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LAYOUT DESIGN OF USER INTERFACE COMPONENTS WITH MULTIPLE OBJECTIVES

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Abstract: A multi-goal layout problem may be formulated as a Quadratic Assignment model, considering multiple goals (or factors), both qualitative and quantitative in the objective function. The facilities layout problem, in general, varies from the location and layout of facilities in manufacturing plant to the location and layout of textual and graphical user interface components in the human–computer interface. In this paper, we propose two alternate mathematical approaches to the single-objective layout model. The first one presents a multi-goal user interface component layout problem, considering the distance-weighted sum of congruent objectives of closeness relationships and the interactions. The second one considers the distance-weighted sum of congruent objectives of normalized weighted closeness relationships and normalized weighted interactions. The results of first approach are compared with that of an existing single objective model for example task under consideration. Then, the results of first approach and second approach of the proposed model are compared for the example task under consideration.

Keywords: Distance, congruent objectives, multi-goal, quadratic assignment model, layout design, user interface components.

1. INTRODUCTION

The user interface components layout problem has the goal of locating the different components in order to achieve the greatest efficiency in exchanging the inputs and outputs between the user and the system. End–user productivity is tied directly to functionality and eases of learning and use (Gerlach and Kuo, 1991). Also, system designers lack the consistent user interface, which is based on the language model of human–computer interaction (HCI). A dominant goal of the HCI has been to design simplistic interfaces that reduce the time to learn computer application. This approach was expected to enable users to quickly perform simple task with the implicit assumption, which they would refine their skills through experience (Bhavnani and John, 2000). Within both the science and engineering of HCI, most models of interaction are task–based. A task is defined as the way in which a goal is attained, taking into account factors such as competence, knowledge and constraints (Wright, Fields and Harrison, 2000). The constraints of screen width and length, display rate, character set, and highlighting techniques strongly influence the graphic layout of menus/icons. Little experimental research has been done on menu/icon layout (Sheniderman, 2000).

In earlier research studies, the menu /icon items were sequenced in functional groups alphabetically and randomly. Card (1989) observed the poor performance with the random sequence and confirms the importance of considering alternative presentation sequences for the items. The basic framework for the design of the user interface including the layout of its components is provided in HCI cognitive modeling (Card, Moran, and Newell, 1983). Cognitive models of knowledge and performance abounded, taking the form of task grammars, production rules, and procedural models such as GOMS (Goals, Operators, Methods and Selection Rules). GOMS model (Sheniderman, 2000) postulates that users formulate goals (edit document) and sub goals (input word), each to which is achieved by using methods and procedures (move cursor to desired location by following a sequence of arrow keys). The elementary perceptual, motor, or cognitive acts, whose execution is necessary to change any aspect of the user's mental state or to affect the task environment, are the operators (press up – arrow keys, move hand to mouse, recall file name, verify that cursor is at end of file). The selection rules are the control structures for choosing among the several methods available for accomplishing a goal (delete by repeated back space versus delete by placing markers at beginning and end of region and pressing delete button).

These models break tasks and knowledge into smaller component parts, which are rule driven and generic. These finely detailed parts are the standardized, context–free building blocks, which logically make up higher level tasks and goals (Mirel, 1998). Olson and Olson (1990) outlined several significant gaps in cognitive theory that prevent cognitive modeling in general form addressing some important aspects of HCI and argued that cognitive models are essentially the wrong form to address certain other aspects of system design, such as user acceptance and fit to organizational life. Several studies have shown GOMS to be a powerful and accurate method of analysis for human performance (Bovair et al., 1990). Later, GOMS was expanded to model tasks with low level perceptual, cognitive, and motor operations (John, 1990). This opens up the possibility of using GOMS to compare different layouts on key stroking or mouse pointing, and textual and graphical layouts, etc. (Chuah et al., 1994).

Sears (1993) developed a task layout metric called layout appropriateness, which is widget level metric that deals with buttons, boxes, and lists. It is used to assess whether the spatial layout is in harmony with the user's tasks. Designers specify the sequences of selections that users make and the frequencies for each sequence. Then, the given layout of widgets is evaluated by how well it matches the tasks. An optimal layout that minimizes visual scanning can be produced, but since it may violate user expectations about positions of fields, the designers must make the final layout decisions. A measure of layout appropriateness (frequently used pair of widgets should be adjacent, and the left – to right sequence should be in harmony with the task – sequence description) would also be produced to guide the designer in a possible redesign.

Layouts in which related items (or components) were clustered increase accuracy by reducing the scanning needed to locate distant items (Vincow and Wickens, 1993). Fortunately, there is much literature reporting research and experience from design projects with automobiles, air craft, typewriters, home appliances, and so on that can be applied to the design of interactive computer systems (Sheniderman, 2000). For example, in the automobile and aircraft, it is the layout design of controls, visual displays, and other devices by which human user and the system exchange inputs and outputs. In the design of interactive computer systems, it is the layout design of screen, keyboard, mouse and other devices. In the layout design of the user interface components, the closeness relationship ratings between the various pairs of components recorded in REL charts are used with the objective of maximizing the closeness relationship score (McCormick et al., 1982). These subjective closeness ratings can be used: A (Absolutely necessary), E (Essentially important), I (Important), O (Ordinary), U (Unimportant) and X (Undesirable), to indicate the respective degrees of necessity that two given facilities be located close together. Layout designers may then assign numerical values to the ratings so that they can be handled mathematically. The numerical values assigned to the ratings have the ranking A>E>I>O>U>X.

In addition to closeness relationships between the items (or components), the users want to consider the shortest or least costly paths between the items (or components). Interface representations include a node – and – link diagram, and a square matrix of items (or components) with the value of a link attribute in the row and column representing a link (Sheniderman, 2000) for each factor. Hence, there is one–to–one relationship between the facilities layout problem in a manufacturing plant and the user interface components layout problem in the human – computer interface. The subjective closeness relationships between the items (or components) are based on the qualitative factors, whereas the objective link attributes related to the cost (or flow) between the items (or components) are based on the quantitative factors.

The issues related to perceptual and cognitive actions, such as familiarity, interface type, instruction type, monotony, boredom, fatigue, anxiety and fear are characterized as qualitative factors (or goals). The effect of these qualitative factors (or goals) of a user will overlap on the final layout (Gray et al., 1993, and John, 1990) and hence all the qualitative factors (or goals) are aggregated into one qualitative factor (or goal). The single-objective layout model with all qualitative factors combined into one qualitative factor and all qualitative factors individually are handled in the objective function for the layout design of user interface components layout problem (Peer and Sharma, 2004). In order to obtain the realistic results, it is required to handle the quantitative factors along with qualitative factors in the objective function. The issues related to motor actions in moving and pointing a mouse is characterized as quantitative factors (or goals). The effect of interactions resulting from the quantitative factors of a user, such as pace-of-interaction, frequency-of use, interaction style, step-by-step, all-at-once work, etc. tend to overlap (Gray et al., 1993 and John, 1990), and hence these factors (or goals) are aggregated into one quantitative factor (or goal) in the objective function. Hence, it is required to include the effect of both the qualitative factors and the quantitative factors in the objective function of multi-objective layout model for the user interface components layout problem.

The objective of this paper is to propose two alternate mathematical approaches to the single-objective layout model, in which the effect of all qualitative factors is combined into one qualitative factor in the objective function. The first one presents a multi-goal user interface component layout problem, considering the distance-weighted sum of congruent objectives of closeness relationships and the interactions. The second one considers the distance-weighted sum of congruent objectives of normalized weighted closeness relationships and normalized weighted interactions. The results of first approach are compared with that of an existing single objective model for example task under consideration. Then, the results of first and second approach of the proposed model are compared for the example task under consideration. The resultant layouts of user interface components are expected to reduce task performance time.

2. MULTI-GOAL APPROACHES FOR FACILITIES LAYOUT PROBLEM

Seehof and Evans (1967), Lee and Moore (1967), Muther and McPherson (1970), and Muther (1973) have developed algorithms to obtain the layouts based on qualitative criteria, in which the distance weighted cost of closeness relationship ratings is handled in the objective function as given in the following equations (1) to (4). The distance weighted cost of closeness relationships rating is considered as total numerical rating (Sayin, 1981).

$$\text{Minimize } Z = \sum_{i}^{n}\sum_{j}^{n}\sum_{k}^{n}\sum_{l}^{n} r_{ik} d_{jl} x_{ij} x_{kl} \tag{1}$$

Subject to

$$\sum_{i}^{n} x_{ij} = 1, \quad j = 1,2,...,n \tag{2}$$

$$\sum_{j}^{n} x_{ij} = 1, \quad i = 1,2,...,n \tag{3}$$

$$x_{ij} = 0 \text{ or } 1, \quad \forall i, j \tag{4}$$

Where,

$$x_{ij} = \begin{cases} 1, & \text{if facility } i \text{ is assigned to location } j \\ 0, & \text{otherwise} \end{cases}$$

$r_{ik} =$ Closeness relationship rating between facilities i and k

$d_{jl} =$ Distance between locations j and l.

In this approach, only qualitative criteria values are considered in the objective function. Later, solution procedures have been developed based on multi-criteria objectives of both qualitative as well as quantitative for the facilities layout problems.

The multi-criteria objectives are classified as conflicting objectives and congruent objectives. Conflicting objectives aim at minimization of total flow cost and maximization of total closeness rating, whereas congruent objectives aim at minimization of distance weighted cost of several attributes, such as, flow, closeness rating, hazardous movements, etc. (Khare et al., 1988). Rosenblatt (1978), Dutta and Sahu (1981, 1985) presented an improvement procedure for facilities layout problem associated with two conflicting objectives. Sayin (1981) presented the layout procedures, considering the cost of distance weighted attributes of flow and closeness rating. Rosenblatt (1979), and Dutta and Sahu (1982) presented the quadratic assignment models associated with two conflicting objectives, whereas Fortenberry and Cox (1985), Urban (1987, 1989), and Khare et al. (1988) presented the quadratic assignment models associated with congruent objectives.

Rosenblatt (1979), and Dutta and Sahu (1982) proposed the cost term (A_{ijkl}) for the quadratic assignment model considering conflicting objectives as follows.

$$A_{ijkl} = (\alpha_2 \, a_{ijkl} - \alpha_1 \, w_{ijkl}) \tag{5}$$

Where, $\alpha_1 + \alpha_2 = 1,\ \alpha_1, \alpha_2 \geq 0$

$$a_{ijkl} = \begin{cases} f_{ik} d_{jl}, & \text{if } i \neq k \text{ or } j \neq l \\ f_{ii} d_{jj}, & \text{if } i = k \text{ and } j = l \end{cases}$$

c_{ij} = cost per unit time associated directly with assigning facility i to location j

d_{jl} = distance between locations j and l

f_{ik} = work flow from facility i to facility k

$$w_{ijkl} = \begin{cases} r_{ik}, & \text{if locations } j \text{ and } l \text{ are neighbors} \\ 0, & \text{otherwise} \end{cases}$$

r_{ik} = closeness relationship rating value between facilities i and k

Fortenberry and Cox (1985) presented the cost term (A_{ijkl}) as given in equation (6)

$$A_{ijkl} = f_{ik} \, d_{jl} \, r_{ik} \tag{6}$$

Urban (1987, 1989) defined the cost term (A_{ijkl}), considering congruent objectives as follows.

$$A_{ijkl} = d_{jl} (f_{ik} + c.r_{ik}) \tag{7}$$

Where, c = constant weight that determines the importance of the closeness rating to the work flow.

Khare et al. (1988) presented the cost term (A_{ijkl}) for the quadratic assignment model considering congruent objectives as given in equation (8).

$$A_{ijkl} = W_1 r_{ik} d_{jl} + W_2 f_{ik} d_{jl} \tag{8}$$

Where, $W_1 + W_2 = 1$ and $W_1, W_2 \geq 0$

The quadratic assignment model for the multi–goal facilities layout problem, included with cost term (A_{ijkl}) is formulated as given in equations (9) to (12).

$$\text{Minimize} \quad Z = \sum_{i}^{n} \sum_{j}^{n} \sum_{k}^{n} \sum_{l}^{n} A_{ijkl} x_{ij} x_{kl} \tag{9}$$

Subject to:

$$\sum_{i}^{n} x_{ij} = 1, \quad j = 1,2,...,n \tag{10}$$

$$\sum_{j}^{n} x_{ij} = 1, \quad i = 1,2,...,n \tag{11}$$

$$x_{ij} = 0 \text{ or } 1 \tag{12}$$

Where

$$x_{ij} = \begin{cases} 1, & \text{if facility } i \text{ is assigned to location } j \\ 0, & \text{otherwise} \end{cases}$$

The listed models are similar in nature, and vary only in stating the relationship between the cost term (A_{ijkl}) and the qualitative and quantitative measures. In all these approaches the qualitative and quantitative factors (or goals) are not represented on the same scale. For example, values for workflow may range from zero to a tremendous amount, while closeness rating values may range from -1 to 4. As a result, the closeness rating would be dominated by work flow and have little impact on the final layout.

3. METHODOLOGY

This section presents a model for the multi–goal facilities layout problem with congruent objectives as an approach 1, in which the sum of weighted closeness relationships and weighted work flows are weighted by distances in the objective function. An approach 2 in the section presents multi–goal facilities layout model with congruent objectives, handling the distance weighted sum of normalized weighted closeness relationships and normalized weighted workflows in the objective function. The layouts of both the approaches are compared, based on the attribute values of their composite relationships.

3.1. Model Formulation

The quadratic assignment model for multi–goal facilities layout problem, handling the distance weighted sum of weighted attributes of closeness relationships and weighted attributes of workflows is presented as an approach 1 as given in the following equations (13) to (16).

$$\text{Minimize } Z = \sum_{i}^{n}\sum_{j}^{n}\sum_{k}^{n}\sum_{l}^{n}(W_1 r_{ik} + W_2 f_{ik}) d_{jl} x_{ij} x_{kl} \quad (13)$$

Subject to

$$\sum_{i}^{n} x_{ij} = 1, \quad j = 1,2,...,n \quad (14)$$

$$\sum_{j}^{n} x_{ij} = 1, \quad i = 1,2,...,n \quad (15)$$

$$x_{ij} = 0 \text{ or } 1, \quad \forall i, j \quad (16)$$

Where,

$$x_{ij} = \begin{cases} 1, & \text{if facility } i \text{ is assigned to location } j \\ 0, & \text{otherwise} \end{cases}$$

Where, $W_1 + W_2 = 1, \quad W_1, W_2 \geq 0$.

In the approach 1, the qualitative and quantitative factors (or goals) may not be represented on the same scale. That is, the range of qualitative closeness relationships rating values may be different from that of quantitative interactions (or work flows) between the facilities. As a result, one of the factors (or goals) may be dominated by other factor (or goal) and has little impact on the final layout (Harmonosky and Tothero, 1992). Hence, it is required to propose a model as an approach 2 for the multi–goal facilities layout problem, so that the final layout reflects the relative importance of the qualitative factor as well as the quantitative factor.

The methodology of an approach 2 begins with normalizing both the qualitative and quantitative factors individually. To normalize a qualitative factor, each relationship value is divided by the sum of all relationship values as given in equation (17).

$$R_{ik} = r_{ik} / \sum_{i}\sum_{k} r_{ik} \quad (17)$$

Where, r_{ik} = closeness relationship value between facilities i and k

R_{ik} = normalized closeness relationship value between facilities i and k

To normalize a quantitative factor, each quantitative workflow (or interactions) value is divided by the sum of all workflow (or interactions) values as given in equation (18).

$$F_{ik} = f_{ik} / \sum_i \sum_k f_{ik} \tag{18}$$

Where, f_{ik} = workflow (or interactions) value between facilities i and k
F_{ik} = normalized workflow (or interactions) value between facilities i and k

Then, the weights are assigned to the normalized qualitative factor (or goal) and normalized quantitative factor (or goal) based on their relative importance, and combined into a single composite factor (A_{ik}) (see algorithm and flow chart below for the steps) as given in equation (19).

$$A_{ik} = (W_1 R_{ik} + W_2 F_{ik}) \tag{19}$$

Where, $W_1 + W_2 \geq 0$, $W_1, W_2 \geq 0$

The resulting quadratic assignment problem is formulated as given in equations (20) to (23).

$$\text{Minimize } Z = \sum_i^n \sum_j^n \sum_k^n \sum_l^n (W_1 R_{ik} + W_2 F_{ik}) d_{jl} x_{ij} x_{kl} \tag{20}$$

Subject to

$$\sum_{i=1}^n x_{ij} = 1, \quad j = 1,2,\ldots,n \tag{21}$$

$$\sum_{j=1}^n x_{ij} = 1, \quad i = 1,2,\ldots,n \tag{22}$$

$$x_{ij} = 0 \text{ or } 1, \quad \forall i, j \tag{23}$$

Where,

$$x_{ij} = \begin{cases} 1, & \text{if facility } i \text{ is assigned to location } j \\ 0, & \text{otherwise} \end{cases}$$

3.2. Algorithm

The basic steps involved to obtain the composite factor (A_{ik}) are as follows.

1. Read input data (i.e., closeness relationship matrix, number of facilities, flow matrix, and weights).
2. Set $i = 1$ and $k = 1$ (facilities).
3. Set $r = r_{ik}$ and $f = f_{ik}$.
4. Compute $r = r + r_{ik}$ and $f = f + f_{ik}$.
5. Check whether $i = n$ and $k = n$. If yes GO TO step 7 otherwise GO TO step 6.
6. Increase i by 1 and k by 1. GO TO step 3.
7. Compute $R_{ik} = r_{ik}/r$ and $F_{ik} = f_{ik}/f$.
8. Check Whether $i = n$ and $k = n$. If yes GO TO step 10 otherwise GO TO step 9.

9. Increase i by 1 and k by 1. GO TO step 7.
10. Compute $A_{ik} = W_1R_{ik} + W_2F_{ik}$.
11. Check whether $i = n$ and $k = n$. If yes GO TO step 13 otherwise GO TO step 12.
12. Increase i by 1 and k by 1. GO TO step 10.
13. Stop.

The flow chart to compute the composite factor (A_{ik}) is given in Fig. 1.

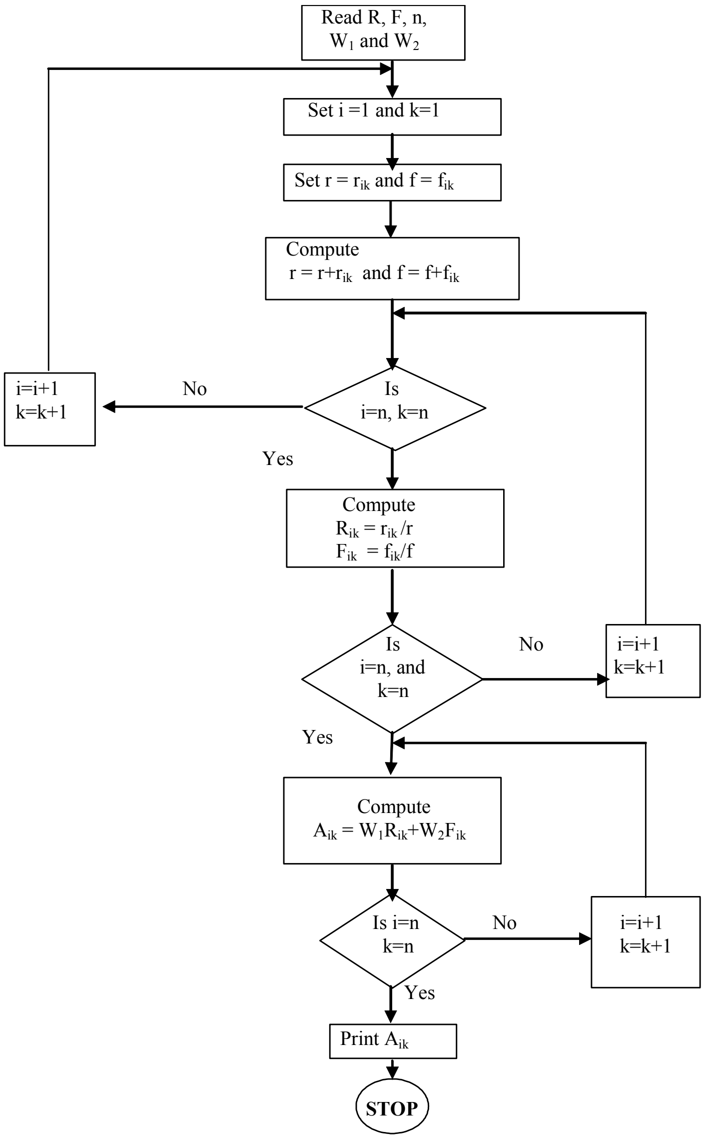

Figure 1: Flow Chart to compute Composite Factor (A_{ik})

Once, the composite factor has been obtained, the problem is solved as a single factor problem by either construction or improvement procedures.

3.3. Construction Procedure

On the basis of the composite criteria, select the pair of facilities, with the highest criteria value in the list to place in the locations close together. Next, select the facility from the list with highest criteria value with one, but not both facilities in the layout, to place near to the location of facility in the layout. Another facility is, now to be selected (using previous criterion) having highest priority of getting placement along with already assigned facilities. The process is continued till all the facilities are assigned to available locations. If there exists a tie between facilities for its selection to place in the plan area, tie is broken randomly with biasness. The constraints with respect to locations available for placement of assigned facilities and breaking of ties, there may exist a number of alternative solutions for each solution.

3.4. Improvement Procedure

The layout generated, using construction procedure, is taken as an initial layout for the improvement procedures. A pair-wise exchange process is followed to determine the best exchange of facilities at their locations exchange is incorporated. The exchanged layout will now become the initial layout. The pair-wise exchange process is followed after each new solution till there is no better solution possible. The better solution means that the value of predetermined objective function is better than the previous solution. When no improvement is possible in the latest solution, the search process is terminated.

Since, there exits one–to–one relationship between the manufacturing facilities layout problem in a plant and the textual and graphical user interface components layout problem in the human–computer interactive systems, the proposed methodology is used for the layout design of the textual and graphical user interface components. The results of an approach 1 and approach 2 of the proposed model are compared for the user interface components layout problem with the help of an example task.

4. EXAMPLE TASK

In order to apply the proposed methodology for the layout design of the textual and graphical user interface components, a text edited in MS-WORD in the study of John and Kieras (1996) is considered as an example task. The text is considered as component 1 and it is required to be modified by deleting the strike–off characters, bringing the rounded phrase to the location indicated by an arrow, setting the text to have right justification, and spell checking as shown in the fig.2 of the example task. In order to accomplish these tasks, the user interface components to be used are Del, Cut, Paste, Right and Spell check, which are numbered as components 2, 3, 4, 5 and 6 respectively. The rating system used for the qualitative relationships between the pairs of components is: A = 5, E = 4, I = 3, O = 2, U = 1 and X = 0. The quantitative factor is characterized as the interactions between the various pairs of components. The interaction between the pair of components is defined as the use of one component immediately after other component to perform an operation. The interactions are observed to be ranging from 1 to 4 for the task under consideration.

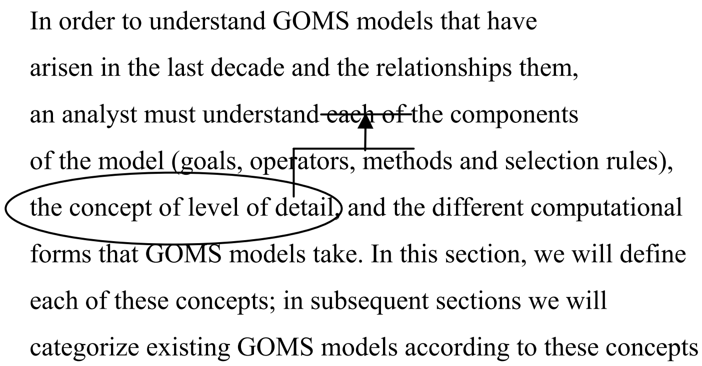
In order to understand GOMS models that have
arisen in the last decade and the relationships them,
an analyst must understand ~~each of~~ the components
of the model (goals, operators, methods and selection rules),
the concept of level of detail, and the different computational
forms that GOMS models take. In this section, we will define
each of these concepts; in subsequent sections we will
categorize existing GOMS models according to these concepts

Figure 2: The example task: editing marked-up manuscript.

The closeness relationships (r_{ik}) between the components i and k, considering 3 qualitative factors (viz., familiarity, anxiety, and fear) aggregated into one qualitative factor, and the interactions (f_{ik}) between components i and k, considering 3 quantitative factors (viz., frequency-of-use, pace-of-interaction, and interaction style) aggregated into one quantitative factor for an intermittent user evaluated in the computer laboratory for 6 - component problem, and the distances (d_{jl}) between the locations j and l are given in Fig.3 as follows.

Qualitative factor

r_{ik} =

	1	2	3	4	5	6
1	-	3	4	3	3	4
2	3	-	0	5	2	3
3	4	0	-	4	4	3
4	3	5	4	-	4	3
5	3	2	4	4	-	5
6	4	3	3	3	5	-

Quantitative factor

$f_{ik} =$

	1	2	3	4	5	6
1	-	4	1	2	4	3
2	4	-	2	2	4	2
3	1	2	-	3	2	1
4	2	2	3	-	2	3
5	4	4	2	2	-	2
6	3	2	1	3	2	-

Distances

$d_{jl} =$

	1	2	3	4	5	6
1	-	3	6	3	5	7
2	3	-	3	5	3	5
3	6	3	-	8	6	3
4	3	5	8	-	3	6
5	5	3	6	3	-	3
6	7	5	3	6	3	-

Figure 3: 6 - Component Problem Data

5. RESULTS AND DISCUSSION

For the data given in fig. 3, an existing single-objective layout model as given in equations (1) to (4), the quadratic assignment model of the approach 1 as given in the equations (13) to (16), and the quadratic assignment model of the approach 2 as given in the equations (20) to (23) are used to obtain the layouts of the components.

Existing Single-Objective Layout Model

$r_{ik} =$

	1	2	3	4	5	6
1	-	3	4	3	3	4
2	3	-	0	5	2	3
3	4	0	-	4	4	3
4	3	5	4	-	4	3
5	3	2	4	4	-	5
6	4	3	3	3	5	-

Construction Heuristic Layout	Score	**Improvement Heuristic** Layout	Score	**% Improvement**
4 1 5 3 6 2	247	4 1 3 5 6 2	245	0.80

Figure 4: Results of Existing Single-Objective Model for Intermittent User

The construction and improvement procedures based on the closeness relationship values are used to obtain the layouts and their scores.

The composite factor ($W_1 r_{ik} + W_2 f_{ik}$) of an approach 1 for $W_1 = 0.6$ and $W_2 = 0.4$, the layouts and scores, with the construction and improvement procedures are obtained as given in Fig. 5 as follows.

$0.6\, r_{ik} + 0.4\, f_{ik} =$

	1	2	3	4	5	6
1	-	3.4	2.8	2.6	3.4	3.6
2	3.4	-	0.8	3.8	2.8	2.6
3	2.8	0.8	-	3.6	3.2	2.2
4	2.6	3.8	3.6	-	3.2	3.0
5	3.4	2.8	3.2	3.2	-	3.8
6	3.6	2.6	2.2	3.0	3.8	-

Construction Procedure			**Improvement Procedure**			
Layout	Score	% Improvement over Single-Objective Model	Layout	Score	% Improvement over Single-Objective Model	**% Improvement over Construction Procedure**
4 1 5 6 2 3	212.8	(247-212.8)x100 / 247 =13.8	2 4 6 5 1 3	204.2	(245-204.8)x100 / 245 =16.7	(212.8-204.2)x100 / 212.8 =4.00

Figure 5: Results of Approach 1 for W_1=0.6 and W_2 =0.4

The layouts and scores of the approach 1 for the data given in Fig. 3 with different combinations of weights are compared with that of an existing single-objective model as given in Table 1(see appendix). It is observed from the results that the solutions of the approach 1 are improved by an average of 15.514 and 18.671 over an existing single-objective model with the construction and improvement procedures, respectively. On the other hand, the solution of the approach 1 is improved by an average of 4.429 percent with the improvement procedure over the construction procedure. It is also observed from the results that the better layouts are obtained with the approach 1 of the proposed model compared to an existing single-objective layout model. Then, the results of the approach 1 and the approach 2 are compared for the example task under consideration.

The composite factor (A_{ik}) of the approach 2 for W_1 = 0.6 and W_2 = 0.4, the layouts and scores, with the construction and improvement procedures are obtained as given in fig.6 as follows.

A_{ik}=0.6R_{ik} + 0.4F_{ik} =

	1	2	3	4	5	6
1	-	0.040	0.030	0.029	0.029	0.040
2	0.040	-	0.011	0.041	0.022	0.024
3	0.030	0.011	-	0.040	0.035	0.024
4	0.029	0.041	0.040	-	0.035	0.034
5	0.029	0.022	0.035	0.035	-	0.041
6	0.040	0.024	0.024	0.034	0.041	-

Construction Procedure		**Improvement Procedure**		**% Improvement**
Layout	Score	Layout	Score	
1 2 5 6 3 4	2.23	5 4 2 3 6 1	2.044	8.30

Figure 6: Results of Approach 2 for W_1 = 0.6 and W_2 = 0.4

The layouts and scores of the approach 2 for the data given in Fig.3 with different combinations of weights are obtained, as given in Table 2 (see appendix). It is observed from the results that the solution is improved by an average of 5.157 percent over the construction procedure.

The layouts and scores obtained, using the construction and the improvement procedures for approach 1 and approach 2 are compared with respect to the attributes of the composite factor (A_{ik}) of the approach 2 for W_1= 0.6 and W_2 = 0.4 as given in fig.7 as follows.

Construction Procedure				**% Improvement over approach 1**	**Improvement Procedure**				**% Improvement over approach 1**
Approach 1		**Approach 2**			**Approach 1**		**Approach 2**		
Layout	Score	Layout	Score		Layout	Score	Layout	Score	
4 1 5 6 2 3	2.325	1 2 5 6 3 4	2.23	4.2	2 4 6 5 1 3	2.201	5 4 2 3 6 1	2.044	7.1

Figure 7: Comparison of layouts of Approach 1 and Approach 2 based on attribute values of Approach 2.

The layouts and scores obtained, using the construction and the improvement procedures of approach 1 and approach 2 are compared with respect to the attributes of the composite factor (A_{ik}) of approach 2 for different combinations of weights as given in Table 3 (see Appendix). It is observed from the results that the solution of approach 2 improved by an average of 4.071 percent over the approach 1 with the construction procedure. It is also observed that the solution of the approach 2 is improved by an average of 5.843 percent over the approach 1 with the improvement heuristic.

The layouts and the scores obtained, using the construction and the improvement procedures for the approach 1 and the approach 2 are compared with respect to the attribute values of the composite factor ($0.6r_{ik} + 0.4f_{ik}$) of the approach 1 for W_1= 0.6 and W_2=0.4 as given in Fig. 8 as follows.

Construction Procedure				**% Improvement over approach 1**	**Improvement Procedure**				**% Improvement over approach 1**
Approach 1		**Approach 2**			**Approach 1**		**Approach 2**		
Layout	Score	Layout	Score		Layout	Score	Layout	Score	
4 1 5 6 2 3	212.8	6 2 5 6 3 4	211.0	0.80	2 4 6 5 1 3	204.2	5 4 2 3 6 1	196.1	4.0

Figure 8: Comparison of layouts of Approach 1 and Approach 2 based on attribute values of Approach 1.

The layouts and the scores obtained, using the construction and the improvement procedures in the approaches 1 and 2 are compared with respect to the attribute values of the composite factor ($0.6r_{ik} + 0.4f_{ik}$) of the approach 1 for different combinations of weights as given in Table 4 (see appendix). It is observed from the results that the solution obtained using the construction procedure in the approach 2 is improved by an average of 3.614 percent over the approach 1. Further, it is observed that the solution obtained with the improvement procedure in the approach 2 is improved by an average of 4.20 percent over the approach 1.

6. CONCLUSIONS

The facilities layout problem varies from location of facilities in a manufacturing plant to the location and layout of textual and the graphical user interface components in human-computer interface. In this paper, we presented an alternate model to the single-objective layout model. The proposed approaches of the model handle multi-objectives in the objective function. The proposed model of the first approach for the quadratic assignment facilities layout problem handles the sum of attributes of congruent objectives of closeness relationships and the interactions weighted by the distances in the objective function. The effects of the issues related to perceptual, cognitive and motor actions such as familiarity, fatigue, monotony, boredom, etc. tend to overlap (Gray et al., 1993, John, 1990) in the layout design of the textual and graphical user interface components, and hence all these factors are treated as a single qualitative factor. The quantitative factors, such as, frequency of use, interaction style, pace of interaction, step-by-step work, all-at- once work concerned with a user are expected to have similar effect on the layout of graphical and textual user interface components, and hence these factors are combined into a single quantitative factor. The quadratic assignment model, which handles the distance weighted sum of one qualitative factor and one quantitative factor assigned with relative weights in the objective function is presented as first approach. It is observed from the results that the solutions of the first approach are improved over an existing single-objective model with the construction and the improvement procedures. Similarly, the solution of the first approach is improved, using the improvement procedure over the construction procedure.

Since, the range of the qualitative relationship ratings may be different from that of the quantitative interactions, and hence the effect of one factor may be dominated by the other factor in the final layout. The second approach presents an alternate quadratic assignment model, in which the distances between the locations weigh the sum of weighted normalized qualitative factor and weighted normalized quantitative factor in the objective function, so that the final layout reflects the relative importance of each factor. It is observed from the results of the second approach that the solution is improved using the improvement procedure over the construction procedure.

In order to judge the effectiveness of the proposed models, the results of the both approaches are compared on the same scale. The layouts obtained in the first approach are evaluated based on the criteria values of the second approach and compared for different combinations of weights. It is observed from the results that the solution of the second approach is improved over the first approach in the construction and improvement procedures.

The layouts obtained in the second approach are evaluated based on the criteria values of the first approach and the results of the first approach and the second approach are compared for different combinations of weights. It is observed from the results that the solution obtained, using the construction and improvement procedures in the second approach is improved over the first approach. It is observed that the better solutions are obtained, using the second approach of the proposed model compared to the first approach. Hence, the layouts of the user interface components obtained, using the second approach are expected to reduce the performance time to accomplish the task.

The proposed methodology can also be used for the layout design of controls and other devices in automobiles and aircrafts with the suitable rating system for the closeness relationships between the components. The quadratic assignment models have been used for the layout design of workstations. Within multiple workstations (terminals), alternate layouts can encourage or limit human interaction, cooperative work, and assistance with problems. Because users can often quickly help one another with minor problems, there may be an advantage to layouts that group several terminals close together or that enable supervisors or teachers to view all screens at once from behind (Sheniderman, 2000).

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APPENDIX

Table 1: Comparison of the Results of Existing Single-Objective Model and Approach 1 of the Proposed Model with Different Combinations of Weights: Area Limited to 2 Rows and 3 Columns

Weights		Construction Procedure			Improvement Procedure			% improvement over Construction Procedure
W1	W2	Layout	Score	% of Improvement over Single-Objective Model	Layout	Score	% of Improvement over Single-Objective Model	
0	1	2 1 4 / 6 3 5	186	24.7	4 3 1 / 2 6 5	180	26.5	3.2
0.2	0.8	4 3 6 / 2 1 5	181.2	26.6	3 4 6 / 1 2 5	176.6	27.9	2.5
0.4	0.6	2 6 4 / 5 3 1	201.2	18.5	3 1 2 / 6 5 4	191.6	21.8	4.8
0.5	0.5	5 6 4 / 2 3 1	211.5	14.4	2 5 6 / 4 1 3	193.3	21.1	8.6
0.6	0.4	4 1 5 / 6 2 3	212.8	13.8	2 4 6 / 5 1 3	204.2	16.7	4.00
0.8	0.2	5 3 2 / 4 1 6	226.8	8.2	6 2 1 / 3 5 4	222	9.4	2.1
1	0	2 3 4 / 5 1 6	241	2.4	5 2 4 / 1 6 3	227	7.3	5.8
		Average % Improvement		15.514	Average % Improvement		18.671	
							Average % Improvement	4.429

Table 2: Results of Proposed Approach 2: Area Limited to 2 Rows and 3 Columns

Weights	Construction Heuristic				Improvement Heuristic				% improvement
W1 W2	Layout			Score	Layout			Score	
0.0 1.0	2	6	5	2.426	4	2	5	2.245	7.50
	1	3	4		6	1	3		
0.2 0.8	4	2	3	2.217	6	4	3	2.161	2.50
	6	5	1		1	5	2		
0.4 0.6	1	2	3	2.268	4	6	2	2.175	4.10
	6	4	5		3	5	1		
0.5 0.5	1	5	2	2.284	1	5	3	2.192	4.00
	6	4	3		2	6	4		
0.6 0.4	1	2	5	2.23	5	4	2	2.044	8.34
	6	3	4		3	6	1		
0.8 0.2	2	1	4	2.239	6	1	2	2.153	3.80
	5	6	3		3	5	4		
1.0 0.0	2	3	4	2.34	6	1	3	2.20	6.0
	1	5	6		2	5	4		
								Avg. % Improvement	5.157

Table 3: Evaluations of Layouts of Approach 1 with Respect to Attribute Values of Approach 2

Weights		**Construction Heuristic**					**Improvement Heuristic**				
W1	**W2**	**Approach 1**		**Approach 2**		**%Improve-ment over Approach 1**	**Approach 1**		**Approach 2**		**% Improve-ment over approach**
		Layout	Score	Layout	Score		Layout	Score	Layout	Score	
0	1	2 1 4 6 3 5	2.456	2 6 5 1 3 4	2.426	1.20	4 3 1 2 6 5	2.44	4 2 5 6 1 3	2.245	8.0
0.2	0.8	4 3 6 2 1 5	2.283	4 2 3 6 5 1	2.217	2.9	3 4 6 1 2 5	2.249	6 4 3 1 5 2	2.161	3.90
0.4	0.6	2 6 4 5 3 1	2.382	1 2 3 6 4 5	2.268	4.80	3 1 2 6 5 4	2.282	4 6 2 3 5 1	2.175	4.70
0.5	0.5	5 6 4 2 3 1	2.44	1 5 2 6 4 3	2.284	6.40	2 5 6 4 1 3	2.307	1 5 3 2 6 4	2.192	5.00
0.6	0.4	4 1 5 6 2 3	2.325	1 2 5 6 3 4	2.23	4.20	2 4 6 5 1 3	2.201	5 4 2 3 6 1	2.044	7.10
0.8	0.2	5 3 2 4 1 6	2.285	2 1 4 5 6 3	2.239	6.10	6 2 1 3 5 4	2.3337	6 1 2 3 5 4	2.153	7.9
1	0	2 3 4 5 1 6	2.410	2 3 4 1 5 6	2.34	2.90	5 2 4 1 6 3	2.30	6 1 3 2 5 4	2.20	4.30
					Avg % Improvement	4.071				Avg.% improvement	5.843

Table 4: Comparison of Layouts of Approach 1 & Approach 2 Based on Attribute Values of Approach 1

Weights		**Construction Heuristic**				**%Improve-ment over Approach 1**	**Improvement Heuristic**				
W1	**W2**	**Approach 1**		**Approach 2**			**Approach 1**		**Approach 2**		**% Improve-ment over approach**
		Layout	Score	Layout	Score		Layout	Score	Layout	Score	
0	1	2 1 4 6 3 5	186	2 6 5 1 3 4	179	3.80	4 3 1 2 6 5	180	4 2 5 6 1 3	171	5.00
0.2	0.8	4 3 6 2 1 5	181.2	4 2 3 6 5 1	177.8	1.90	3 4 6 1 2 5	176.6	6 4 3 1 5 2	173.2	1.90
0.4	0.6	2 6 4 5 3 1	201.2	1 2 3 6 4 5	192.4	4.40	3 1 2 6 5 4	191.6	4 6 2 3 5 1	184	4.00
0.5	0.5	5 6 4 2 3 1	211.5	1 5 2 6 4 3	199.5	5.70	2 5 6 4 1 3	193.3	1 5 3 2 6 4	186.5	3.50
0.6	0.4	4 1 5 6 2 3	212.8	1 2 5 6 3 4	211	0.80	2 4 6 5 1 3	204.2	5 4 2 3 6 1	196.1	4.00
0.8	0.2	5 3 2 4 1 6	226.8	2 1 6 4 5 3	213.6	5.80	6 2 1 3 5 4	222	6 1 2 3 5 4	204.4	7.90
1	0	2 3 4 5 1 6	241	2 3 4 1 5 6	234	2.90	5 2 4 1 6 3	227	6 1 3 2 5 4	220	3.10
					Avg. % Improvement	3.614			Avg.% improvement		4.20