations. Alternate panel layouts can be obtained at any station by specifying different input data for each run of the model. The layout which minimizes the evaluative measures may be considered for implementation.

CONCLUSION

Both WOLAG and WORG are interactive computerized decision making tools for a human engineer who is facing a crew station design problem. Each can be used independent of the other for enhanced flexibility in the design process. The ergonomic design rules embedded into the models allow for content validity.

Interested readers may contact the author for possible applications.

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APPENDIX I. A Sample WORG Output

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TOTAL LINK FOR THIS LAYOUT IS 4239

SEQUENCE OF ASSIGNMENT

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** DENOTES COMMON PANELS

APPENDIX II. A Sample WOLAG Output

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

LAYOUT FOR PANEL 2

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SEQUENCE OF GROUP LOCATION

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SEQUENCE OF UNIT LOCATION

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TOTAL LINKS FOR THIS LAYOUT = 0.00

TOTAL ZONAL DEVIATION = 293.

AVERAGE ZONAL DEVIATION PER UNIT = 24.38

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